

The neuroscience of “ego depletion” or: How the brain can help us understand why self-control seems limited

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Self-control, known colloquially as willpower, refers to the mental processes that allow people to override any of their thoughts, emotions, or behaviors that compete with their overarching goals. At its heart, self-control is instigated when a person faces a conflict between two competing desires or response tendencies—say, when a dieter is conflicted between ordering a salad or a juicy hamburger for lunch; or when a writer is conflicted between putting pen to paper or checking her favorite social media websites; or even when a study participant is conflicted between naming the color of a word and reading the word in a Stroop task. Such conflict is experienced as subjectively aversive (Saunders, Milyavskaya, & Inzlicht, in press) and can lead people to inhibit or suppress one set of desires or responses and replace them with the second set (Inzlicht, Bartholow, & Hirsh, 2015). Self-control is thought to be applied when a person chooses to inhibit and transcend their immediate desires (e.g., a juicy hamburger, Twitter, word-reading) and to replace them with behavior that is in line with their longstanding goals (e.g., healthy salad, writing, color-naming). As such, self-control is based on core executive functions (Hofmann, Schmeichel, & Baddeley, 2012), specifically inhibitory cognitive control (Miyake et al., 2000).

Self-control, then, helps people to stick to their jogging routine when it is raining outside, stay composed when their boss is yelling at them, and save money instead of making an impulsive purchase. Given the impressive array of behaviors it is thought to underlie, part of the excitement surrounding research on self-control is the promise of what it can uncover: by studying how self-control works, we can discover how to improve it (Inzlicht, Legault, & Teper, 2014). Indeed, a search for ways to improve people's self-control capabilities is an implicit (if

not explicit) goal of much contemporary research on the topic. Many of us would like to know how to better control our behavior, and reducing self-control to its basic psychological and neural operations will facilitate this.

Neuroscience may be a particularly effective lens to understand a construct as complex as self-control because it allows for explanations that penetrate surface differences and uncover mechanistic similarities. As chapters in the current volume demonstrate, neuroscience-level explanations are excellent for breaking-down and understanding psychological phenomena in terms of root processes and mechanisms. Because biological approaches to social psychology have the potential to measure social-psychological processes as they occur in real time, they can tap online processes without being tainted by retrospective memory biases; they can also tap processes that are implicit in nature and beyond conscious retrospection or control (Harmon-Jones & Winkielman, 2007; Ochsner & Lieberman, 2001). Most exciting, perhaps, is that measures derived from neuroscience are now at a point where they can meaningfully predict real-world outcomes, and thus complement more traditional measures (Berkman & Falk, 2013). This is especially the case for the neuroscience of self-control, where by connecting brain measures of self-control with self-control in the real-world, we are gaining a deeper appreciation of what self-control is, how it works, and potentially, how to improve it (e.g., Berkman, Falk, & Lieberman, 2011).

In this chapter, we explore the psychology and neuroscience of self-control, focusing specifically on one of its important facets: its apparent refractory period. For some time, it has been known that self-control wanes after previous efforts at control, such that self-control appears to have some temporal processing limit (Baumeister & Heatherton, 1996; Muraven & Baumeister, 2000). The dominant account of this limit is that self-control is based on some finite

resource or energy, such that engaging self-control quickly consumes this inner capacity and leaves one in a state of “ego depletion,” with further attempts at self-control prone to failure (Baumeister, Vohs, & Tice, 2007). The resource account has been highly influential and has informed most subfields of psychology and human neuroscience, as well as the related fields of behavioral economics, organizational behavior, and consumer behavior. Despite its prominence, however, a thorough understanding of how and why self-control has an apparent refractory period has been slow to develop, and it is clear that more theoretical and empirical work is needed (Inzlicht & Schmeichel, 2012).

Here, we explore some issues in the psychology and neuroscience of ego depletion, in the hopes that an understanding of how self-control is implemented in the brain can teach us how and why self-control has a refractory period. We start with an overview of the traditional resource model of self-control, and explore a number of empirical findings that are hard to reconcile with the resource account. Having conveyed that this account may be lacking in explanatory and predictive power, we then search for answers in some of the still nascent but burgeoning literature on the neuroscience of self-control, and on the neuroscience of ego depletion in particular. This is then followed by a discussion of a more mechanistically-informed alternative to the resource account, called the process model or *shifting priorities model*, which integrates evolutionarily-informed explanations for why self-control is aversive with proximal explanations of how acts of self-control change people’s motivational priorities and expectations for what they are capable of. We then offer potential neurocognitive mechanisms by which this model can be implemented in the brain, with depletion seen as a product of a valuation process that changes dynamically in response to bouts of effort. Finally, we end with a discussion of how

our new understanding of self-control's limits can teach us about how to improve it as a process in general.

The Resource Model of Self-Control

The resource model of self-control suggests that self-control is based on a kind of fuel that powers the will (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven & Baumeister, 2000). The resource model makes two major claims. First, self-control is claimed to draw upon a shared, central resource that underlies a vast array of behaviors that may be different from one another, but that each involve the inhibition of some pressing urge or impulse. Self-control, for example, fuels the ability to eat broccoli over chocolate. The second major claim of the resource account has garnered far more attention, and, in recent years, has proven somewhat controversial (Inzlicht & Schmeichel, 2012; Kurzban, Duckworth, Kable, & Myers, 2013).

The second claim is that self-control is based on a limited resource or fuel that runs out after use. Thus, engaging self-control is thought to consume and deplete this limited inner capacity, leaving further control attempts underpowered. Just like your car consumes fuel to get from one point to another, until there is no more fuel and no more driving, the argument goes that you consume some limited resource to control your behaviors throughout the day until you reach a point where this resource is consumed and you are left without the ability to control yourself any further.

The main evidence in support of the resource model comes from studies showing that exerting effortful control at some earlier Time 1 impairs self-control performance on a different task at some later Time 2. To date, over 200 studies have used this “sequential task paradigm” to support the notion that self-control is based on a limited resource (e.g., Hagger, Wood, Stiff, & Chatzisarantis, 2010). For example, staying calm under emotional duress has been found to make

it more difficult to restrain from eating ice-cream, maintain items in working memory, and maintain physical stamina (Muraven, Tice, & Baumeister, 1998; Schmeichel, 2007; Vohs & Heatherton, 2000). Studies using this sequential task paradigm have suggested that self-control is limited and relies on a finite resource. To date, however, studies scrutinizing the precise processes via which self-control failure in the sequential task paradigm comes about have been lacking, with many questions remaining (Inzlicht & Berkman, in press). It is thus possible for self-control to wane after initial exertion, but for reasons that have little to do with depleted resources (Inzlicht, Schmeichel, & Macrae, 2014).

Before we more directly delve into some of the literature that challenges the resource account, it seems pertinent at this point to make clear some of the assumptions that underlie ego depletion and the use of the sequential task paradigm. Much of the ego depletion literature either implicitly or explicitly (e.g., Schmeichel, Harmon-Jones, & Harmon-Jones, 2010) endorses the notion that self-control behavior is the product of two competing forces: an impulsive force pushing against self-control, and a countervailing controlling force pushing toward it (Figure 1). The crux of the depletion phenomenon is captured nicely in this “dual-process” model under the assumption that the impulsive force is constant (i.e., an automatic, “System 1” process) whereas the controlling force is finite or depletable (i.e., a controlled, “System 2” process; Hofmann, Friese, & Strack, 2009). Thus, in a given situation, while the controlling force might win out for some time, it will inevitably become depleted, at which point the automatic force—which is always present—takes over. This model has been adopted in social and cognitive neuroscience studies of depletion (Heatherton & Wagner, 2011), and in large part explains the design of those studies. Notably, these studies typically manipulate the controlled process (e.g., emotional

suppression, attention control), and then examine its effect on some measure that taps an automatic or impulsive process (Stroop errors, emotional reactivity, food consumption, etc.).

In what ways are these studies problematic, or more particularly, are the explanations of their results as an example of depleted resources problematic? In the following section, we summarize these issues before turning to the neuroscience of self-control for alternative explanations of the refractory period.

Problems with the resource account

What's the Resource? The first problem with the resource account is the inability to specify a *plausible* resource that fuels the will. Instead of being measured, the presence of a depleted resource has mostly been inferred based on performance on the second of two self-control tasks in the sequential task paradigm. However, self-control can have a refractory period without it being based on the depletion of limited energy stores (Inzlicht & Schmeichel, 2012). So what is the resource?

Most studies never observe resource depletion. The one exception comes from studies that have measured glucose (Gailliot et al. 2007), which is a carbohydrate that circulates in the blood stream and that supplies energy for diverse activities of the body and brain. By showing that initial self-control exertion leads to measurable drops in circulating blood glucose, which then mediated the reductions in self-control attributed to ego depletion, these studies vindicated the resource model. The physical resource at the core of the resource model, then, is glucose. But is it really?

The glucose findings have proven to be very controversial and have been challenged on multiple grounds. First, the idea that self-control can consume inordinate amounts of brain glucose is biologically implausible (Kurzban, 2010). Studies using positron emission

tomography (PET), which directly measures localized changes in brain glucose metabolism, suggest that specific mental activities cause a local increase in glucose utilization of no more than one percent above resting levels (Raichle & Mintun, 2006). Mental effort, in other words, consumes very little brain glucose, and the little that it does use is readily circulating in the brain (Hockey, 2013). Second, the finding that self-control actually depletes measurable levels of blood glucose has been difficult to replicate. Molden and colleagues (2012), for example, repeatedly assessed carbohydrate metabolization with highly precise measurements under carefully standardized conditions and failed to find that exerting self-control reduced levels of blood glucose. Third, the original studies used to support the glucose account (Gailliot et al., 2007) have been criticized on statistical grounds, with some claiming the studies suffered from excessively low statistical power and were thus “incredible” or too good to be true (Schimmack, 2012), and others reanalyzing the original data with claims of discrepant results (Kurzban, 2010).

In short, if exerting self-control does not reliably reduce blood glucose levels, then the idea that glucose is the physical manifestation of the metaphorical resource is in doubt. Self-control may nevertheless operate based on some limited inner resource, but the resource must be something other than glucose.

Incompatible findings. While the identity of the fuel-like resource remains in doubt, findings have accumulated that are incompatible with a resource account, thus straining the necessity of a resource concept to explain self-control’s refractory period (Inzlicht, Schmeichel, et al., 2014; Navon, 1984). The ever growing numbers of incompatible findings are of two sorts. The first typically indicates that depletion effects are moderated by adding extra inputs or reward to the self-control task, while the second indicates that depletion is moderated by subjective perceptions, expectations, and construals.

First, rewarding self-control undoes the depletion effect; it cancels its apparent refractory period. This first was discussed by Muraven and Slessareva (2003), who found that participants could maintain high levels of control over time if they were offered cash or interpersonal incentive to do so. Similarly, incentivizing control by re-framing temptations as tests of willpower cancels depletion (Magen & Gross, 2007). Rewarding effort on the Time 2 task, then, undoes the reductions in control due to previous task exertion. In addition to adding value to the Time 2 task, value can be enhanced by adding other inputs or rewards to the intervening period between the two tasks; and when this is done, depletion effects become knocked-out. Thus smoking cigarettes (Heckman, Ditte, & Brandon, 2012), watching a favorite television program (Derrick, 2012), experiencing a positive change in mood (Tice, Baumeister, Shmueli, & Muraven, 2007), affirming some core value (Schmeichel & Vohs, 2009), gargling with sugar (Hagger & Chatzisarantis, 2013; Molden et al., 2012), meditating (Friese, Messner, & Schaffner, 2012), or even praying (Friese & Wanke, 2014) similarly defend against the reductions in self-control observed in the sequential task paradigm.

These sorts of studies are very hard to reconcile with a resource account. If self-control truly relies on some limited, slowly replenishing resource that becomes depleted after use, it is difficult to understand how simple incentives can reverse this depletion. It appears from these studies as if self-control's refractory period has more to do with motivation and value, rather than capacity. Although some have claimed that motivation only matters when people are "partially depleted", and that "true depletion" cannot be counteracted (Vohs, Baumeister, & Schmeichel, 2012), this is incompatible with field and lab studies showing that simple incentives can counteract the effects of fatigue from very long bouts of cognitive labor (Boksem, Meijman, & Lorist, 2006; Hockey & Earle, 2006). Thus, anything that adds value—be that the perception of

choice, a cigarette, or positive feelings—acts like an input that determines whether a person decides to apply effortful control or not. Self-control's refractory period, then, may be based on changes in people's willingness to engage control rather than changes in some physical capacity.

Second, changing perceptions and construals can also counteract depletion. Thus, when people perceive themselves as being depleted despite not having engaged in previous cognitive work, they exhibit poor self-control; conversely, when people perceive themselves as having lots of energy and stamina, in contrast, they show fully intact self-control (Clarkson, Hirt, Jia, & Alexander, 2010). Likewise, perceptions of sleep quality predict cognitive performance, while actual sleep quality does not (Draganich & Erdal, 2014). Perception of depletion, then, predicts control outcomes. Similarly, lay theories about how self-control works and whether it does or does not have a refractory period trumps “actual” depletion (Job, Dweck, & Walton, 2010). When people believe that self-control wanes over time, they show typical depletion effects; however, when they believe that self-control is renewable, they show no noticeable drops in self-control over time. Finally, new work suggests that the construal of effort itself can determine whether it leads to depletion. When people construe an effortful activity as work, they tend to show subsequent failures in control; when they construe the same task as fun and enjoyable, they tend not to show these deficits (Werle, Wansink, & Payne, 2014).

As with the studies of motivation, it is difficult to reconcile these studies with the resource model. If self-control is based on some physical resource that is depletable, it is not clear how subjective perceptions, expectations, and construals should make a difference. Self-control's refractory period, then, may be due to people consciously or unconsciously limiting themselves, believing that they can't go on when they can (Hockey, 2013), or conserving energy for an upcoming challenge (Muraven, Shmueli, & Burkley, 2006; Tyler & Burns, 2009). It may

have more to do with their expectations about how feelings of fatigue predict performance, and less about fatigue signaling some biologically-mediated incapacity.

Taken together, it is clear that the resource model as originally conceived is untenable. No reliable and plausible resource has ever been found, and more and more studies implicate motivation and expectations in driving the ego depletion effect. Despite this, this ego depletion effect is real and replicable (Hagger et al., 2010; however, see Carter & McCullough, 2013), and thus there is a real need for a plausible, mechanistic, and neuroscientifically-informed model to help understand it. And so we now briefly explore some of the neuroscience of self-control—and the neuroscience of depletion—to find clues about the true mechanisms underlying the depletion effect.

The Neuroscience of Self-Control

Quite a bit of knowledge has been created by studies from cognitive neuroscience focusing on what might be considered sub-components of self-control such as response inhibition, attentional control, and error monitoring (see Schmeichel, 2007, for a discussion of the relations among several of these). A full review of these studies is beyond the scope of this chapter and, more importantly, because the purpose of those studies is to identify which brain regions are involved in self-control, they do not necessarily advance social psychological theories on what self-control is, why it has an apparent refractory period, or how to improve it (we'll return to that point below). For our purposes here, it is sufficient to say that a network of brain structures broadly implicated in “top-down” cognitive control including the dorsolateral and ventrolateral prefrontal cortices (DLPFC, VLPFC), the dorsal anterior cingulate cortex (dACC), and the lateral parietal cortex are reliably found to be active during tasks related to self-control (Cohen, Berkman, & Lieberman, 2013; Wager et al., 2005). Since establishing the basic

network, researchers in cognitive neuroscience have focused their efforts on pinpointing the specific mental processes linked with the various anatomical regions involved in top-down control. Though this work is still ongoing, there is some consensus that the DLPFC is involved in planning and rule maintenance (Miller & Cohen, 2001), the VLPFC is involved in inhibitory control and set shifting (Aron, Robbins, & Poldrack, 2004; 2014; Monsell, 2003), the dACC in conflict/error monitoring (Botvinick, Cohen, & Carter, 2004), and lateral parietal regions are involved in working memory maintenance and updating (Vilberg & Rugg, 2008). From a social psychological perspective, each of these processes might be considered necessary, but not sufficient, for self-control.

Moving beyond broad cognitive studies on the details of self-control, a handful of recent neuroimaging studies have specifically targeted self-control depletion. To some extent, it is surprising that this research did not emerge until now given the relatively long time that cognitive neuroscientists have studied constructs related to self-control. One reason this may be is that the cognitive sub-components of self-control do not appear to fatigue with use in the way they are studied in the cognitive neurosciences. For example, working memory or error monitoring tasks can last 30-40 minutes—longer than the typical ego depletion study—without an apparent drop-off in performance (though we note that one study found that 2 hours of continuous performance did eventually decrease error monitoring performance; Boksem et al., 2006). Nonetheless, there is very little evidence of fatigue effects in the cognitive neuroscience literature, suggesting that whatever the cause of the depletion is, it is likely not a predetermined limit on core cognitive processes *per se*.

Researchers have now conducted studies of ego depletion using the two predominant human neuroimaging modalities: electroencephalography (EEG) and functional magnetic

resonance imaging (fMRI). EEG has been deployed to measure event-related potentials (ERPs) associated with self-control and/or self-control failure, and fMRI has been used to indirectly measure neuronal activity (in the form of blood oxygenation-level dependent, or BOLD, signal) before and after depletion.

Two EEG studies have now used a key neural correlate of error monitoring, the so-called error related negativity (ERN), as an index of self-control ability following a self-control effort (emotional suppression; Inzlicht & Gutsell, 2007; Wang & Yang, 2014). The ERN is an evoked brain potential time-locked to when people make errors (Gehring, Goss, Coles, Meyer, & Donchin, 1993), and it is thought to reflect activity in a performance or conflict-monitoring system (Botvinick, Cohen, & Carter, 2004; Holroyd & Coles, 2002) that is generated by the dACC (Dehaene, Posner, & Tucker, 1994). In both studies, participants who suppressed their emotions in an initial phase subsequently performed worse on a Stroop task and had diminished ERNs on error trials compared with control participants who did not suppress their emotions. The reduced ERN mediated the decrement in performance (Inzlicht & Gutsell, 2007), and this effect was specific to emotional suppression and not to emotional reappraisal (Wang & Yang, 2014). These two studies are consistent with the general prediction of the resource model that some specific top-down cognitive resource, perhaps error monitoring, becomes fatigued with use, which in turn hampers subsequent self-control efforts.

Three fMRI studies have attempted to map out the neural effects of ego depletion using similar paradigms to the EEG studies described above. In the most similar study, Frieze and colleagues (Frieze, Binder, Luechinger, Boesiger, & Rasch, 2013) assessed neural activity during both an initial emotion suppression (or control) task and then a subsequent Stroop task. Relative to the control group, DLPFC activation in the suppression group was greater during the initial

task and then reduced on incongruent trials during the Stroop task. However, this pattern emerged *only* for the right DLPFC, and not for the left DLPFC, nor the dACC, even though all three regions were co-active during both tasks and thus presumably involved in self-control in some way. Furthermore, the key relationship between DLPFC activation during the Time 1 emotion suppression task and the Time 2 Stroop task (within the suppression group) was not reported. The presence of this relationship would suggest that the degree of effort in the Time 1 task was directly related to the decrement in performance on the Time 2 task, which follows from the prediction that both tasks draw upon the same (depletable) resource. Without evidence of a shared process, the possibility remains that the Time 2 decrements are caused by the Time 1 exertion via a separate process (e.g., shifting priorities and/or motivation).

The other two fMRI studies leveraged the ability of fMRI data to interrogate connectivity between various brain regions to address the underlying neurocognitive process(es) of depletion in a more nuanced way than was previously possible. Both studies examined the effect of ego depletion, this time generated by effortfully inhibiting attention to distracting words overlaid on a video, on behavioral and neural responses to negative emotional scenes (Wagner & Heatherton, 2013) and to delicious but unhealthy food images in a dieting sample (Wagner, Altman, Boswell, Kelley, & Heatherton, 2013). Neural activity was measured in both studies during cue exposure (to negative scenes or food images) before and after the depletion phase, and both studies found *increases* during exposure in emotional reactivity regions (amygdala and orbitofrontal cortex) from pre- to post-depletion in the depleted group; conversely, there was either a decrease or no change in the control group. In other words, depletion caused people to be more reactive to some affective stimuli than they otherwise would have been. Intriguingly, there were no between-group differences in the activity of any top-down control regions, but both studies reported

diminished *functional connectivity* between the DLPFC and the respective reactivity regions; in controls, there was a robust inverse relationship between DLPFC and amygdala/orbitofrontal cortex, but that inverse relationship was eliminated in the depletion group. According to the fMRI studies, then, the apparent process is not that depletion entirely knocks out top-down control per se, but rather that depletion uncouples top-down control from emotional reactivity when it otherwise would be engaged. Control processes, in other words, become unmoored from reactivity, when they normally operate in a synchronized, albeit reciprocal fashion.

It is important to emphasize at this point that these studies highlight some of the limitations of the “dual-process” aspect of much of the ego depletion literature. First, in the fMRI studies that examined connectivity (Wagner & Heatherton, 2013; Wagner et al., 2013), self-control performance decrements following depletion were systematically linked to the degree of coupling between the controlling process and the impulsive process. This pattern suggests that the two processes do not independently compete for control of behavior; but instead they are in some way interdependent. This is important because there is evidence that the degree of the coupling is context dependent (e.g., that it changes as a function of the stimulus class, e.g., Wagner & Heatherton, 2013), indicating that additional processes beyond the basic two might modulate the competition between them and its outcome. Secondly, and supporting the first idea, even after 2 hours of depleting mental effort, participants’ ability to engage in self-control could be restored (or “repleted”) by increasing their motivation to perform well on the task with a monetary incentive (Boksem et al., 2006). On the surface, this finding suggests that motivation must be accounted for somehow in depletion models. As we will see, this is a challenge for the dual-process models that underlie depletion accounts, because motivation doesn’t cleanly fit in either of the dual processes since it can be driven both by automatic (e.g., primary reward) and

controlled (e.g., goal setting) processes. On a deeper level, this finding challenges the basic assumption that there is a hard limit on certain (i.e., controlled) processes but not on others (i.e., impulsive). At the neural level, signals such as the ERN can be restored, even after two hours of effort, with minimal incentives.

The Refractory Period as Changes in Motivation

As we have just seen, the still emerging literature on the neuroscience of self-control depletion offers clues to the processes that underlie self-control's refractory period. Some studies indicate that depletion leads to decreases in brain activity in regions related to cognitive control (Friese et al., 2013; Inzlicht & Gutsell, 2007; Wang & Yang, 2014). These sorts of studies are consistent with the resource model view of depletion as an inability to regulate—depletion here could be interpreted as some neural deficiency whereby initial effort reduces neural resources available for the top-down regulation of prepotent responses. Other studies, however, fail to show deficiencies in brain regions related to control and instead show increased activity in brain regions related to motivational salience and reward value (Wagner & Heatherton, 2013; Wagner et al., 2013). These latter sorts of studies add nuance to the depletion literature and suggest that self-control's refractory period may be less a product of an inability to control oneself and more a product of people's desires changing and strengthening over time.

Alternative Account 1: The shifting priorities model

Also called the process model of depletion (Inzlicht & Schmeichel, 2012; Inzlicht, Schmeichel, et al., 2014), the shifting priorities model integrates research from multiple areas, including the opportunity cost model of performance (Kurzban et al., 2013), work on the aversiveness of control (Botvinick, 2007; Kool, McGuire, Rosen, & Botvinick, 2010), and the psychology of fatigue (Hockey, 2013).

The model first attempts to address *why* self-control wanes over time, suggesting that this temporal dynamic was evolutionarily selected to solve a recurrent problem in human life (Tooby & Cosmides, 1992): the problem of balancing the needs for exploitation versus exploration, whereby the value of exploiting established sources of reward is pitted against the utility of exploring the environment for other opportunities (Cohen, McClure, & Yu, 2007; Tooby & Cosmides, 2005). Balancing this trade-off involves regulating the extent to which the control system favors task engagement (exploitation) versus task disengagement (exploration). Knowing when to persevere and when to change course is a balancing act—if the appropriate balance is not maintained, people may expend too much effort for too little reward or prematurely give-up on an endeavor before some large payoff. The point here is that natural selection would have favored adaptations that minimize opportunity costs caused by a poor decision about whether to engage or to disengage from a task (Kurzban et al., 2013). One such adaptation is making effortful control aversive, having inherent disutility (Kool et al., 2010).

Because effortful control is aversive, not only do people tend to avoid it, their desire to avoid it increases with the more time they spend engaged in effortful control (Kool & Botvinick, 2014). In other words, the inherent disutility of cognitive work accumulates the more one has engaged in work already. This is another way of saying that people increasingly prefer rest and leisure after engaging in cognitive work and effort.

From this perspective, self-control's refractory period may be the motivated switching of task priorities, wherein all forms of mental effort become increasingly aversive, making mental leisure increasingly attractive. What this means is that depletion may not be about some finite resource being exhausted, but about people's preferences and priorities changing. Specifically, initial bouts of effort may lead people to subsequently prefer engaging in "want-to" goals as

opposed to “have-to” goals (Inzlicht, Schmeichel, et al., 2014). That is, people may experience a shift in motivation away from “have-to” or “ought-to” goals, which are carried out through a sense of obligation and duty, and instead come to prefer “want-to” goals, which are fun, personally enjoyable, and meaningful (Deci & Ryan, 2002). Although this motivational shift was originally conceived as primarily influencing subsequent attention (Inzlicht & Schmeichel, 2012), or subsequent attention and emotion (Inzlicht, Schmeichel, et al., 2014), it likely affects all information processing modalities (e.g., perception, memory, etc.) given motivation’s far reach. Thus, depletion might not only affect what people pay attention to in their environment, but also how they perceive and remember it.

Without some countervailing reward to offset the increasing aversiveness of work, people will prefer to engage in activities they find more immediately pleasurable (Inzlicht, Schmeichel, et al., 2014). Thus, self-control can be seen as the product of multiple inputs that either add or subtract value from the eventual decision about whether to engage cognitive effort. While effort may itself have inherent disutility, this can be countered by the many additional sources of value that may lead someone to decide to forego immediate gratification to engage control, including being self-affirmed (Schmeichel & Vohs, 2009), gargling with sugar (Molden et al., 2012), or getting the opportunity to pray (Frieze & Wake, 2014). This disutility can also be countered by framing effort as a means toward some inherently fun and enjoyable end, thereby changing the value of effort itself, like when walking is framed as sight-seeing instead of as exercise (Werle et al., 2014). In this light, expectations about how self-control works (Job et al., 2010) and perceptions of fatigue and vitality (Clarkson et al., 2010; Draganich & Erdal, 2014) are additional inputs that add or subtract value from the decision about whether or not to apply

effort. Seeing self-control as the product of multiple inputs that influence the decision about whether to exert effort is consistent with emerging views from cognitive neuroscience.

Alternative account 2: The valuation model

A second model, which complements the first, is derived from neuroeconomics literature on decision-making and the valuation of stimuli. In this model, self-control is driven by *subjective value*, such that the perceived value (or utility) of the response options are the principal determinant of any given self-control decision. Subjective value is a function of input from a large range of sources (e.g., perceived difficulty, monetary value, social value, self-relevance, etc.) that are integrated into a common value signal that then presumably drives self-control (or impulsive) actions. Critically, these sources (a) can fluctuate over time as situations evolve and (b) contain a blend of automatic and controlled processes that do not necessarily oppose one another. Thus, self-control can be viewed as a “single-process”, namely as the integration of an arbitrary number of value signals to a unitary value calculation. This idea nicely accounts for both traditional ego depletion effects and the more recent data that challenge the original dual-process account, and is supported by emerging evidence from neuroscience. Below, we review recent evidence from social neuroscience and social psychology for this view.

The strongest neuroscience evidence for this valuation model of self-control comes from the neuroeconomics literature. This research explicitly models decision-making as a process of value comparison among various response options wherein the option with the highest subjective value is chosen (Rangel, Camerer, & Montague, 2008). Studies adopting this approach consistently find that activation in one region in particular—the ventromedial prefrontal cortex, or vmPFC—is involved in value computations of both appetitive and aversive stimuli (Tom, Fox, Trepel, & Poldrack, 2007). In their program of research, Rangel and colleagues have found

that the vmPFC integrates information across a range of properties about a stimulus to produce a final value signal that includes stimulus properties, active goals, costs, and other types of choice-relevant information (Rangel & Hare, 2010). For example, in one study (Hare, Camerer, & Rangel, 2009) participants separately rated the tastiness and healthiness of a series of food stimuli, and then made choices about whether or not to eat each food. Activity in vmPFC predicted stimulus value (i.e., choice) regardless of whether the choice was driven by health or taste concerns. In another study (Hare, Camerer, Knoepfle, O'Doherty, & Rangel, 2010), activity in vmPFC at the time of choice correlated with previous ratings of the value of charitable organizations. That study also found that vmPFC received inputs from brain regions associated with social cognition, which is presumably involved in placing a subjective value on charitable giving options. Thus, the vmPFC appears to be a point of convergence for value-related information during choices that may be relevant to self-control (e.g., tasty vs. healthy food choices).

In further support of the notion that the vmPFC is a global valuation region, the vmPFC appears to calculate the subjective value of a range of stimuli. For example, vmPFC activity accurately predicts choices regardless of whether the stimuli in question are food or money (Levy & Glimcher, 2011). A related study found that activity in vmPFC scales with the subjective value of a monetary gain for oneself and another person (Zaki, Lopez, & Mitchell, 2014). First, in a series of binary forced-choice options, participants chose between gains for themselves or gains for another person. Based on these responses, the experimenters computed a scaling factor to describe the relative value of gains for oneself and another (e.g., if I'm equally likely to keep \$8 for myself as I am to give \$4 to you, then my scaling factor between self and other is 2). Then, in a separate set of trials, gains were separately offered to the self or the other.

In these trials, vmPFC activity linearly scaled with the *subjective* value of the gains (e.g., was equal for an \$8 gain for you and a \$4 gain for myself). Not only does vmPFC reflect value, then, but it also scales value across disparate outcome types in a common valuation system to facilitate choice among them (Levy & Glimcher, 2011), making this region a likely candidate to be the final locus of value inputs from a range of qualitatively different processes.

From this perspective, self-control is less a battle between “hot” impulses and “cold” control (Metcalf & Mischel, 1999) than it is an integration of value inputs from an arbitrary number of sources including primary rewards, salient goals, social value, effort costs, etc. (see Figure 2). Critically, under the value calculation model, self-control success can be increased by amplifying the value of the self-control action (i.e., boosting the *goal-relevant* value), attenuating the value of the impulsive action, or some combination of the two. A dramatic example of the success of this approach comes from research on contingency management treatment for substance use disorders (Bigelow & Silverman, 1999), in which the value of drug abstinence is increased with monetary incentives. A meta-analysis found this approach to have an effect size $d = 0.42$ on treatment for alcohol, tobacco, and illicit drugs, which was larger than therapy ($d = 0.25$) and outpatient treatment ($d = 0.37$), and comparable to methadone treatment for opiate use (Prendergast, Podus, Finney, Greenwell, & Roll, 2006). Another line of work relating value to self-regulation has found that monetary incentives increase persistence at exercise (Cabanac, 1986) and endurance on a cold-pressor task (Baker & Kirsch, 1991). A final example comes from research on the ego depletion effect itself. Rewarding participants with monetary incentives for performance (Muraven & Slessareva, 2003), or even the thought of incentives (Boucher & Kofos, 2012), mitigates or eliminates the ego depletion effect, consistent with the idea that

increasing the value of self-control can improve performance in cases when it would otherwise drop off.

Other psychological processes beyond reward can also impart value to self-control. For example, identity or self-relevance has intrinsic value (Greenwald et al., 2002), so, all else being equal, decisions that are related to one's identity would be expected to have higher value—and therefore are more likely to promote self-control—than decisions that are not identity-relevant. Identity priming and other manipulations that make identity salient (e.g., self-affirmation) can thus attenuate the ego depletion effect or eliminate it altogether. Schmeichel and Vohs (2009) tested this by inserting a self-affirmation manipulation between the first and second self-control tasks of the sequential task paradigm, and found that participants who wrote about core values showed just as good, if not better, performance on the second of the two tasks after they were “depleted.” Choice and autonomy also eliminate or reduce the ego depletion effect relative to autonomy-undermining or forced conditions (Moller, Deci, & Ryan, 2006; Muraven, Gagné, & Rosman, 2008; Sheldon & Elliot, 1998). These results are consistent with self-determination theory's (Deci & Ryan, 1985; Ryan & Deci, 2000) prediction that tasks motivated intrinsically (vs. extrinsically) are viewed as more self-relevant, and are thus afforded greater effort and resources. Along these lines, one study even found that inducing self-awareness between the first and second self-control tasks eliminates the depletion effect (Alberts, Martijn, & de Vries, 2010). Finally, manipulating the salience of self-control itself increases self-control, presumably because many people value willpower as an attribute (Magen & Gross, 2007; Study 2). In that study, participants completed a self-control task twice, and in between were randomly assigned to reconstrue *the task itself* as a measure of their own “willpower” or not. Performance improved only among participants whose perceptions of the task were changed from non-diagnostic to

diagnostic of willpower. All of these findings are consistent with a single-process model such that increasing the salience of identity (via self-affirmation, increasing self-awareness, or priming autonomy goals) bolsters self-control performance by reminding people of the inherent value of their identity in the relevant domain.

The link between identity and subjective value is further supported by the fact that the neural systems for the two processes are nearly identical. As noted above, the vmPFC appears to be the locus of a common value calculation; this region is also active in a range of self and identity processes. The vmPFC is active when people reflect on their own traits (Kelley, Macrae, Wyland, Caglar, Inati, & Heatherton, 2002; Pfeifer, Lieberman, & Dapretto, 2007), attitudes and preferences (Ames, Jenkins, Banaji, & Mitchell, 2008; Mitchell, Macrae, & Banaji, 2006), and ongoing emotional experience (Ochsner, Knierim, Ludlow, Hanelin, Ramachandran, Glover, et al., 2004; Phan, Wager, Taylor, & Liberzon, 2002). Furthermore, activity in mPFC during encoding of information correlates with memory recall for that information, but only when encoding used a self-referential mnemonic (Macrae, Moran, Heatherton, Banfield, & Kelley, 2004). A recent meta-analysis of over 200 neuroimaging studies further supports the role of mPFC in self-related processes, particularly implicating the vmPFC in self processing (Van Overwalle, 2009). Indeed, the high degree of overlap between self-processing and value in the vmPFC have led researchers to re-characterize its function as a hybrid between the two, to “assign significance to self-relevant experiences based on individuals’ motivations (needs, goals) that are salient at a given moment” (Kim & Johnson, 2014).

Implications of the new models for understanding and improving self-control

Integrating the two alternative accounts —the shifting priorities model and the valuation model—presents an entirely new perspective of self-control and its depletion. The fundamental

cause of depletion, in this view, is that people value task performance less and value disengagement more. Indeed, why shouldn't they? Presumably, research participants enter the laboratory with some amount of motivation to engage in the experimental task. The source of this motivation might be to get course credit or money, or might be a result of a self-consistency motive ("I showed up to the experiment, so I must want to be here", etc.). In any case, these participants typically have little reason to value their performance, particularly after they've completed the first task. Valuation is an ongoing process; it changes with the situation. After an initial task, participants may feel that their obligations are fulfilled or that they are licensed to slack off more (Huberts, Evers, & Ridder, 2012). Eventually, self-control falls off because priorities shift to more highly valued activities, such as leisure, or even effortful tasks that are more personally relevant or rewarding.

The integrated model makes a number of new predictions that will need to be tested and borne out empirically. We close by discussing its implications for self-control improvement. On the first order, the most direct way to boost self-control is to increase its value. We've alluded to several ways of doing that: through monetary incentives, through identity / self-affirmation, and even by reminding people about the value of self-control itself. If self-control strength is driven more by value than by a particular cognitive ability, then a new aim for the field of self-control becomes the characterization of what people value and how to push those values around.

We suggest that the study of self and identity is a rich starting point for these investigations. For example, self-determination theory (Deci & Ryan, 1985) has articulated the effects of intrinsic motivation on goal pursuit broadly and self-control specifically. We've already discussed the idea that depletion signals an opportunity cost of effort (Kurzban et al., 2013); an intriguing possibility under our model is that self-control enacted in the service of the

most highly prioritized intrinsic goals will evince little or even no depletion because there's literally nothing else with higher value. Anecdotal evidence certainly supports this idea, as suggested in the famous quote attributed to Confucius, "Find a job that you love and you will never work another day in your life." The vast majority of the ego depletion literature involves tasks that have little intrinsic value for participants. A straightforward research question is to establish whether intrinsically motivated self-control is depletable to the same degree as extrinsically motivated self-control. There is some indirect evidence that this may be the case (Moller et al., 2006), but more direct evidence is needed.

In the long term, the field may need to develop ways of turning extrinsic goals into intrinsic ones. How can or does something *become* self-relevant? How can we turn our "should" goals into "want" goals? Again, the literature from self and identity reveals some promising ideas. For example, a simple "noun-verb" manipulation has been shown to increase self-regulatory behaviors if not self-control per se. In one study, phrasing questions about voting intentions in terms of identity (noun: "being a voter") instead of an action (verb: "voting") increased voting intentions and actual turnout in statewide elections (Bryan, Walton, Rogers, & Dweck, 2011). In another, participants were less likely to cheat (by claiming money they were not entitled to) if the behavior was described as an identity (noun: "being a cheater") instead of an action (verb: "cheating"; Bryan, Adams, & Monin, 2013). Both of these results are consistent with the idea that identity influences self-control, perhaps by highlighting the subjective value of desired ("voter") or undesired ("cheater") identities. The field has made tremendous progress by going down the "control" road to understanding self-control; perhaps it is time to follow studies like these down the "self" path for a while.

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Figure Captions

Figure 1. The dual-process account of self-control implied by the strength model. Two processes, one top-down and controlled, and the other bottom-up and automatic, compete with each other to determine self-control success or failure.

Figure 2. The valuation model of self-regulation. An arbitrary number of input processes such as primary/secondary rewards, identity, social context, and effort costs (left) contribute to the subjective value (middle) of the response options (e.g., the “regulated” and “impulsive” actions). The option with the highest subjective value is enacted (right).

Figure 1.

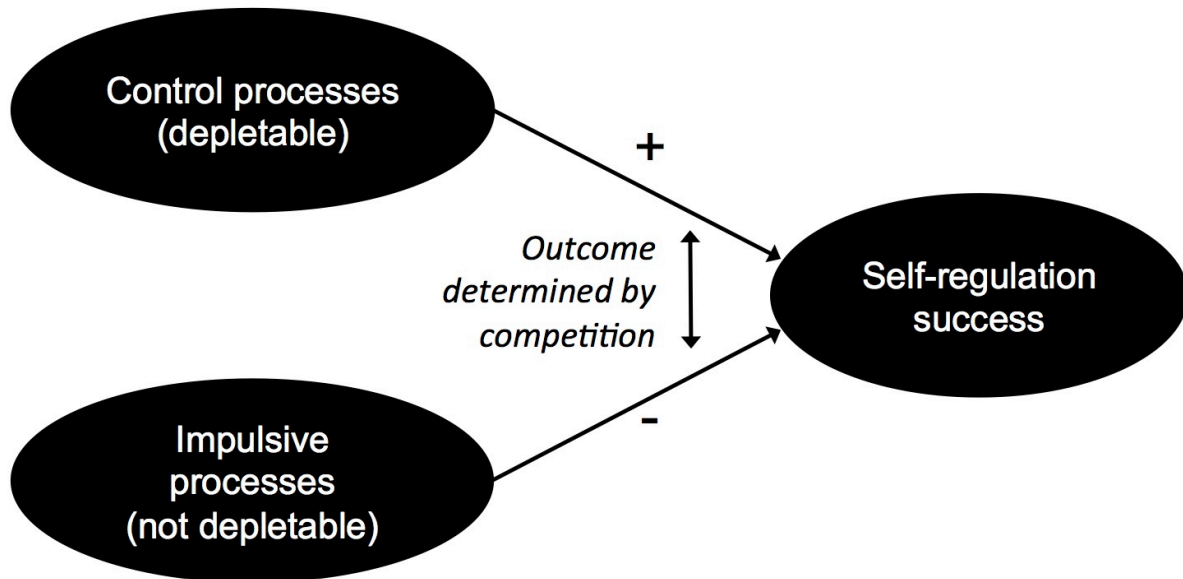


Figure 2.

