**Bored into depletion? Towards a tentative integration of perceived self-control exertion
and boredom as guiding signals for goal-directed behavior**

Wanja Wolff^{1,2,*} & Corinna S. Martarelli^{3,*}

¹ Department of Sport Science, University of Konstanz, Germany

² Department of Educational Psychology, University of Bern, Switzerland

³ Faculty of Psychology, Swiss Distance University Institute, Switzerland

*equal contribution

Author Note

Wanja Wolff, University of Konstanz, Universitätsstrasse 10, 78464 Konstanz, Germany, Phone: +49 (0)7531 88 3535, Email: wanja.wolff@uni-konstanz.de; Corinna Martarelli, Swiss Distance University Institute, Überlandstrasse 12, 3900 Brig, Switzerland, Phone: +41 (0)76 340 09 82, Email: corinna.martarelli@fernuni.ch

Correspondence concerning this article should be addressed to Wanja Wolff.

Abstract

During the past two decades, self-control research has been dominated by the strength model of self-control which is built on the premise that the capacity for self-control is a limited global resource that can become temporarily depleted, resulting in a state called ego depletion. The foundations of ego depletion have recently been questioned. Thus, although self-control is among the most researched psychological concepts with high societal relevance, an inconsistent body of literature limits our understanding of how self-control operates. Here, we propose that the inconsistencies are partly due to a confound that has unknowingly and systematically been introduced into ego depletion research: Boredom. We propose that boredom might affect results of self-control research by 1) placing an unwanted self-control demand, and 2) signaling that one should explore behavioral alternatives. To account for boredom in self-controlled behavior, we provide a working model that integrates evidence from reward-based models of self-control and recent theorizing on boredom to explain effects of both self-control exertion and boredom on subsequent self-control performance. We propose that task-induced boredom should be systematically monitored in self-control research to assess the validity of the ego depletion effect.

Keywords: self-control, ego depletion, boredom, value-based models, psychoneurophysiological approach

Bored into depletion? Towards a tentative integration of perceived self-control exertion and boredom as guiding signals for goal-directed behavior

Self-control is a crucially important human capacity. Self-control facilitates goal achievement by volitionally directing attention towards goal-directed behavior (de Ridder, Lensvelt-Mulders, Finkenauer, Stok, & Baumeister, 2012). Testament to its' societal relevance, self-control is among the most researched psychological concepts (Duckworth, 2011). In everyday life, people face many self-control challenges and the effectiveness in how they deal with those challenges greatly affects success in diverse parts of their life. For example, in a 32-year longitudinal study, Moffitt et al. (2011) showed that “childhood self-control predicts physical health, substance dependence, personal finances, and criminal offending outcomes (2011; p. 2693)”.

Despite good intentions, self-control does not always work (Hagger, Wood, Stiff, & Chatzisarantis, 2010) and applying self-control is generally perceived as effortful and aversive (Wolff, Sieber, Bieleke, & Englert, 2019). A multitude of theoretical accounts as to *why* and *when* self-control fails to work have been proposed and tested (e.g., Beedie & Lane, 2012; Inzlicht, Schmeichel, & Macrae, 2014; Kotabe & Hofmann, 2015). By far the most popular theoretical account on self-control is the strength model of self-control (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Baumeister, Tice, & Vohs, 2018; Baumeister, Vohs, & Tice, 2007). The strength model states that self-control relies on a limited metabolic resource that can become temporarily depleted by prior self-control exertion (Baumeister et al., 2007). This supposedly leads to a state called *ego depletion*, where subsequent self-control demanding acts are performed less effectively (Baumeister et al., 1998). A substantial body of evidence supports the ego depletion concept (Cunningham & Baumeister, 2016). On the behavioral level, a multitude of studies has shown that ego depletion leads to impaired performance in a broad range of subsequent self-control demanding tasks (for meta-analyses, please see Giboin & Wolff, 2019; Hagger et al., 2010). On the experiential level, applying

self-control leads to perceptions of exertion (Milyavskaya, Inzlicht, Johnson, & Larson, 2019; Wolff et al., 2019), thereby attesting to the implied costliness of exerting self-control (Baumeister et al., 1998). However, large scale pre-registered replication failures (Hagger et al., 2016; Koppel, Andersson, Västfjäll, & Tinghög, 2019), evidence of publication bias (Carter & McCullough, 2014; Wolff, Baumann, & Englert, 2018), and critiques regarding the models' mechanistic underpinning (Beedie & Lane, 2012; Inzlicht et al., 2014; Kurzban, Duckworth, Kable, & Myers, 2013) have severely questioned its' main premise (i.e., the ego depletion effect) in recent years.

Taken together, self-control is among the most researched psychological concepts (Duckworth, 2011) which is of great societal relevance (Moffitt et al., 2011), but an inconsistent body of literature limits our understanding of how self-control operates. In part one of this paper, we discuss *boredom* as one potential confound that might have contributed to the heterogenous findings in ego depletion research. Notable recent exceptions notwithstanding (e.g., Milyavskaya et al., 2019), the postulated role of boredom in ego depletion research has been largely overlooked so far. In part two, we propose that integrating conceptualizations of self-control allocation as a reward-based choice (e.g., Berkman, Hutcherson, Livingston, Kahn, & Inzlicht, 2017; Kool & Botvinick, 2014; Kurzban et al., 2013; Shenhav, Botvinick, & Cohen, 2013) and current theorizing on boredom (Westgate & Wilson, 2018) can contribute to a better understanding of how people choose to allocate effort and engage in goal-directed behavior (Cohen, McClure, & Yu, 2007; Mansouri, Koechlin, Rosa, & Buckley, 2017).

Part one: Bored into depletion?

To most, boredom is a ubiquitous experience (Harris, 2000), but until recently it has received surprisingly little attention as a research topic (Bench & Lench, 2013; Gomez-Ramirez & Costa, 2017; Westgate & Wilson, 2018). This has prompted researchers to emphasize the need for more research on this topic (Mills & Christoff, 2018), and recent years have seen

increased interest in boredom (van Tilburg & Igou, 2017). While researchers initially ascribed relatively little functional relevance to boredom for the understanding of human behavior, this view has changed too (Gomez-Ramirez & Costa, 2017; Westgate & Wilson, 2018). Indeed, boredom has been identified as an influential motivator for negative and positive behaviors alike (Westgate & Wilson, 2018). Boredom is related to a host of negative outcomes, like gambling behavior (Goldstein, Vilhena-Churchill, Stewart, Hoaken, & Flett, 2016), poor mental health (Binnema, 2004), violent offenses (Dåderman & Lidberg, 1999) and even youth suicide (Heled & Read, 2005). However, boredom also appears to facilitate creativity (Harris, 2000) and pro-social intentions (van Tilburg & Igou, 2017). More generally, it has been proposed that boredom is neither good nor bad per se, but rather assumes a key role in indicating that a change of behavior is required (Danckert, 2019; Westgate & Wilson, 2018).

When do we get bored?

Imagine being a university student and to receive course credit, you have to take part in an experiment where your task is to simply transcribe a text for an uncertain amount of time. In this situation you are likely to get bored. According to the *Meaning and Attention Components* (MAC) model, boredom arises when one feels unable to successfully engage attention in an activity and/or when the current activity is perceived as low in meaning (Westgate & Wilson, 2018). Both attentional failure (i.e., incongruity of cognitive demands and mental resources; Wickens, 2002) and lack of meaning (i.e., incongruity of current activities and one's own goals) are thought to independently contribute to the sensation of boredom (Westgate & Wilson, 2018). Attentional boredom occurs when task-induced attentional demands are too low (understimulation) or too high (overstimulation). This implies that boredom does not only occur as a result of too little demands (e.g., while transcribing a text from a computer screen) but also when demands exceed one's resources (e.g., while trying to solve anagrams without knowing that they are unsolvable). Indeed, if one conceives boredom as a functional signal that computational capabilities should be oriented somewhere

else (Gomez-Ramirez & Costa, 2017), this makes sense: if a task is too hard to make its' pursuit worthwhile, deploying attentional capabilities towards this activity is a non-functional course of action. The MAC model also proposes mixed states of boredom which occur when people fail to successfully engage attention in an activity that is also perceived as meaningless. It is likely that many experimental tasks (willingly or unwillingly) invoke some form of mixed boredom. Lastly, state boredom is not static and the boredom one experiences at any given time is likely to vary both in intensity (Mills & Christoff, 2018) and in type (Westgate & Wilson, 2018).

How can boredom account for (some) inconsistencies in the ego depletion literature?

We propose that the causes of state boredom (i.e., attentional failure and/or lack of meaning) and its' functional role (i.e., signaling that one should change activity), as conceptualized by the MAC model make it very likely that boredom might have unwillingly been introduced as a confound into ego depletion research. Specifically, we suggest that the experimental approach that has traditionally been used to investigate ego depletion is prone to inducing forms of boredom as specified in the MAC model, thereby altering behavior and affecting performance on subsequent control demanding tasks.

The ego depletion effect is traditionally induced with the sequential-task paradigm, where the effect of performing a primary self-control task on performance of a subsequent secondary self-control task is assessed in the experimental group (Hagger et al., 2016). As high self-control tasks (HCTs), researchers generally use tasks whose completion is demanding. For example, rapidly transcribing a text while omitting each instance of the letter *e* (Wolff et al., 2018). In contrast, the control group performs a primary task that supposedly does not rely on self-control (or places substantially less self-control demands than the HCT). This low control task (LCT) is usually very simple, for example, merely transcribing a text.

Central to the tasks that are frequently used in ego depletion research is the requirement for varying levels of attentional control that are needed to effectively complete

the task (i.e., more control is needed in a HCT compared to a LCT). From an ego depletion point of view this makes sense because it has been proposed that “attention control is the single most important or influential form of self-control (Schmeichel & Baumeister, 2010, p. 31)”. Thus, the more attentional control a task demands, the more self-control is required to complete the task. To ensure that participants in the control group are not depleted too, a LCT should then place as little attentional demands as possible.

However, according to the MAC model, boredom occurs because a task places attentional demands that are either too high or too low (Eastwood, Frischen, Fenske, & Smilek, 2012; Westgate & Wilson, 2018). Thus, while being low in self-control demands, it is conceivable that a LCT also causes higher levels of boredom than a HCT due to understimulation. While there are more than 600 studies on ego depletion (Cunningham & Baumeister, 2016), we know of only one study that has directly tested this possibility (Bieleke, Barton, & Wolff, in preparation). Supporting the ideas presented here, Bieleke et al., observed that a traditional Stroop task (i.e., with congruent and incongruent blocks) was perceived as being more boring than the more demanding modified Stroop task (i.e., with interspersed task-switching blocks). Importantly, we are not the first to suggest that boredom might have confounded results in ego depletion research (e.g., Francis, Milyavskaya, Lin, & Inzlicht, 2018; Job, Dweck, & Walton, 2010; Milyavskaya et al., 2019) and fellow researchers have interpreted inconsistent findings in terms of boredom. For example, Job, Dweck, and Walton (2010) found that in one experimental condition, instead of performing worse, participants performed better after the HCT than after the LCT (study 2). In their discussion, Job et al. suggested that boredom in the LCT might have led to these surprising findings. However, they did not test the hypothesis further. Probably the strongest evidence regarding a potential overlap between boredom and LCTs is more indirect: Tasks that have been used in ego depletion research (e.g., Stroop task, transcription task, N-back task; Wolff et al., 2018)

are sometimes also used as experimental inductions of boredom (Atchley, Klee, & Oken, 2017; London, Schubert, & Washburn, 1972; Markey, Chin, Vanepps, & Loewenstein, 2014).

We believe that boredom-induced inconsistencies in ego depletion research largely stem from understimulation in the LCT compared to the HCT. However, following from the MAC model, it is also likely that overstimulation might have acted as a confounding factor. For example, the time spent trying to solve anagrams (which, unbeknownst to the participant, are in fact unsolvable) has been used as a measure of currently available self-control strength (i.e., as an indicator of ego depletion) (Baumeister et al., 1998). In addition to being self-control demanding, working on such a task might also induce boredom due to overstimulation because the cognitive demands (i.e., complicated anagrams) appear to exceed one's mental resources (i.e., the skills to solve the anagrams). Although we are not aware of any research that has directly tested this, we would argue that overstimulation in HCTs is likely to be less prevalent than understimulation in LCTs: While HCTs tend to be perceived as more difficult (Hagger et al., 2016), there appears to be no consistent ceiling effect in task difficulty ratings of HCTs (Milyavskaya et al., 2019; Wolff et al., 2019) and performance on the HCT can quickly improve over time, suggesting that participants get better at the task (Wolff et al., 2019).

To arrive at tasks that only differ in regard to the self-control demands they impose, researchers often use LCTs and HCTs that are structurally very similar. For example, merely transcribing a text (LCT), compared to transcribing the same text while omitting any instance of the letter *e* (HCT). Thus, in regard to the meaning component of boredom, it is conceivable that HCTs and LCTs tend to be perceived similarly. However, while we expect differential effects of perceived meaning to play only a minor role in LCTs and HCTs, it is very likely that individual differences affect the meaning one ascribes to a self-control task and consequently the boredom one experiences while performing the task. For example, when participants were asked to perform a self-control task that was more congruent with their own

interests, depletion effects tended to be smaller (for a meta-analysis, please see Giboin & Wolff, 2019). However, it is important to note that the interpretation of these findings in terms of boredom is speculative and we are not aware of any research that has tested the role of meaningless boredom in ego depletion research.

Finally, and to complicate matters further, task characteristics can change as a function of time and this might alter sensations of boredom, perceived self-control costs and how the latter is required in dealing with the former: A task that was initially (over)challenging might become easy after prolonged execution. This is important, because although an easier task might place less self-control demands, boredom is thought to signal that one should allocate one's attention somewhere else (Danckert, 2019; Westgate & Wilson, 2018). This might lead to the paradoxical effect that self-control is needed to keep attention on track in a task that was originally designed to place little to no self-control demands. In line with this, participants reported elevated levels of effort and fatigue in a boring task that simply required passive number viewing (Milyavskaya et al., 2019).

Taken together, sensations of boredom might affect results of self-control research by 1) placing an unwanted self-control demand, and 2) signaling that one should explore behavioral alternatives. This confound likely primarily manifests itself as understimulation in LCTs, thereby contributing to replication failures in ego depletion research (for a similar argument, please see Milyavskaya et al., 2019). However, boredom due to overstimulation and lack of meaning could both also have altered outcomes of ego depletion studies. For example, if, in addition to being self-control demanding, a HCT would also be perceived as meaningless, this might result in an inflated effect size of the observed ego depletion effect. As long as this potential confound of boredom in ego depletion research has not been systematically assessed, it is impossible to truly evaluate the merit of the strength model of self-control. In addition, due to its reliance on a metabolic self-control resource, the strength model of self-control appears ill-suited to conceptually incorporate the functional role of

boredom for performance in self-control demanding tasks. We propose that propositions from the MAC model of boredom and from recent reward-based conceptualizations of self-control can be integrated to specify how both concepts affect goal-directed behavior.

Part two: Towards a tentative integration of perceived self-control exertion and boredom as guiding signals for goal-directed behavior

Adaptive behavior relies on a continuous cost-benefit analysis that weighs the merits of continuing with a course of action against switching to an alternative activity (Mansouri et al., 2017). Essentially, this cost-benefit analysis assesses if the brains computational capabilities are being put to adequate use. We suggest that the sensation of applying self-control (i.e., perceived exertion) and the experience of boredom contribute distinctively to the outcome of this cost-benefit analysis and thereby to the resultant behavior (see Figure 1 for our proposed working model).

#####Insert Figure 1 about here#####

In line with other researchers, we suggest that perceived exertion primarily reduces the willingness to further exert effort (e.g., Inzlicht et al., 2014). More precisely, this effort avoidance is driven by the outcome of a continuous comparison between the value that is expected from exerting control against its costs, which scale as a function of the duration control is applied for (Kurzban et al., 2013). In line with recent work, we suggest that the sensation of boredom primarily instigates behavioral change (Danckert, 2019; Westgate & Wilson, 2018). More precisely, this impulse to search for alternative activities stems from discounting the value of a current activity (Berlyne, 1970) and an increased sensitivity to future rewards (Milyavskaya et al., 2019). We suggest that within the course of goal-directed behavior, self-control costs and boredom have unique functions; the former triggering effort avoidance and the latter triggering behavioral change (In the Figure this triggering function of

self-control costs and boredom is expressed by the terms “avoid effort!” and “change behavior!” respectively).

To elaborate on these propositions, we will first briefly summarize theoretical accounts and empirical support for the notion that self-control is indeed costly, and that exerting control skews the underlying cost-benefit analysis towards effort aversion. Second, we will summarize recent computational and empirical evidence supporting the proposition that boredom indeed signals the need for behavioral change. Finally, we briefly summarize the neuroscientific understanding of how control operates and highlight similarities to findings in the emerging literature on the neuronal correlates of boredom.

Costs of self-control and effort avoidance

The application of self-control is perceived as costly and perceived costs of control scale with the duration of control allocation (Kurzban et al., 2013; Wolff et al., 2019). For example, a recent high-powered study showed that performing a Stroop task led to sensations of tiredness that increased as a function of task duration (Wolff et al., 2019). Importantly, these perceived costs of control must not necessarily represent structural limitations of the brain (e.g., a limited metabolic self-control resource; Baumeister et al., 2007), but might be due to functional constraints of the processing system itself¹ (Shenhav et al., 2017). Circumventing the notion of intrinsic costs of control altogether, it has been proposed that the costs of control are opportunity costs (Kurzban et al., 2013). Thus, while exerting control in one activity, one has to forego other opportunities with potential value. Regardless of whether the application

¹ Computational work indicates that the brain might have developed a preference for multiplexing (i.e., use of shared representations for different tasks) over multitasking (use of task-specific representations) (Feng, Schwemmer, Gershman, & Cohen, 2014). While multiplexing conveys many advantages, it also severely limits the capacity for performing more than one mental operation at a time, due to ‘cross talk’ which is thought to occur when two tasks compete for the same local processing resource at the same time (Feng et al., 2014). For example, in an incongruent Stroop trial, the default response would be to categorize the word according to its’ meaning, thereby causing cross talk with the task to categorize the word according to its’ font color (Cohen, Dunbar, & McClelland, 1990). According to this view, rather than being limited itself, control is then employed to manage the detrimental impact of cross talk (Feng et al., 2014). The perception of effort, which arises when control is applied, can then be understood as an indicator of the costs that arise in tasks that compete for the same representations and that as a consequence require control to prevent deleterious effects of cross talk (Shenhav et al., 2017).

of control is costly due to functional processing constraints or opportunity costs (or a combination of both), it has been suggested that the resultant perceived exertion serves as a signal that indexes these costs (Kurzban et al., 2013; Shenhav et al., 2017). Supporting this, research shows that applying constant levels of effort towards a self-control demanding task for a prolonged time leads to a rise in perceived exertion, while task performance might not deteriorate or even improve (Wolff et al., 2019). This indicates that perceived exertion does not reflect depletion of self-control resources (which should result in performance impairment) but rather reflects rising intrinsic and/or opportunity costs of control. This disconnect between perceived exertion and actual performance has not only been observed in ego depletion research (Francis et al., 2018; Wolff et al., 2019) but also in related neurological research on fatigue (DeLuca, 2005). Interestingly, and in line with the above, researchers in this field have suggested that perceptions of fatigue do not directly map onto fatigued resources (Sandry, Genova, Dobryakova, DeLuca, & Wylie, 2014).

Recent theorizing and empirical evidence on self-control appear to agree that the allocation of self-control is effortful and that the sensation of control-induced exertion has the function of tracking the costs of one's current activity. These costs of exerting self-control in turn reduce the motivation to further exert self-control (Inzlicht & Schmeichel, 2012). Empirically, effort avoidance has been reflected for example in a reduced willingness to engage in tasks that are effortful (Sjåstad & Baumeister, 2018) or in a reduction of effort that is invested in control demanding activities (e.g., Lin, Saunders, Friese, Evans, & Inzlicht, in press). It is important to note that some findings suggest that rather than causing effort avoidance, self-control exertion might increase approach motivation (Schmeichel, Harmon-Jones, & Harmon-Jones, 2010) and reward sensitivity (Wagner, Altman, Boswell, Kelly, & Heatherton, 2013). At first sight, this is at odds with the ideas presented here and more closely linked to the function, we suggest for boredom in the present framework (see Figure 1). However, more recent studies that followed up on these findings indicate that rather than

increasing the approach motivation, self-control exertion appears to reduce the motivation to control approach motivation (e.g., Haynes, Kemps, & Moffitt, 2016). Further, prior self-control exertion only led to increased approach behaviors, when the required effort for approaching rewards was low (Giacomantonio, Jordan, Fennis, & Panno, 2014). If the required effort was high, then prior self-control exertion even reduced approach behavior. This is in line with the ideas we put forward in the current paper. If the to-be-approached activities are intrinsically rewarding (e.g., delicious candy) but one has already exerted control in a previous HCT, then approach behavior is only expected when the new task itself does not require (much) effort.

Although exerting self-control is aversive and its application leads to the avoidance of further effort, self-control is also highly functional and facilitates goal attainment (Moffitt et al., 2011; de Ridder et al., 2012). Accordingly, more recent theoretical accounts have conceptualized the allocation of self-control as a reward-based choice (Berkman et al., 2017), where an agent weighs the benefits of pursuing a current course of action against the costs that increase over time. For example, it has been suggested that the choice to apply control is driven by a utility maximization approach as specified by labor-supply theory (Kool & Botvinick, 2014), by the computation of opportunity costs (Kurzban et al., 2013), or by a maximization of the expected value of control (Shenhav et al., 2013). All these approaches have in common that self-control is only applied if it is subjectively worth it. In turn, exertion induced effort avoidance can be overcome by increasing the value of an activity. This is in line with research, showing that incentives can offset ego depletion effects (Muraven & Slessareva, 2003).

Boredom as a functional signal to explore behavioral alternatives

While applying self-control produces costs that serve as an adaptive signal (e.g., *should I continue to put effort into this Stroop task?*), boredom appears to track the diminishing value of an activity, thereby serving as a prompt to explore more interesting or enjoying alternatives

(e.g., *transcribing this text is boring, I should rather change activity*) (Westgate & Wilson, 2018). Importantly, what is deemed rewarding likely depends on the situation a person finds itself in: In addition to instigating a shift to more pleasurable behavioral alternatives, boredom might sometimes even prompt a shift towards hedonically negative experiences (Bench & Lench, 2019). It has been suggested, that whether boredom causes people to seek positive or negative experiences depends on the type of experience that has led to boredom. Specifically, getting bored during a hedonically negative activity should instigate the search for hedonically positive experiences and vice versa. Given that ego depletion tasks tend to be perceived as somewhat aversive (e.g., Hagger et al., 2016; Wolff et al., 2019), boredom during ego depletion might primarily instigate behavioral change towards hedonically positive experiences (e.g., delicious candy).

The conceptualization of boredom as an adaptive signal to shift one's resources to seek out a more rewarding experience has been supported by recent computational (Gomez-Ramirez & Costa, 2017) and experimental work (Geana, Wilson, Daw, & Cohen, 2016). Cognitive neuroscience conceptualizes the brain as Bayesian, trying to minimize surprise by constantly integrating sensory information to update its' estimate of the current state of the world. However, it has been argued that this model does not suffice to explain decisions under uncertain conditions; or more generally to explain exploration behavior (e.g., stop trying to solve unsolvable anagrams and engage attention in alternative activities). To address this, Gomez-Ramirez and Costa (2017) propose a mathematical model that ascribes a key role to boredom as a signal to discount current rewards and to trigger a change in behavior (Gomez-Ramirez & Costa, 2017). Geana et al. (2016) tested these predictions empirically in a series of experiments: They manipulated the amount of information in a computer game to cause either understimulation or overstimulation. Both understimulation and overstimulation (to a lesser extent) caused boredom and triggered exploration behavior (switch to another task) when compared to a condition in which no boredom was induced because attentional demands and

mental resources were matched. Most importantly, exploration behavior was positively correlated with the subjective experience of boredom as well as with the value of other future options (future reward). A more drastic example attesting to the aversive nature of boredom that in turn instigates behavioral change comes from research showing that some people rather self-administer electric shocks than doing nothing (Wilson et al., 2014). These theoretical, computational, and behavioral approaches have been accompanied by research on the mechanisms by which boredom triggers behavioral change. For example, research indicates that the sensation of boredom leads to a discounting of an activity's current value (Berlyne, 1970) and increases approach motivation (Moynihan, et al., 2015). Further, very recent neuroscientific work showed that after a boring task, participants displayed a larger feedback negativity, which has been interpreted as a neural index for reward sensitivity (Milyavskaya et al., 2019). In line with the present proposal, the authors did not find evidence for a change in reward sensitivity in participants that had performed a self-control demanding task instead.

To sum up, we propose that the effortful sensation that accompanies the application of self-control and the sensation of boredom have distinct functions in the cost-benefit analysis that drives goal-directed behavior. By triggering effort avoidance, exerting self-control primarily affects the cost side of this analysis. In contrast, by instigating behavioral change, boredom primarily affects the benefit side. In regard to ego depletion, this implies that performance in the secondary task should hinge on the combined effects of the self-control demands and boringness of the primary task. As costs and benefits combine to guide behavior, we propose that boredom and control exertion interact in how they affect future behavior. In regard to ego depletion research, this is likely to affect performance on the secondary task in intricate ways. For example, by causing a devaluation of an activity, boredom also reduces the cost one can justifiably incur in this activity. In addition, boredom increases sensitivity to more rewarding alternatives, thereby increasing the effort (i.e., cost)

that is needed to stay engaged in the current activity. Importantly, since task-induced boredom and self-control demands dynamically change over time (e.g., due to learning or habituation), the influence both signals have on performance should also vary as a function of task duration in an ego depletion task. To further advance research on the ego depletion effect, it is therefore crucial to track boredom and self-control costs with high temporal resolution during the primary and the secondary task.

(Dis)similarities in the neuroscience of self-control and boredom

A substantial body of research has investigated the neural correlates and mechanistic underpinnings of self-control (Heatherton, 2011; Shenhav et al., 2017; Turner et al., 2019). In a nutshell, control processes are primarily orchestrated by structures in the executive network, namely the dorsal Anterior Cingulate Cortex (dACC) and the lateral Prefrontal Cortex (IPFC) (Shenhav et al., 2013; Turner et al., 2019). Specifically, research indicates that the dACC calculates the value of applying control by integrating “information about rewards and costs that can be expected in a control-demanding task (Shenhav et al., 2013, p. 217)”. Information on potential rewards is primarily received from the ventromedial Prefrontal Cortex (vmPFC), which provides information on the current action’s value relative to alternative actions (Berkman, 2017; Gläscher, Hampton, & O’Doherty, 2009; Mansouri et al., 2017; Strait, Blanchard, & Hayden, 2014). Further, the dACC specifies the control command (*identity* and *intensity*) and the actual top-down control is then governed by structures in the IPFC. The dACC monitors (on the afferent side) and adjusts if necessary (on the efferent side), the control process. The effortful/costly part of control is then executed by the IPFC. To summarize, the dACC and the IPFC (among others) differentially contribute to the Specification, Regulation and Monitoring of control processes (for a comprehensive review of dACC function in regard to self-control as a reward-based choice, please see Shenhav et al., 2013; Shenhav et al., 2017).

So far, only few studies have investigated the neuronal underpinnings of boredom (Mills & Christoff, 2018). Particularly the default mode network has been implicated in boredom (Danckert & Merrifield, 2018). The association of boredom with the default mode network appears to be quite intuitive, since activation in the default mode network has been found across many studies (that did not directly investigate boredom) when people are not attentionally engaged in a primary task (e.g., Christoff, Gordon, Smallwood, Smith, & Schooler, 2009; Mason et al., 2007). Within the default mode network, the association of the vmPFC with boredom is of particular interest for the present proposal (Mathiak, Klasen, Zvyagintsev, Weber, & Mathiak, 2013): Research indicates that the vmPFC integrates competing value signals (Strait et al., 2014), encodes expectations about future rewards (Gläscher et al., 2009) and thereby assumes a key role in signaling whether a change in behavior is needed (Domenech & Koechlin, 2015). Importantly, vmPFC activity appears to be highly relevant for self-control too (Berkman, 2017) as the dACC monitors information from the vmPFC to adjust the control command if necessary (Shenhav et al., 2013). The joint importance of the vmPFC for boredom and self-control and its link to the dACC, might point toward a tentative mechanistic path on how boredom can affect self-control demands in a LCT. In the context of the framework we present here, this indicates how boredom-induced changes in valuation might affect how much effort one can justifiably [CM1]put into a task.

Interestingly, some studies have also reported boredom-induced activations in structures of the executive network. However, these findings are somewhat inconsistent. For example, in one study, the LPFC was implicated in boredom (Dal Mas & Wittmann, 2017), whereas other studies did not find this implication (e.g., Danckert & Merrifield, 2018). Further, some studies showed that boredom was associated with activation in the cingulate cortex (Dal Mas & Wittmann, 2017; Danckert & Merrifield, 2018). As has been outlined above, these areas also play an important role in self-control. It is possible that some of the inconsistencies in regard to the involvement of the executive network in boredom stem from

between study-variation. Specifically, differences in regard to whether or not boredom manipulations require some form of sustained attention (i.e., self-control) might affect the involvement of structures in the executive network. Thus, some boredom manipulations might also impose self-control demands (possibly due to the effort needed to stay attentionally engaged when the task is very boring). Indeed, in the study where the boredom manipulation required simple but frequent yes/no responses towards stimuli, higher activations in the IPFC were observed (Dal Mas & Wittmann, 2017). No such activation was found, when the boredom manipulation consisted of passive video watching (Danckert & Merrifield, 2018). The differential recruitment of structures in the executive control network in different boredom inductions can cautiously be interpreted in line with the ideas presented here: Experimental approaches in the ego depletion and in the boredom literature might sometimes partially overlap, causing one construct to affect the results obtained in research that was targeted at the other construct. Beyond reflecting a potential methodological overlap, this also suggests that boredom and self-control costs closely and dynamically interact in guiding goal-directed behavior.

Concluding remarks

To stimulate scientific progress in our understanding of self-control and boredom, we conclude with two suggestions for future research.

First, task-induced boredom should be systematically monitored in research that is informed by the strength model of self-control to better assess the validity of the ego depletion effect: As outlined above, recognizing boredom (and related constructs, such as deliberate and spontaneous mind wandering, Seli, Risko, Smilek, & Schacter, 2016) as potential mediators of self-controlled behavior is essential to better understand how people apply self-control in the lab as well as in everyday life. Figure 1 is designed to offer a working model that highlights testable hypotheses regarding the potential interplay of boredom and self-control within the context of a traditional ego depletion study. For example,

the model suggests that LCTs are indeed less self-control demanding, which should lead to better self-control performance (mediating role of self-control demands). However, LCTs might also cause more boredom, which should lead to impaired self-control performance (mediating role of boredom). Importantly, the magnitude of task-induced boredom and self-control demands (and consequently the resulting performance in a subsequent self-control task) should be highly dependent on task type and task duration. Thus, while the suggested model can serve as a template for designing ego depletion experiments that take boredom, as well as changing self-control demands into account, researchers need to be careful in taking the differential influences of task type and task duration into account. Further, in light of research that points toward an inverse relationship between trait boredom proneness and trait self-control (Mugon, Struk, & Danckert, 2018), it is conceivable that both variables moderate the occurrence (and magnitude) of an ego depletion effect. For example, people with high levels of trait boredom are likely to display impaired self-control performance following a LCT, while those low in trait boredom should be relatively unaffected by such a prior LCT. In line with this hypothesis, the inverse moderating role has been proposed for trait self-control (Muraven, Collins, Shiffman, & Paty, 2005).

Second, emphasis should be placed on psychoneurophysiological approaches that have a high temporal resolution which allows to understand the dynamic interplay between self-control and boredom and the mediating psychological, neuronal, and physiological parameters: Following from the first point, the effect of a primary self-control task on subsequent self-control performance is not trivial and task-induced boredom and self-control demands vary by task type and a prolonged task duration might even change task characteristics (e.g., a task that was designed as a HCT might turn into a LCT due to learning). To better understand these temporal dynamics (which must not be linear), measures with high temporal resolution are needed to accurately track changes that occur over the course of prolonged exposure to a self-control task. In addition to self-report measures (e.g.,

perceived boredom, self-control demands), emphasis should be placed on physiological (e.g., heart rate variability, galvanic skin response, pupil dilation) and neuronal correlates of boredom and self-control (e.g., hemodynamic and electrophysiological changes in areas that have been implicated in boredom and self-control) in order to understand mechanistic similarities, differences, and potential interdependencies of both concepts. Such an approach would allow to clarify the relation between these two seemingly opposing constructs and bring together two research areas that are reciprocally relevant.

Boredom and self-control are two highly complex constructs with great societal importance. Self-control is one of the most-researched constructs in psychology and boredom research has experienced a surge in research interest recently. In the past, inconsistent findings in ego depletion research have sometimes been interpreted in terms of boredom but only very recently have researchers started to concurrently investigate boredom and self-control (Milyavskaya et al., 2019). Here, we provide ideas that are intended as a starting point for making future scientific progress in understanding their intricate interdependence and to provide a first working model regarding how both concepts interplay. We hope the present paper will inspire discussions and some much-needed research to unravel this interdependence and to clarify misunderstandings in ego depletion research.

References

- Atchley, R., Klee, D., & Oken, B. (2017). EEG Frequency Changes Prior to Making Errors in an Easy Stroop Task. *Frontiers in Human Neuroscience*, 11, 521. <https://doi.org/10.3389/fnhum.2017.00521>
- 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*, 74(5), 1252–1265. <https://doi.org/10.1037/0022-3514.74.5.1252>
- Baumeister, R. F., Tice, D. M., & Vohs, K. D. (2018). The strength model of self-regulation: Conclusions from the second decade of willpower research. *Perspectives on Psychological Science*, 13(2), 141–145. <https://doi.org/10.1177/1745691617716946>
- Baumeister, R. F., Vohs, K. D., & Tice, D. M. (2007). The strength model of self-control. *Current Directions in Psychological Science*, 16(6), 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(2), 143–153. <https://doi.org/10.1177/1088868311419817>
- Bench, S. W., & Lench, H. C. (2013). On the function of boredom. *Behavioral Sciences*, 3(3), 459–472. <https://doi.org/10.3390/bs3030459>
- Bench, S. W., & Lench, H. C. (2019). Boredom as a seeking state: Boredom prompts the pursuit of novel (even negative) experiences. *Emotion*, 19(2), 242–254. <https://doi.org/10.1037/emo0000433>
- Berkman, E. T. (2017). The neuroscience of self-control. In D. T. d. Ridder, M. A. Adriaanse, & K. Fujita (Eds.), *The Routledge international handbook of self-control in health and well-being: Concepts, theories, and central issues* (pp. 112–126). Routledge. <https://doi.org/10.4324/9781315648576-10>
- Berkman, E. T., Hutcherson, C. A., Livingston, J. L., Kahn, L. E., & Inzlicht, M. (2017). Self-control as value-based choice. *Current Directions in Psychological Science*, 26(5), 422–428. <https://doi.org/10.1177/0963721417704394>
- Berlyne, D.E. Novelty, complexity, and hedonic value. *Perception & Psychophysics* 8, 279–286 (1970). <https://doi.org/10.3758/BF03212593>
- Bieleke, M., Barton, L., & Wolff, W. (December, 2019). *Self-Control as a Limited Resource? Subjective Experience of Exertion and Objective Performance Over Time*. Manuscript in preparation
- Binnema, D. (2004). Interrelations of psychiatric patient experiences of boredom and mental health. *Issues in Mental Health Nursing*, 25(8), 833–842. <https://doi.org/10.1080/01612840490506400>
- 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>
- Christoff, K., Gordon, A. M., Smallwood, J., Smith, R., & Schooler, J. W. (2009). Experience sampling during fMRI reveals default network and executive system contributions to mind wandering. *Proceedings of the National Academy of Sciences of the United States of America*, 106(21), 8719–8724. <https://doi.org/10.1073/pnas.0900234106>
- Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, 97(3), 332–361. <https://doi.org/10.1037/0033-295x.97.3.332>
- Cohen, J. D., McClure, S. M., & Yu, A. J. (2007). Should I stay or should I go? How the human brain manages the trade-off between exploitation and exploration. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362(1481), 933–942. <https://doi.org/10.1098/rstb.2007.2098>
- 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, 1639. <https://doi.org/10.3389/fpsyg.2016.01639>
- Dåderman, A. M., & Lidberg, L. (1999). Flunitrazepam (Rohypnol) abuse in combination with alcohol causes premeditated, grievous violence in male juvenile offenders. *The Journal of the American Academy of Psychiatry and the Law*, 27(1), 83–99.
- Dal Mas, D. E., & Wittmann, B. C. (2017). Avoiding boredom: Caudate and insula activity reflects boredom-elicited purchase bias. *Cortex*, 92, 57–69. <https://doi.org/10.1016/j.cortex.2017.03.008>
- Danckert, J. (2019). Boredom: Managing the delicate balance between exploration and exploitation. In J. Ros Velasco (Ed.), *Boredom is in your mind: A shared psychological philosophical approach* (Vol. 2, pp. 37–53). [S.l.]: Springer. https://doi.org/10.1007/978-3-030-26395-9_3

- Danckert, J., & Merrifield, C. (2018). Boredom, sustained attention and the default mode network. *Experimental Brain Research*, 236(9), 2507–2518. <https://doi.org/10.1007/s00221-016-4617-5>
- DeLuca, J. (2005). *Fatigue as a Window to the Brain*: The MIT Press. <https://doi.org/10.7551/mitpress/2967.001.0001>
- Domenech, P., & Koechlin, E. (2015). Executive control and decision-making in the prefrontal cortex. *Current Opinion in Behavioral Sciences*, 1, 101–106. <https://doi.org/10.1016/j.cobeha.2014.10.007>
- Duckworth, A. L. (2011). The significance of self-control. *Proceedings of the National Academy of Sciences of the United States of America*, 108(7), 2639–2640. <https://doi.org/10.1073/pnas.1019725108>
- Eastwood, J. D., Frischen, A., Fenske, M. J., & Smilek, D. (2012). The unengaged mind: Defining boredom in terms of attention. *Perspectives on Psychological Science*, 7(5), 482–495. <https://doi.org/10.1177/1745691612456044>
- Feng, S. F., Schwemmer, M., Gershman, S. J., & Cohen, J. D. (2014). Multitasking vs. multiplexing: Toward a normative account of limitations in the simultaneous execution of control-demanding behaviors. *Cognitive, Affective & Behavioral Neuroscience*, 14(1), 129–146. <https://doi.org/10.3758/s13415-013-0236-9>
- Francis, Z. L., Milyavskaya, M., Lin, H., & Inzlicht, M. (2018). *Development of a Within-Subject, Repeated-Measures Ego Depletion Paradigm: Inconsistent Results and Future Recommendations*. <https://doi.org/10.31234/osf.io/xcnfk>
- Geana, A., Wilson, R., Daw, N., & Cohen, J. D. Boredom, Information-Seeking and Exploration. *CogSci*, 2016.
- Giacomantonio, M., Jordan, J., Fennis, B. M., & Panno, A. (2014). When the motivational consequences of ego depletion collide: Conservation dominates over reward-seeking. *Journal of Experimental Social Psychology*, 55, 217–220. <https://doi.org/10.1016/j.jesp.2014.07.009>
- Giboin, L.-S., & Wolff, W. (2019). The effect of ego depletion or mental fatigue on subsequent physical endurance performance: a meta-analysis. *Performance Enhancement and Health*. <https://doi.org/10.1016/j.peh.2019.100150>
- Gläscher, J., Hampton, A. N., & O'Doherty, J. P. (2009). Determining a role for ventromedial prefrontal cortex in encoding action-based value signals during reward-related decision making. *Cerebral Cortex*, 19(2), 483–495. <https://doi.org/10.1093/cercor/bhn098>
- Goldstein, A. L., Vilhena-Churchill, N., Stewart, S. H., Hoaken, P. N. S., & Flett, G. L. (2016). Mood, motives, and money: An examination of factors that differentiate online and non-online young adult gamblers. *Journal of Behavioral Addictions*, 5(1), 68–76. <https://doi.org/10.1556/2006.5.2016.003>
- Gomez-Ramirez, J., & Costa, T. (2017). Boredom begets creativity: A solution to the exploitation-exploration trade-off in predictive coding. *Bio Systems*, 162, 168–176. <https://doi.org/10.1016/j.biosystems.2017.04.006>
- Hagger, M. S., Chatzisarantis, N. L. D., Alberts, H., Anggono, C. O., Batailler, C., Birt, A. R., . . . Zwieneberg, M. (2016). A Multilab Preregistered Replication of the Ego-Depletion Effect. *Perspectives on Psychological Science*, 11(4), 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(4), 495–525. <https://doi.org/10.1037/a0019486>
- Harris, M. B. (2000). Correlates and characteristics of boredom proneness and boredom. *Journal of Applied Social Psychology*, 30(3), 576–598. <https://doi.org/10.1111/j.1559-1816.2000.tb02497.x>

- Haynes, A., Kemps, E., & Moffitt, R. (2016). Too depleted to try? Testing the process model of ego depletion in the context of unhealthy snack consumption. *Applied Psychology: Health and Well-Being*, 8(3), 386–404. <https://doi.org/10.1111/aphw.12080>
- Heatherington, T. F. (2011). Neuroscience of self and self-regulation. *Annual Review of Psychology*, 62, 363–390. <https://doi.org/10.1146/annurev.psych.121208.131616>
- Heled, E., & Read, J. (2005). Young peoples' opinions about the causes of, and solutions to, New Zealand's high youth suicide rate. *Suicide & Life-Threatening Behavior*, 35(2), 170–180. <https://doi.org/10.1521/suli.35.2.170.62881>
- 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(5), 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(3), 127–133. <https://doi.org/10.1016/j.tics.2013.12.009>
- 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(11), 1686–1693. <https://doi.org/10.1177/0956797610384745>
- Kool, W., & Botvinick, M. (2014). A labor/leisure tradeoff in cognitive control. *Journal of Experimental Psychology: General*, 143(1), 131–141. <https://doi.org/10.1037/a0031048>
- Koppel, L., Andersson, D., Västfjäll, D., & Tinghög, G. (2019). No effect of ego depletion on risk taking. *Scientific Reports*, 9(1), 9724. <https://doi.org/10.1038/s41598-019-46103-0>
- Kotabe, H. P., & Hofmann, W. (2015). On integrating the components of self-control. *Perspectives on Psychological Science*, 10(5), 618–638. <https://doi.org/10.1177/1745691615593382>
- 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(6). <https://doi.org/10.1017/S0140525X12003196>
- Lin, H., Saunders, B., Friese, M., Evans, N. J., & Inzlicht, M. (in press). Strong effort manipulations reduce response caution: A preregistered reinvention of the ego depletion paradigm. *Psychological Science*. <https://doi.org/10.31234/osf.io/dysa5>
- London, H., Schubert, D. S., & Washburn, D. (1972). Increase of autonomic arousal by boredom. *Journal of Abnormal Psychology*, 80(1), 29–36. <https://doi.org/10.1037/h0033311>
- Mansouri, F. A., Koechlin, E., Rosa, M. G. P., & Buckley, M. J. (2017). Managing competing goals - a key role for the frontopolar cortex. *Nature Reviews. Neuroscience*, 18(11), 645–657. <https://doi.org/10.1038/nrn.2017.111>
- Markey, A., Chin, A., Vanepps, E. M., & Loewenstein, G. (2014). Identifying a reliable boredom induction. *Perceptual and Motor Skills*, 119(1), 237–253. <https://doi.org/10.2466/27.PMS.119c18z6>
- Mason, M. F., Norton, M. I., van Horn, J. D., Wegner, D. M., Grafton, S. T., & Macrae, C. N. (2007). Wandering minds: The default network and stimulus-independent thought. *Science*, 315(5810), 393–395. <https://doi.org/10.1126/science.1131295>
- Mathiak, K. A., Klasen, M., Zvyagintsev, M., Weber, R., & Mathiak, K. (2013). Neural networks underlying affective states in a multimodal virtual environment: Contributions to boredom. *Frontiers in Human Neuroscience*, 7. <https://doi.org/10.3389/fnhum.2013.00820>
- Mills, C., & Christoff, K. (2018). Finding consistency in boredom by appreciating its instability. *Trends in Cognitive Sciences*, 22(9), 744–747. <https://doi.org/10.1016/j.tics.2018.07.001>
- Milyavskaya, M., Inzlicht, M., Johnson, T., & Larson, M. J. (2019). Reward sensitivity following boredom and cognitive effort: A high-powered neurophysiological investigation. *Neuropsychologia*, 123, 159–168. <https://doi.org/10.1016/j.neuropsychologia.2018.03.033>

- Moffitt, T. E., Arseneault, L., Belsky, D., Dickson, N., Hancox, R. J., Harrington, H., . . . Caspi, A. (2011). A gradient of childhood self-control predicts health, wealth, and public safety. *Proceedings of the National Academy of Sciences of the United States of America*, 108(7), 2693–2698. <https://doi.org/10.1073/pnas.1010076108>
- Moynihan, A. B., Van Tilburg, W. A., Igou, E. R., Wisman, A., Donnelly, A. E., & Mulcaire, J. B. (2015). Eaten up by boredom: Consuming food to escape awareness of the bored self. *Frontiers in Psychology*, 6, 369. <https://doi.org/10.3389/fpsyg.2015.00369>
- Mugon, J., Struk, A., & Danckert, J. (2018). A failure to launch: Regulatory modes and boredom proneness. *Frontiers in Psychology*, 9, 1126. <https://doi.org/10.3389/fpsyg.2018.01126>
- Muraven, M., Collins, R. L., Shiffman, S., & Paty, J. A. (2005). Daily fluctuations in self-control demands and alcohol intake. *Psychology of Addictive Behaviors*, 19(2), 140–147. <https://doi.org/10.1037/0893-164X.19.2.140>
- Muraven, M., & Slessareva, E. (2003). Mechanisms of self-control failure: Motivation and limited resources. *Personality and Social Psychology Bulletin*, 29(7), 894–906. <https://doi.org/10.1177/0146167203029007008>
- Ridder, D. T. D. de, 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(1), 76–99. <https://doi.org/10.1177/1088868311418749>
- Sandry, J., Genova, H. M., Dobryakova, E., DeLuca, J., & Wylie, G. (2014). Subjective cognitive fatigue in multiple sclerosis depends on task length. *Frontiers in Neurology*, 5. <https://doi.org/10.3389/fneur.2014.00214>
- 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. 29–50). Cambridge, Mass: The MIT Press. <https://doi.org/10.7551/mitpress/9780262013840.003.0002>
- Schmeichel, B. J., Harmon-Jones, C., & Harmon-Jones, E. (2010). Exercising self-control increases approach motivation. *Journal of Personality and Social Psychology*, 99(1), 162. <https://doi.org/10.1037/a0019797>
- Seli, P., Risko, E. F., Smilek, D., & Schacter, D. L. (2016). Mind-wandering with and without Intention. *Trends in Cognitive Sciences*, 20(8), 605–617. <https://doi.org/10.1016/j.tics.2016.05.010>
- Shenhav, A., Botvinick, M. M., & Cohen, J. D. (2013). The expected value of control: An integrative theory of anterior cingulate cortex function. *Neuron*, 79(2), 217–240. <https://doi.org/10.1016/j.neuron.2013.07.007>
- Shenhav, A., Musslick, S., Lieder, F., Kool, W., Griffiths, T. L., Cohen, J. D., & Botvinick, M. M. (2017). Toward a rational and mechanistic account of mental effort. *Annual Review of Neuroscience*, 40, 99–124. <https://doi.org/10.1146/annurev-neuro-072116-031526>
- Sjåstad, H., & Baumeister, R. F. (2018). The future and the will: Planning requires self-control, and ego depletion leads to planning aversion. *Journal of Experimental Social Psychology*, 76, 127–141. <https://doi.org/10.1016/j.jesp.2018.01.005>
- Strait, C. E., Blanchard, T. C., & Hayden, B. Y. (2014). Reward value comparison via mutual inhibition in ventromedial prefrontal cortex. *Neuron*, 82(6), 1357–1366. <https://doi.org/10.1016/j.neuron.2014.04.032>
- Turner, B. M., Rodriguez, C. A., Liu, Q., Molloy, M. F., Hoogendijk, M., & McClure, S. M. (2019). On the neural and mechanistic bases of self-control. *Cerebral Cortex*, 29(2), 732–750. <https://doi.org/10.1093/cercor/bhx355>
- Van Tilburg, W. A. P., & Igou, E. R. (2017). Boredom begs to differ: Differentiation from other negative emotions. *Emotion*, 17(2), 309–322. <https://doi.org/10.1037/emo0000233>

- Wagner, D. D., Altman, M., Boswell, R. G., Kelley, W. M., & Heatherton, T. F. (2013). Self-regulatory depletion enhances neural responses to rewards and impairs top-down control. *Psychological science*, 24(11), 2262-2271. <https://doi.org/10.1177/0956797613492985>
- Westgate, E. C., & Wilson, T. D. (2018). Boring thoughts and bored minds: The MAC model of boredom and cognitive engagement. *Psychological Review*, 125(5), 689–713. <https://doi.org/10.1037/rev0000097>
- Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science*, 3(2), 159–177. <https://doi.org/10.1080/14639220210123806>
- Wilson, T. D., Reinhard, D. A., Westgate, E. C., Gilbert, D. T., Ellerbeck, N., Hahn, C., . . . Shaked, A. (2014). Social psychology. Just think: The challenges of the disengaged mind. *Science*, 345(6192), 75–77. <https://doi.org/10.1126/science.1250830>
- Wolff, W., Baumann, L., & Englert, C. (2018). Self-reports from behind the scenes: Questionable research practices and rates of replication in ego depletion research. *PloS One*, 13(6), e0199554. <https://doi.org/10.1371/journal.pone.0199554>
- Wolff, W., Sieber, V., Bieleke, M., & Englert, C. (2019). Task duration and task order do not matter: No effect on self-control performance. *Psychological Research*, 1-11. <https://doi.org/10.1007/s00426-019-01230-1>

Figure 1. Working model on the potential interplay between boredom and self-control within the context of a traditional ego depletion study (to be read from left to right): Primary tasks are designed to be either LCTs or HCTs. For example, the congruent Stroop is frequently used as a LCT and the incongruent Stroop is frequently used as a HCT (Wolff, et al., 2018). In the published literature, the duration of the primary task (horizontal arrow in the middle) varies greatly among studies (Giboin & Wolff, 2019). For example, the primary task might consist of 50 Stroop trials (e.g., Job, Dweck, & Walton, 2010) or of 200 Stroop trials (e.g., Govorun & Payne, 2006). The model proposes that task characteristics change as function of task duration and this in turn leads to changes in task-imposed self-control demands and task-induced boredom. Red rectangles depict self-control demands and green rectangles depict task-induced boredom. The gradient highlights increasing/decreasing self-control demands or task-induced boredom. We propose that understimulation in LCTs leads to increases in self-control that is needed to keep attention on track while working on a boring task. On the other hand, HCTs might be boring at the beginning due to overstimulation and at the end due to understimulation. The figure is schematic and meant to illustrate dynamical changes in task-imposed self-control and task-induced boredom as a function of task duration. We suggest that these changes distinctively contribute to the outcome behavior. In the figure this is illustrated by the paths that connect boredom and self-control demands with subsequent self-control performance. In terms of a cost-benefit analysis, boredom signals whether one should seek out a more rewarding behavioral alternative (“change behavior!”), and the perceived costs of self-control signal whether one should avoid investing further effort (“avoid effort!”). Whether or not an ego depletion effect is observed should then depend on the separate and multiplicative effects of both pathways on performance in the secondary task. For example, rising boredom is expected to instigate behavioral change but also increase the self-control demands that are required to keep attention on track. Not only the attention, but also the meaning component of the MAC model (Westgate & Wilson, 2018) is integrated in the proposed working model: depending on the meaning that one attributes to the task, the experience of boredom and the allocation of self-control can vary. Finally, the ego depletion effect is likely moderated by individual differences. We propose that trait self-control and boredom proneness are likely to moderate the ego depletion effect.