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## Editorial

# Imaging depletion: fMRI provides new insights into the processes underlying ego depletion*

**'Ego depletion' refers to the phenomenon of diminished ability to enact self-regulation with repeated efforts. Several models offer process accounts of how ego depletion works, but few studies directly investigate these processes. A study in this issue of *Social, Cognitive, & Affective Neuroscience* by Wagner and Heatherton is among the first to do so. Their results substantiate one possible mechanism of ego depletion and, more broadly, illustrate how neuroscience data can further social psychological theory.**

Performance on a task requiring self-control reduces performance on subsequent self-control tasks—an effect that psychologists have dubbed 'ego depletion'—but the mechanisms behind ego depletion are largely unknown. In an article in this issue of *Social, Cognitive, & Affective Neuroscience*, Wagner and Heatherton (this issue) provide some of the first insights into the neural processes the give rise to ego-depletion effects, and what they found has major implications for theories of self-control.

This article comes at an exciting time in ego-depletion research. Extensive evidence for ego depletion (e.g. Hagger *et al.*, 2010) has led to strong consensus that it occurs in a variety of contexts, so the field is now turning to the question of mechanism—how does ego depletion work?

Three main theories are currently under investigation. Each accounts for some but not all of the available data, perhaps because each focuses on one piece of a complicated, multifaceted process. The first holds that ego depletion happens because various forms of self-control all rely upon a common physiological resource—blood glucose—that is quickly consumed by effortful self-control attempts, and subsequent self-control efforts are diminished when glucose levels are low or appear low to a glucose monitoring system. Evidence in favor of this hypothesis shows that the ego-depletion effect is mitigated by intake of a high-glucose drink following the first task, but not by intake of a low-glucose but otherwise similar control drink (Gailliot *et al.*, 2007). Nonetheless, a handful of recent findings run counter to the notion that self-control relies upon a limited physiological resource (Clarkson *et al.*, 2010; Kurzban, 2010). For example, Job *et al.* (2010) found that only those who believed that self-control was a limited resource showed the depletion effect; those with an unlimited belief about self-control resources did not evince ego depletion following a self-control task (regardless of whether the belief existed prior to the experiment or was induced by an experimenter). These findings imply that the relationship between glucose and self-control is not one-to-one and begin to explore other factors that alter the relationship between resources (glucose or some other type) and self-control effort.

Two additional accounts of depletion have emerged that complement the resource model and account for some of the recent data. One idea is that engaging in self-control heightens reactivity to affective stimuli in general (K.D. Vohs, R.F. Baumeister, N.L. Mead, S. Ramanathan, W. Hofmann, B.J. Schmeichel, submitted for publication). This hypothesis is grounded in the idea of a trade-off between affective evaluation and executive function, or, more specifically, between emotion reactivity and emotion regulation (Heatherton and Wagner, 2011), whereby weakening one system intensifies the other. For example, exerting effort on a cold pressor task (which requires a large amount self-control) will increase subjective reactivity to emotional stimuli making a subsequent emotion regulation task more difficult. In this 'trade-off' model, stronger emotions or impulses, not necessarily reduced self-control resources, cause the decrements in performance on sequential self-control tasks in ego-depletion studies.

Another explanation of ego-depletion effects is that self-control exertion generates concurrent shifts of motivation away from self-control and toward self-gratification and of attention away from control-related cues and toward gratification-related cues (Inzlicht and Schmeichel, 2012). In this model, self-control resources are not depleted so much as re-allocated based on context, needs and priorities; self-control efforts hamper subsequent performance because of reduced motivation to engage in further control (e.g. self-licensing to take a break) and/or a lack of attention to cues signaling the need for control (e.g. diminished error monitoring). Consistent with other work on the importance of beliefs about (Job *et al.*, 2010) or perceptions of (Clarkson *et al.*, 2010) resources, this model hypothesizes that the motivation to exert self-control varies with appraisals of available resources, and that appraisals are only loosely connected to actual resources. A variety of factors such as beliefs, recent exertion and glucose levels can affect appraisals of resources, which in turn determine self-control allocation.

The ego-depletion literature is thus blessed with ample theory about process and literally hundreds of empirical studies demonstrating the effect (Hagger *et al.*, 2010), but lacks almost any data that speak directly to its underlying processes. Thus, the article by Wagner and Heatherton in this issue is a significant step forward because it provides some of the first data on the neural processes of depletion. The same article also makes a more broad contribution by serving as an excellent model of how neuroscience data can inform social psychological theory.

So what did they do? The experimenters employed a standard sequential task paradigm to induce ego depletion, or not, in their participants (Wagner and Heatherton, this issue). What's new is that the participants' brain activation was measured using functional magnetic resonance imaging (fMRI) before and after the depletion induction (or control), which allowed the experimenters to look at the changes in activation caused by earlier self-control efforts. Participants first viewed a series of highly emotional positive and

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negative images, in addition to neutral images, and made an indoor/outdoor decision about each. They then viewed a video overlaid with a series of distracting words, and were told either that they should ignore the words (the depletion condition) or that they could read them if they chose to do so (the control condition). This manipulation has reliably produced ego-depletion effects in participants in several previous studies. Finally, participants viewed a new series of emotional and neutral images and completed the same scene discrimination task. By comparing the depletion with the control group in the amount of change in neural activation between the first and second emotional tasks, this design allowed the researchers to examine the effects of a class ego depletion induction on neural activation.

The pattern of results was fascinating, and provided some support for each of the new theories. First, depleted participants showed increased activation in the left amygdala from before to after the depletion condition, whereas controls showed no change or possibly a slight decrease. In other words, control participants may have habituated to the images, but depleted participants were more reactive to the images on a neural level following self-control exertion. On its own, this result is consistent with both the trade-off model, which predicts increased reactivity following self-control exertion, and the motivation–attention model, which predicts that subjects will be less motivated to regulate and more attentive to emotional stimuli after exertion. However, there was only an increase in amygdala reactivity in response to negative, and not to positive or neutral images (see figure 3 in Wagner and Heatherton, this issue). This result runs counter to the prediction made by the trade-off model of increased overall emotional reactivity, but can be explained by the motivation–attention model in terms of reduced motivation to engage in regulation, which is presumably engaged more during negative than other kinds of stimuli. The finding that regions known to be involved in emotion regulation, such as the right inferior frontal gyrus, were more active during viewing of negative than positive or neutral images across both time points also fits this explanation (see table 1 and figure 2 in Wagner and Heatherton, this issue).

The second main finding was that the control group displayed increased functional connectivity between left amygdala and ventromedial prefrontal cortex (vmPFC)—a region associated with incidental or spontaneous emotion regulation (i.e. regulation that was not prompted by the experimenter; Berkman and Lieberman, 2009)—while viewing negative images, but the depletion group showed no change in the coupling between these regions (see figure 4 in Wagner and Heatherton, this issue). It is as though the control group participants increased their spontaneous regulatory efforts during the second run of the emotion reactivity task, but the group difference emerged because the depletion group participants merely failed to ramp up their regulatory efforts (as opposed to a depletion-like pattern of reduced regulation). Like the previous one, this result is also in line with motivation–attention model, which would suggest the interpretation that the 'depleted' participants could but simply did not deploy self-control.

This pattern of results, together with knowledge gained from cognitive neuroscience studies, can directly inform social psychological theories of the ego-depletion process. On the one hand, the motivation–attention model suggests that participants in the depletion condition may have been less motivated to engage in control, less attentive to cues to engage control or both. On the other, we have the result that depleted participants failed to show increased vmPFC–amygdala connectivity whereas controls did not. What could the role of the vmPFC be here? That region is involved in a number of processes including self-related processing, emotion and long-term memory (Wager *et al.*, 2007), but in the context of emotional stimuli, several studies have found the vmPFC to be involved in the modulation of the perceived relevance, valence or value of a stimulus with respect to current goals (Phelps *et al.*, 2004; Hare *et al.*, 2009). In the Wagner and Heatherton study, it is possible that the lack of regulation in the depletion group reflects a diminished value of self-control in that group—perhaps those participants simply abandoned the goal to regulate following the first emotional task.

From the broader perspective of the field of social neuroscience, this article provides an excellent example of how neuroimaging can complement existing social or cognitive measures in theory development and testing. This is particularly true in research areas such as this one that have several competing theories to explain a phenomenon, with each theory predicting the involvement of a different set of mental processes (e.g. emotional reactivity, self-regulation, attentional control, motivation, etc.). At this point, cognitive neuroscience studies have amassed sufficient knowledge about the neural systems involved in many of these processes to begin to attach relative likelihoods to various mental processes given a set of activations (Yarkoni *et al.*, 2011; Berkman and Falk, in press). Here, for example, the involvement of vmPFC is more likely to reflect motivational than attentional processes based on what we know about those two systems. In addition, neuroimaging methods can be especially helpful where other measures are unreliable, unavailable or inaccessible to subjective report. For instance, ego depletion produces a small effect on self-reported negative affect that only has been detectable with large samples or meta-analyses (Hagger *et al.*, 2010), and researchers have been unable to identify any other subjective measures that reliably indicate a depleted state. Similarly, research on implicit motives shows that people may not have a strong sense of their own motivational state at a given moment (McClelland *et al.*, 1989), and people spontaneously engage in emotion regulation without necessarily being aware of it (Berkman and Lieberman, 2009), so verbal reports of motivation and emotion regulation can be unreliable. In these cases, neuroimaging data have the potential to provide a unique way of testing the theory.

The study by Wagner and Heatherton is an excellent first step toward understanding the neural systems of ego depletion and exemplary in its use of fMRI for testing social psychological theory more broadly. But the field is still well short of a complete mechanistic explanation of how one act of self-control influences the next, which is why more neuroscience research is so critical in this area. We are delighted to see neuroscience used in these ways, and optimistic that this article presages many future studies clarifying how motivation, emotion and attention all fit together during self-control.

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