RESOURCE-DEPLETION: OUTCOME OF FAILED ENERGY MANAGEMENT OR ADAPTIVE EMOTION?

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

RESOURCE-DEPLETION:

OUTCOME OF FAILED ENERGY MANAGEMENT OR ADAPTIVE EMOTION?

presented by Curtis Von Gunten,

a candidate for the degree of master of arts

and hereby certify that, in their opinion, it is worthy of acceptance.

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Professor Bruce Bartholow

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Professor Kennon Sheldon

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Professor Nelson Cowan

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Professor Philip Robbins

To Nietzsche,

whose Apollonian and Dionysian drives

impeccably characterize the process of completing this project:

from the dreamy optimistic illusion that I could predict nature,

to the recurrent liberation from such delusions,

which redirected my motives towards:

the intoxication of rich imperial stouts,

the jagged harmonies of phase-shifted sawtooth waveforms,

and the frenzied chaos of the Sicilian Defense.

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Abstract

After exerting a demanding amount of mental effort people perform worse on a second unrelated task that also requires mental effort (resource-depletion). Limited resource explanations of this effect (such as the Strength Model) remain popular. Theories of this sort maintain that there is a real sense in which the operations needed to perform demanding mental tasks are compromised after use. The following experimental study tested a purely motivational account of "depletion" effects. This theory does not posit depletable resources, and instead, appeals to shifts in the motivational priority assigned to activities available to a person. Based on evidence demonstrating that non-rewarding mental labor increases the motivation to pursue activities associated with approach motivation, this motivation-based theory predicts that "depleted" participants should perform *better* than non-depleted participants on rewarded trials of cognitive control tasks. Contrary to this prediction, results indicated that rewards had a greater influence on control participants, supporting a depleted capacity theory. In addition, the depleting task was not rated as any less enjoyable relative to the control task, again supporting a limited resource theory. However, the study did not replicate the resource-depletion effect inasmuch as the depletion manipulation had no influence on non-rewarded trials. Thus, the experiment provides support for a limited capacity theory of depletion effects as motivational explanations rise in popularity. Yet, these results need to be interpreted with caution since the thing to be explained--namely resource-depletion--did not occur in the first place.

Between-task Performance Decrements Over Time

It is a well-replicated finding that after exerting a demanding amount of effort people perform worse on a second unrelated task also requiring effort. Effort refers to both cognitively demanding operations relying on executive functioning (e.g. solving complicated math and logic problems) and to self-control (e.g. suppressing an impulse to buy a flashy shirt when on a tight budget). An example of a study using cognitive operations to induce effort had participants recall sets of words after they were serially presented on a screen. Participants who were also required to solve math equations that were presented between each word performed worse on a subsequent task requiring participants to suppress their facial reactions to an emotionally disturbing film clip relative to participants who were only presented with the words and not the equations (Schmeichel, 2007). As an example of a study using self-control as a stand-in for effort, Baumesiter et al. (1998) found that forcing participants to eat radishes subsequently made them quit sooner on an unsolvable puzzle than participants who were forced to eat chocolates instead of radishes. A meta-analysis conducted in 2010 found over two hundred published studies investigated this finding, which has become known as the resource (or ego) depletion effect (Hagger, Wood, Stiff, & Chatzisarantis, 2010). By far the most popular explanation of the resource-depletion effect holds that the mental operations required for controlled information processing have a limited capacity, which necessarily constrains the operations' performance over time (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Baumeister, Vohs, & Tice, 1998). This Strength Model avers that mental exertion draws from a domain-general pool of limited control resources. Upon the application of effort this reserve is depleted, thus resulting in less mental resources for future effort applications. Just as a muscle requires energy to operate and also becomes fatigued after use, acts of effort such as self-control use mental energy and result in psychic exhaustion. However, unlike a muscle--which only services certain types of movements--the effortful volitional "muscle" or "fuel" is mobilized by all types of mentally effortful tasks from quelling dieting impulses to solving syllogisms.

The Motivational Turn

Recently there has been an upsurge in theoretical accounts that deemphasize the notion of mental resources. Instead, these theories highlight the role motivation might play in producing resource-depletion effects. This switch in trajectory is partly motivated by the impressive number of phenomena that have been found to moderate the resource-depletion effect. “The moderation of depletion by motivation suggests that self-control suffers in many situations because individuals are not unable but instead are not willing to exert sufficient self-control to overcome the impulse” (Muraven, Shmueli, & Burkley, 2006, p. 525). Such moderators include motivational interventions involving money (Muraven & Slessareva, 2003) and autonomy support (Moller, Deci, & Ryan, 2006; Muraven, Gagne, & rosman, 2008), along with manipulations that frame the dependent task as important (Muraven & Slessareva, 2003). In addition, praying (Friese & Wanke, 2014), smoking cigarettes (Heckman, 2012), affirming core values (Schmeichel, & Vohs, 2009), and relaxation (Tyler and Burns, 2008), among others, can also remove, and sometimes reverse, the effect. This has led the primary exponents of the capacity theory to incorporate motivation into their theory: “Ego depletion effects thus indicate conservation of a partly depleted resource, rather than full incapacity because the resource is completely gone” (Baumeister & Vohs, 2007, p. 11).

Nonetheless, several theorists are not satisfied with this limited capacity-plus-motivation position, and instead, claim that the notion of a limited resource should be entirely abandoned. According to these perspectives, processes underlying the determination of motivation are entirely sufficient to explain resource-depletion effects (Inzlicht & Schmeichel, 2012; Inzlicht, Schmeichel, & Macrae, 2014; Kool, McGuire, Wang, & Botvinick, 2013; Kurzban, Duckworth, Kable, & Myersm, 2013). While earlier theorists discovered and accepted that motivation can moderate the depletion effect, they simply appended motivation onto the depleted ability theory (Muraven, Shmueli, & Burkley, 2006; Muraven & Slessareva, 2003). They did not discard depletion as an explanation. In effect, they ascribed to both (a) the idea that controlled processing's ability to perform over time is limited due to some mechanism being compromised and (b) the idea that motivation can influence the extent to which controlled processing is employed. Pure motivation theories claim that (b) is sufficient for explaining "resource-depletion". To discriminate the two, it might be useful to think in terms of a continuum ranging from a strict, capacity-only theory, to a pure motivation-based theory. In the following, these different theories--along with their key assumptions and predictions--will be outlined.

The Theories

Strict Capacity Theory: according to this view, performance decrements are solely the result of a mental operation decreasing in performance over time due to the operation being *impaired* in some way. While the specification of the mechanism responsible for the diminishment is open to interpretation, the majority of theorists working in this context posit some limited, domain-general internal energy that underlies the impairment. Theories of this sort have naturally led to research programs seeking limited physiological resources and to the use of constructs which presume their existence. For instance, researchers make use of phrases such as "costly physiological resources" (Tops, Boksem, & Koole, 2013), "energetical costs, (Boksem & Tops, 2008), and "use-dependent weakening" of brain region (Friese, Binder, Luechinger, Boesiger, & Rasch, 2013), and have proposed specific substances such as glucose (Gailliot et al., 2007), and cortisol (Tops, Boksem, Wester, Lorist, & Meijman, 2006; Tops & Boksem, 2011) as the candidate limited resource. The aspect of these limited resources theories that can make them *strict* capacity theories are the additional claims that the relevant psychological process must become impaired with continued use, and that performance is *only* a product of the process's capacity at any point in time. This implies that performance must decrease over time. Evidence showing that performance remains the same or increases would count as evidence against this view. Crucially, this would appear to obviate any possible influence of motivation in psychological performance over time. While this may seem like a straw man when used to characterize psychological fatigue, since the development of the Hill model of athletic performance in the 1920s, a strict capacity theory has been the most popular explanation of *physical depletion* in exercise science (Noakes, 2012). The Hill model holds that peripheral fatigue--fatigue that is exclusively situated in the skeletal muscles--explains all forms of physical fatigue. The theory claims that the particular limited resource required by the skeletal muscles is oxygen which, in turn, is determined by the heart's capacity to pump blood to these muscles. The 2008 Olympic Games edition of the Journal of Physiology, for example, claims that features of cardiac output (e.g. VO2 max) are the primary distinguishing characteristic of elite endurance athlete (Levine, 2008). Crucial to the present study is that by understanding physical fatigue purely on the basis of the body's physiological and metabolic responses to exercise (viz. heart failure followed by skeletal muscle function impairment) the theory makes no appeal to the central nervous system, and therefore makes no recourse to motivation at all (Noakes, 2012). This is a strict capacity model. Given that the original limited resource theory of *psychological* function drew from metaphors of physical fatigue (it is called the Strength Model after all), it is not surprising that the theory had the flavor of a strict capacity model. "If the tank were truly and thoroughly empty, it is unlikely that increasing incentives would counteract depletion" (Baumeister & Vohs, 2007, p. 11). Given the abundant evidence demonstrating the moderation, and even reversal, of performance decrements over time (mentioned above) this theory is likely mistaken.

Capacity-plus-motivation Theories: like strict capacity theories, theories of this sort maintain that the mental operations employed in effortful tasks must decrease in performance as a result of the operations being impaired in some way; however, the theory also claims that the rate of the decrease can be modulated by the extent to which a person is motivated to conserve his or her processing ability over time. For this reason, this theory has also been referred to as the Resource Management Model(RMM) (Muraven & Slessareve, 2003). Operating capacity does decrease over time and sets an *upper limit* on what can be achieved. The crucial difference between this position and the strict capacity position is that mental systems underlying controlled information processing need not work at full capacity. Depending on how much a person values the current task and on the expectancies a person has regarding the likelihood of performing other valued tasks in the future, she can "choose" the level at which the operation performs and thus conserve its working capacity across time. The amount of operational ability remaining after performing a task feeds into the motivation system that, in turn, determines the *extent* to which the operation is used. This theory is buttressed by work showing that incentives (such as money) can attenuate depletion effects (Muraven & Slessareve, 2003; Moller, Deci, & Ryan, 2006; Muraven, Gagne, & Rosman, 2008). Further support for this view comes from Muraven et al. (2006) who found that when participants are told that they will be performing a third effortful task (a) they perform worse on the second task when they are depleted first (the resource-depletion effects), (b) they perform worse on the second task than people who are not told that they will perform a third task, and (c) they perform better on the third task when they conserved resources during the second. Continuing the analogy of physical and psychological fatigue, capacity-plus-motivation theories have been proposed to explain physical performance. By allowing for a role of motivation and a central executive in performance outcomes, these theories can accommodate such things as the anticipatory aspect of physical performance (e.g. speeding up near the end of exercise), the fact that only between 35% to 50% of active muscle mass is recruited during prolonged exercise (Tucker et al., 2004; Amann et al., 2006), and can alleviate the need to state the awkward claim that "one continues to move the legs until they fail" (Noakes, 2012).

Pure Motivation Theories: as the name implies, these theories attempt to excise the notion of psychological depletion, claiming instead that motivation should be the primary explanatory factor of performance impairments over time. Several different frameworks have been espoused that emphasize this motivational turn (Inzlicht, et al., 2014; Kool & Botvinik, 2014; Kurzban, et al., 2013). While the frameworks differ, it seems that they share a common perspective regarding the nature and function of psychological fatigue. Theories of mental fatigue that posit the depletion of limited energy resources, inevitably must think of fatigue as an unwanted byproduct. The subjective noxious symptoms of psychological fatigue and its behavioral concomitants are the inevitable outcome of the excessive consumption of vital products during the normal process of energy management. Just as it would be better if humans were designed such that they could run faster or longer, it would be a better state of affairs if humans had more mental endurance. Pure motivation theories differ from this perspective quite drastically. Rather than think of the subjective symptoms of mental fatigue such as experienced effort, apathy, and distraction as lamentable byproducts of mental exertion, these theories conceive of mental fatigue as an adaptive system akin to the primary emotions. While theorists of this sort differ on the details, the adaptive function generally attributed to mental fatigue involves goal redirection. Maintaining a specific cognitive goal means suppressing all others. Working on a manuscript, for instance, precludes the possibility of engaging in other activities such as replying to email, exercising, attending to unrelated emerging thoughts, and investigating novel environmental events. Fatigue is conceptualized as a "stop emotion" (van der Linden, 2011) that solves this opportunity cost problem (Kurzban, et al., 2012). In particular, it serves the function of interrupting a currently active goal in order to allow for the engagement of alternative valuable goals (Dodge, 1917; Boksem et al. 2005; Botvinick, 2007; Hockey 2011; Lorist et al. 2005). This mechanism does not prevent prolonged fixation on a current cogntive task because the mechanism is simply unable to do so due to energetic operational demands, but because it facilitates redirecting attention to other cogntive tasks. While the processes underlying controlled information processing are finite in the sense that the number of tasks for which they can be recruited at any given point in time is limited, they are not finite in the sense of beind depleted over time (Kurzban et al., 2012). This has the implication that, in principle, these operations should be able to perform at the same level when directed at certain alternative tasks, which is not the case for the depleted energy perspective.

This perspective gives an alternative reasonf for why people cannot perform well on simple cogntive tasks involving sustained attention over time, such as vigilance tasks (Scerbo 2001, Warm et al., 2008). It might seem a bit unbelievable when considering the impressive cognitive abilities humans possess, that performing accurately on a task that requires monitoring a visual display for infrequent signals for hours on end is beyond human capability (Charney, 2012). Depleted energy theories need to conceptuatlize this "limitation" as a regretable fact that evolution is not optimal. Just as it would have arguably been better if humans had more physical endurance or had greater intellectual ability, it would have been better if they also had enhanced mental endurance. Alternatively, this "limitation" becomes an adaptive advantage when treating psychological fatigue as an emotion that prevents an organism from fixating on the same mental task (e.g. counting blades of grass) for sustained periods of time. Some ancestral humans may have been completely able to direct their attention at the same task for days on end, only stopping to fulfill vital needs, without experiencing any decline in how stimulating and enjoyable the activity was and without any decline in performance; it just may have been determintal to the fitness of the organism, relative to one that regularly experienced boredom and distractability. Even certain present populations, such as "idiot savants", are known to obsessively devote hours to tasks that most would find quite dull (e.g. calender calculating) without decrement (Howe & Smith, 1988; Kurzban et al., 2012). This general idea is not new. One of the first reserachers of psychological fatigue claimed in the early 1900s that "feelings of faituge serve as a sign to us to stop working long before our actual ability to work has suffered any important decrease" (quoted in Arai, 1912, pp. 72-23).

A Pure Motivation Explanation of Resource-depletion Effects

It should be kept in mind that none of the scholars promulgating pure motivation theories have explicitly adopted everything stated above. By interpreting these theories in a broad adaptive-emotion manner, we may have imposed more order on these theories than exists. Each of the theories do differ in the details. To empirically test a pure motivation theory against a capacity-plus-motivation theory, one of the theories needs to be utilized. Importantly, some of these theories (in particular, Kool, McGuire, Rosen, & Botvinick, 2010) are largely consilient with the pattern of data expected by a capacity-plus-motivation theory, making it hard to distinguish the theories empirically. However, the theory proposed by Inzlicht et al. (2014) does seem to deviate from the capacity-plus-motivation theories in terms of predicted empirical outcomes. This theory, which I will refer to as the Motivational Shifting Theory (MST), holds that regulatory failures reflect "the motivated switching of task priorities as people strive to strike an optimal balance between engaging in cognitive labor to pursue 'have-to' goals versus preferring cognitive leisure in the pursuit of 'want-to' goals" (Inzlicht et al., 2014, p. 127). The theory emphasizes the tendency for motivational systems to attain a balance between externally rewarding labor and inherently rewarding leisure. As people engage in cognitively demanding tasks, the inherent cost of that mental work accumulates, requiring ever greater external rewards to counteract the growing aversiveness (Inzlicht, Schmeichel, & Macrae, 2014). This results in decreased motivation to engage in effortful control and increased motivation to pursue activities that are enjoyable or personally gratifying.

While this is a promising idea, we think the theory is conflating two separable aspects of a task. As stated, the theory appears to assume that mental labor is definitionally not enjoyable, while mental leisure is. This can be seen by the fact that have-to goals are associated with cognitive work while want-to goals are associated with cognitive leisure, and be the fact that intrinsic costs are attributed to mental labor (Kool, McGuire, Botvinick, & Rosen, 2010; Kool, McGuire, Wang, & Botvinick, 2013). While there is likely a correlation between intrinsic interest and the objective cognitive demands of a task (with more difficult tasks being less enjoyable), this certainly is not always the case. People often spontaneously engage in difficult cognitive processing for fun, such as completing puzzles like Sudoku, and playing board and card games. Particularly relevant are intricate video games that require the application of most executive functions in the cognitive toolbox, but which are sometimes so engrossing that they can result in addiction. On the opposing end of the spectrum, cognitively mundane activities such as performing vigilance tasks, stapling stacks of papers, and even doing nothing at all, can result in symptoms of fatigue like low mood states (boredom) and unfocused mental states (restlessness). Therefore, we propose that a more accurate theory is one that attributes performance decrements across time not to the objective cognitive demands of a task (e.g. recalling an item that is 2 items back vs. 4 items back), but to the subjective appraisals and/or experiences associated with the task, such as how fun, interesting, and engaging it is for a particular person. With this modification, the crux of MST is that after performing a task that is *experienced* as work, there is a shift in motivation orientation away from suppressing and inhibiting desires and toward approaching and gratifying them (Inzlicht et al, 2014; Inzlicht, & Schmeichel, 2012). Put more colloquially, after doing unsatisfying work a person will be less motivated to continue working and more motivated to pursue the idiosyncratic activities that he finds enjoyable.

This explanation of depletion effects differs from explanations based on capacity and limited resources. To see this, consider the experimental procedure typically used to assess the resource-depletion effect. The dual-task paradigm first assigns participants to either a depleting version of a task (resource-depletion group), or a non-depleting version of a task (or in some cases, an entirely different non-depleting task). After an interim period, all participants then complete a second depleting task distinct from the first. Resource-depletion is evidenced by worse performance on this second task for the depletion group relative to the control group. For instance, all participants might be asked to watch an emotionally upsetting video segment (e.g. two adults vomiting on each other and subsequently consuming each other's vomit, (Dvorak & Simons, 2009)). Participants in the depletion group would be instructed to suppress their emotional (facial) reactions, while the control group would not be given any regulation instructions. Both groups would then subsequently perform the same dependent task requiring effort. Common dependent tasks include squeezing a handgrip, reading the color of words that differ from the color in which they are written, taste testing delicious food, and solving math problems (Hagger et al., 2010).

An aspect of this paradigm that is not often broached is the likely possibility that the tasks used to deplete participants are not experienced as intrinsically rewarding or engaging, or at the least, are not experienced as being fun. On the contrary, the tasks are likely frustrating and experienced as dull and boring, resulting in an increasing need to try hard in order to maintain good performance--a typical symptom of mental fatigue. According to MST, after doing things they do not want to do, people are less motivated to continue doing such things, and more motivated to do things that they want to do. The fact that the tasks in the dual-task paradigm are experienced as aversive--in the sense that they are appraised by the subject as non-meaningful work--decreases the amount of effort participants put into their performance on the following task, while making the participants more eager to do things that they find personally rewarding. Since the participants in the control group do not engage in mentally taxing work (or do so to a lesser degree), they are less subject to the shift away from self-control and towards self-indulgence, and therefore perform better on the second demanding task relative to the depletion group.

Discriminating the Limited Capacity-plus-Motivation Theory from the Pure Motivation Theory

There has been some confusion in the literature regarding whether the capacity-plus-motivation position (i.e., the Resource Management Model(RMM)) implies that performance reductions are a strict necessity (Muraven, 2006; Kurzban et al., 2013). Kurzban et al. (2012) hold that, according to this view, depleted subjects can perform without decrement in virtue of changed incentives. However, given the claim that the mental operations employed in effortful tasks diminish in performance over time, it will be assumed here that while the *extent* to which a depleted participant's performance is reduced relative to a non-depleted participant can alter, depleted subjects are not *capable* of performance equal to that of non-depleted subjects when motivation is equal. Accordingly, people who are hypothetically equally motivated to complete a task should show decreases in performance at the rate at which their psychological systems are impaired. However, the limited number of studies examining the role of motivation on self-control failure have found that depleted subjects who are motivated to perform the second task do not differ statistically from subjects who were depleted first but also given the motivation induction (Muraven & Slessareva, 2003). Actually, in three experiments, mean performance was *better* in the depleted reward condition than in the non-depleted reward condition (Muraven & Slessareva, 2003). It is as if motivation removed the depletion effect, which at first glance, seems to count against RMM since the data suggests that depletion has no effect when motivation is high. This may seem problematic since the point of keeping the limited capacity component in the theory is to hold onto the claim that there is a real sense in which that capacity lowers over time such that two people with the same motivation should not perform equally if one is depleted first. Vohs, Baumesiter, & Schmeichel (2012) provide some clarity on this issue. They found that motivation only moderated the depletion effect when depletion was at moderate levels. When depletion was high (performing 4 depleting tasks instead of only 2), the effect of motivation vanished. They conclude that depletion is in fact real and that motivation can only impose an influence when there is at least some control resources left to conserve or waste. When the tank is empty, motivation is inefficacious.

Now that the implications of the RMM have been outlined, we will discuss one way to empirically discriminate a pure motivation theory like MST from theories like RMM that posit a role for genuine resource-depletion. One implication of MST is that "depleted" subjects can actually increase their performance on a second demanding task. In particular, the theory predicts that if a person performs a dull task that he does not find engrossing, then he should be more motivated to perform a task that he does find enjoyable, or towards which he has an appetitive drive, and therefore perform better or persist longer than if he had not previously performed the dull task. Additionally, and this is the most relevant point, this improvement should occur even if the task the person wants to perform is cognitively demanding. This would be a reversal of the depletion effect: when the second task is positively associated with appetitive drives, those who are "depleted" first should perform better or persist longer on the second task than those who are not "depleted" first. Such a finding would be difficult for the RMM to explain.

To test for this depletion effect reversal, the dependent task needs to be such that increases in approach motivation, and decreases in self-control ability, do not lead to the same outcome. Additionally, the task needs some version where participants have a strong approach-related impulse to perform the task and where that version of the task would also be expected to deplete subjects according to RMM. These two conditions will be discussed in the next two sections, respectively. Both conditions, it will be argued, preclude the use of self-control tasks.

Separating Decreased Control Strength from Increased Approach Motivation

The tasks normally used in the dual-task paradigm involve behaviors that people typically try to regulate, such as eating high-calorie foods, alcohol consumption, and compulsive spending. Since these behaviors are targets of self-control, it is expected that if self-control ability were decreased, the ability to resist these behaviors would decrease, and people would therefore be more likely to perform them. However, these behaviors are also associated with approach motivation tendencies. For this reason, if there were an increase in a person's motivation to reward themselves with things that are immediately satisfying, an increase in these behaviors would also be expected. This is partly problematic because this is just what MST proposes: the latter process of moving towards appetitive or enjoyable stimuli and away from non-engaging stimuli is sufficient to explain the "depletion effect" without the need to postulate an additional process involving a self-control system being impaired or compromised over time.

Fortunately, over the past several years numerous studies have reported the presence of an increase in approach oriented motivation after depletion manipulations. Most importantly, the various variables used to assess this increase in approach motivation are not targets of self-control, and so the outcomes cannot be explained in terms of the amount of hypothetical self-control resources available. For example, participants assigned to a depletion condition have been shown to score higher in self-reports of approach motivation (Schmeichel et al., 2010), score higher in low-stakes gambling (Schmeichel et al., 2010), are better at identifying the presence of reward cues (i.e. money signs) in a perceptual search task (Schmeichel et al., 2010), are more sensitive to appetitive stimuli (i.e. food) as measured by increased activity in parts of the cortex thought to code the value of a stimulus (orbitofrontal cortex; Wagner et al. 2013), are more optimistic about whether they will later acquire medical problems (Crowell et al. 2014), and have broadened attentional focus (Crowell et al. 2014). The present study attempts to show not only that typical depleting tasks increase approach related behaviors, but that these depleting tasks will increase performance on tasks with approach-related incentives *even if the tasks require cognitive control*--that is, a reversal of the resource-depletion effect.

Approach Motivation, Self-Control, or Cognitive Control: What Aspect of a Task Really Results in Resource-depletion Effects?

The notion of a task where increased approach motivation and decreased self-control push in opposite directions may require some background to comprehend. The current proposal has treated both the operation of controlled information processing and the exertion of self-control as potentially depleting. However, there has been some confusion surrounding which one is primarily responsible for depletion effects. Self-control is stipulated here to be the process of resisting immediate pleasure for the sake of partial fulfillment of a longer-term goal leading to a greater reward (Baumeister, Bratslavsky, Muraven, & Tice, 1998; Kool, McGuire, Wang, & Botvinick, 2013). Controlled information processing refers to executive functions--limited capacity mechanisms that coordinate other processing resources such as memory, attention, and action selection, in the service of specific goals (Kool, McGuire, Wang, & Botvinick, 2013).[1] While the self-control orientation seems to dominate, cognitive control perspectives of depletion effects are not uncommon (Hofmann, Schmeichel, & Baddeley, 2012; Robinson, Schmeichel, Inzlicht, 2010; Schmeichel, 2007). Additionally, a meta-analysis has revealed that effect sizes for self-control tasks (e.g. suppressing facial reactions during an emotional film) were similar to executive functioning tasks (e.g.

[1] Note that limited-capacity here does not refer to temporal capacity. The claim that there are limits to such things as working memory capacity such that some people can have better working memory than others, is not challenged in this paper.

complicated math problem) (Hagger, Wood, Stiff, & Chatzisarantis, 2010). Early explanations for why tasks involving executive functions were used in resource-depletion studies explicitly addressing self-control, were grounded in the fact that both self-control and cognitive control involve impulse suppression (Baumeister, Bratslavsky, Muraven, & Tice, 1998). Not eating delicious ice cream requires suppressing an impulse. Incongruent Stroop trials require suppressing an impulse. However, from the perspective of the motivation-based account of resource-depletion outlined above, there are important differences between the two. In particular, self-control tasks (e.g. suppressing the desire to drink more alcohol) confound depletion with low approach motivation in a way that executive functioning does not.

To see this, recognize that activities towards which a person must exercise self-control, almost by definition, are not enjoyable--since they requires a person to suppress an impulse to do something that the person wants to do. The transposition of this claim may be more evident. Activities which are enjoyable, or on par with an impulsive craving, do not require self-control to perform; if acting impulsively was also a type of self-control, self-control would itself become a candidate urge in need of resisting. For these reasons, self-control will result in resource-depletion according to MST. This is because the theory maintains that it is the degree of approach motivation a person has towards an activity which determines whether it will result in what is typically referred to as resource-depletion. And since preventing oneself from doing what one wants to do in the immediate present (i.e., self control) is constitutive of low approach motivation, self control should result in "depletion". However, the theory denies that depletion is occurring, and claims, instead, that doing frustrating, work-like activities that are not immediately rewarding makes one less willing to continue performing activities of that sort. It just so happens that instances of self-control are, by their nature, activities of this sort.

However, the impulse suppression required on a Stroop task and, more generally, the cognitive operations required to complete tasks meant to assess executive functioning more generally, are not intrinsically aversive (Kurzban, Duckworth, Kable, & Myers, 2013; for opposing views see Kool, McGuire, Botvinick, & Rosen, 2010; Kool & Botvinick, 2012; Inzlicht, Schmeichel, and Macrae, 2014). As mentioned previously, mentally demanding tasks, while objectively difficult in terms of the types of mental capacities required to perform them (e.g. a 1-back task versus a 2-back task), need not be accompanied with the phenomenology of experienced mental difficulty and effort (Kurzban, Duckworth, Kable, & Myers, 2013; Csikszentmihaly, 1991). It is possible that doing a 1-back task long enough could be experienced as mentally taxing--as revealed by the role of novelty and sustained attention in alleviating boredom (Eastwood, Frischen, Fenske, & Smilek, 2012)--while performing a 2-back task could be accompanied with subjective states of immersion, flow, and enjoyment if participants are intrinsically motivated enough. If the 2-back task seems farfetched, consider the earlier point made that people spontaneously engage in cognitively taxing activities like playing games, and would presumably rather do this than do nothing at all. Now it is likely the case that when participants perform these tasks in the lab they are experienced as effortful work. Given this fact, it is hard to determine what the depleting aspect of these tasks is: self-control (and thereby low approach motivation), or executive functioning. To see how self-control could be a culprit here, notice that participants have to exert self-control inasmuch as they have to force themselves to continue doing something that they do not want to do in the face of their desire to do something else. In fact, theorists have sometimes resorted to explaining the depleting effect of tasks in this way: depleting tasks are experienced as more frustrating and difficult than non-depleting (or control tasks) and so participants need to suppress the impulse to stop (Hagger et al., 2010). The physical handgrip exercise is a good example of this. The handgrip exercise is commonly used as a dependent task in dual-task paradigm studies. Participants are required to squeeze and hold a spring-loaded handgrip to exhaustion. No one argues that "psychological fatigue" actually physically fatigues hand muscles; rather, depleted participants are thought to persist less long on the handgrip because they have less self-control resources available to inhibit the urge to end this frustrating task. Importantly, the same rational can be applied to cognitive control tasks, and such a rational makes no appeal to the detailed cognitive operations involved. However, while these tasks are often inversely associated with enjoyment, this need not be the case. In fact, for someone high in achievement motivation or in need-for-cognition, a simple, monotonous task may be more subjectively aversive (Kurzban, Duckworth, Kable, & Myers, 2013). According to the pure motivation-based theory proposed, the control task would then become the "depleting" task.

In summary, from the perspective of the motivational account of resource-depletion suggested here, it is essential that the proposed depleting aspect of a task be conceived of as the cognitive operations that the task requires (e.g. executive functioning, working memory, global workspace operations). In this way, approach motivation can be crossed with a depletion variable thought to impair control. Since approach-motivated tendencies associated with self-control are--by definition--low, it is hard to determine whether it is the broader construct of low approach motivation doing the work--of which self-control happens to be an instance--or something unique to self-control itself. For these reasons, the following study utilizes a cognitive control task (rather than a self-control task).

Overview of the Current Study

Limited capacity explanations of resource-depletion remain popular. The following experimental study tests predictions of a purely motivational account of "depletion" effects--the Motivation Shifting Theory (MST). Based on the postulate that performing work-like tasks increases approach motivation tendencies, it was expected that "depleted" participants would perform *better* than non-depleted participants on the rewarded trials of a cognitive control task. On this task, half of the trials were preceded by a motivational incentive precue and half of the trials were preceded by a control precue. If the RMM theory is correct, depleted subjects should perform worse than non-depleted subjects on both reward and non-reward trials--since when motivation is equal the partially vitiated control system of the depleted participants should be apparent. If MST is correct, approach motivation and sensitivity to incentives should be enhanced for depleted participants, resulting in *better* performance than non-depleted subjects on the rewarded trials. In summary, the study provides a critical test between a capacity-plus-motivation theory of resource-depletion effects and a pure motivation theory.

Method

Participants and design

Participants were 100 University of Missouri students enrolled in an introduction to psychology course.[2] Participants were recruited through the subject pool in exchange for partial fulfillment of course requirements.

Procedure

Participants signed up for a study titled, "Reward Processing and Cognitive Control". After giving informed consent, participants first completed a congruent Stroop task that lasted roughly 4 minutes. After this task, a questionnaire measuring trait approach and avoidance motivation was administered. Next, participants completed the task constituting the depletion manipulation (around 13 minutes). The task required participants to cross out letters on pages of type-written text (Baumeister, Bratslavsky, Muraven, Tice, 1998; DeWall, Baumeister, Stillman, & Gailliot, 2007; Tyler & Burns, 2009. The text was taken from a difficult statistics textbook and was intended to be dry and incomprehensible. Participants were given a single page of text and instructed to cross out every instance of the letter "e". This was meant to establish a routine of crossing out "e"s. After 3 minutes passed, the experimenter gave participants another sheet of text. Participants assigned to the control group were asked to continue crossing out all instances of the letter "e". Participants in the depletion condition were instructed to "cross out all occurrences of the letter "e" except those followed by a vowel in the same word (e.g. "read"), or when a vowel is two letters away from an "e" in either direction (e.g. "vowel")". After 10 minutes the participants were stopped (none completed the task in time). Next a manipulation check questionnaire and a mood measure were administered (around 3 minutes). Participants then completed a modified

[2] Based on the estimated effect size (d^{+}) of the resource-depletion effect (which is likely inflated due to publication bias), a sample size of 100 results in statistical power of 0.92.

incongruent Stroop task involving rewards, which constituted the primary dependent measure and which lasted around 12 minutes. The Stroop task contained both rewarded and non-rewarded trials for all participants. Thus the reward manipulation was within-subjects. Participants were told that they would receive 5 cents for each win on rewarded trials (see below). In reality, each participant received the same monetary "bonus". This value (i.e. $5.00) was equal to the quantity participants would win if they performed perfectly on the rewarded trials. Finally, a questionnaire assessing the participant's retrospective motivation to do the previous Stroop task was given, along with a questionnaire assessing the task's difficulty and enjoyability (around 2 minutes).

Measures

Congruent Stroop Task. The purpose of this task was to calculate a reaction time threshold for determining wins on the subsequent incongruent Stroop task. Since individuals are known to vary systematically in performance on speeded reaction time tasks, this approach allowed us to calculate a unique threshold for each individual, thereby reducing unnecessary error variance. Stimuli consisted of the words "red", "green", "purple", and "yellow" presented in red, green, purple, and yellow font, respectively. Each color word appeared in a color that matched its semantic meaning (e.g., ‘‘green’’ presented in green font). Stimuli were presented on a black background. Participants responded to each stimulus by pressing one of 4 buttons ("v", "b", "n", and "m") corresponding to each of the 4 font colors. On each trial, a blank screen appeared for 500 ms, after which the stimulus word appeared until participants responded. A response deadline was not used. There were 20 practice trials that presented "XXXX"s rather than color words in each of the 4 font colors. There were 2 non-practice blocks.

Each block contained 50 trials. The response time cutoff for each participant was determined by taking the median response time of the 100 trials (M = 604ms). This included error trials (M = 4).

Approach Avoidance Temperament Scale. Individuals differ in how responsive they are to positive and negative stimuli (Corr, 2008; Gray & McNaughton, 2000). The Approach Avoidance Temperament Scale is a validated self-report measures of these traits (Elliot & Thrash, 2002; Elliot & Thrash, 2010). The scale consists of 12 items (6 approach items, 6 avoidance items) rated on a 7 point scale (1 = strongly disagree to 7 = strongly agree). Sample approach items include, "When I want something, I feel a strong desire to go after it" and "Thinking about things I want really energized me". Sample avoidance items include, "By nature, I am a very nervous person" and "It doesn't take much to make me worry". A single lure item was also included, "Respond to this question by selecting "3" on the scale". Approach scores were expected to correlate with performance on Stroop reward trials with higher scores resulting in better performance. Further, high scores were predicted to enhance (or even moderates) the expected inverse depletion effect. Specifically, trait approach motivation was expected to interact with the depletion variable such that the difference between depleted and non-depleted participants on reward trials would be smaller (or non-existent) for those with low approach motivation scores relative to those with larger scores. The rational for this prediction is based on the proposed motivational explanation of depletion effects. In particular, depletion is expected to enhance approach motivation. It may be the case that this occurs more robustly (or only) for those already high in approach motivation. No theoretical predictions were made regarding avoidance motivation. However, it should be noted that trait motivation of this sort is known to be associated with anxiety, vigilance, and caution. In the context of a speeded reaction time task like the Stroop, this translates into enhanced conflict detection and monitoring (Boksem, Tops, Wester, Meijman, & Lorist, 2006), which often results in better performance in the form of less errors (Amodio, Master, Yee, & Taylor, 2008; Inzlicht and Gutsell, 2007).

Manipulation check. In order to verify the effectiveness of the depletion manipulation participants completed an 8 item questionnaire with each item falling on a five-point Likert-scale (1 = Not at all; 5 = Extremely). 4 of the items mirrored the typical manipulation check items used in resource-depletion studies. These were expected to gauge the objective difficulty of the task, and included items assessing difficulty and demandingness, as well as items addressing the amount of effort and concentration required to complete the task. The four remaining items were included with the intention of measuring the more subjective, motivational factors associated with the task, and included items assessing enjoyability, interest, boredom and engagingness. Since MST claims that it is the enjoyability of an activity that determines whether the activity results in subsequent depletion effects, and since it also claims that this is normally conflated with cognitive demand in typical depletion studies, it was expected that those assigned to the depleting version of the manipulation would rate the task as both more difficult and less enjoyable than the control version.

Brief Mood Introspection Scale (BMIS). The BMIS is a well-validated and reliable instrument used to assess arousal and valence (Mayer & Gaschke, 1988). It consists of 16 adjectives (e.g. lively, nervous, drowsy), each rated on a 4-point scale (1 =

"definitely do not feel" to 4 = "definitely feel"). The adjectives load on two mood factors: pleasantness-unpleasantness (valence) and arousal-calm (arousal), which allows for 2 composites to be calculated. The administration of the BMIS was intended to examine whether variation between the groups on the dependant task could be attributed to differences in mood caused by the depletion manipulation. No predictions were made regarding these outcomes.

Rewarded Incongruent Stroop Task. This task constituted the primary dependent variable of the study (see Figure 7). Like the previous congruent Stroop task, stimuli consisted of the words "red", "green", "purple", and "yellow" presented in red, green, purple, and yellow font, respectively. Stimuli were presented on a black background. Participants responded to each stimulus by pressing one of 4 buttons ("v", "b", "n", and "m") corresponding to each of the 4 font colors. In order to alter motivation, an incentive precue was presented at the beginning of each trial. The precue consisted of either a green money sign (reward trials) or a grey square (non-rewarded trial). Participants were instructed that if they performed accurately and fast enough on the money sign trials, they would be rewarded 5 cents, thereby incentivizing participant's to perform better. Participants were told that they could not win money on the grey square trials. The precues were randomized across trials. Each trial consisted of a precue (1000ms), a blank screen (75ms), a color-word (until response), a second blank screen (75ms), a feedback screen (1000ms), and a randomized inter-trial interval (250, 350, 450ms). On congruent trials, a color-word appeared in a color that matched its semantic meaning (e.g., ‘‘purple’’ presented in purple font); on incongruent trials, a color word appeared in a color that mismatched its semantic meaning (e.g., ‘‘red’’ presented in green font). Trials were randomized within blocks. On non-rewarded trials, the feedback message read "Trial Over" if the participant answers correctly and "Error" if the participant answered incorrectly. On the rewarded trials the feedback message read "You Won a Bonus!" if the participant replied accurately and faster than the reaction time (RT) cutoff , "Trial Over" if the participant responded accurately but slower than the RT cutoff, and "Error" if the participant made an error. There were 12 practice trials without precues and feedback, followed by 4 normal blocks of 4 trials each.

Motivation Measure. Inzlicht & Schmeichel (2012) note the scarcity of studies that measure the motivation to perform the dependent task.   In order to further examine whether the letter cross-out task altered participants motivation to perform on the Stroop task, a three item questionnaire (e.g. "How hard did you try on the previous task"), measured on a five-point Likert-scale, was administered. Since it is unclear whether the predicted approach motivation boost from prior "depletion" is consciously accessible, and since the boost is only expected to be relevant to the rewarded trials, no predictions were made regarding self-reported retrospective motivation.

Results

Manipulation Checks. To determine whether the harder version of the depleting task was perceived as more difficult than the easier version, the 4 difficulty items were averaged together to create a single difficulty rating index ($\alpha = .70$).   This same process was performed on the 4 enjoyability items ($\alpha = .82$) in order to assess the relative engagingness of the two versions of the task. In addition, participants who did not respond correctly to the lure item (N = 3) were removed from analysis.[3] Results indicated that the difference in difficulty ratings for the two versions of the task was statistically significant, $t(96) = 2.32$, $p = .022$, $\eta^2_p = .05$, with the version of the task requiring vowel monitoring resulting in greater difficulty ratings (M = 11.72, SD = 2.77) than the version that simply instructed participants to cross out all "e"s (M = 10.42, SD = 2.76). However there was no significant difference in enjoyability ratings between the two tasks, $t(96) = 0.00$, $p = .973$, $\eta^2_p = .00$.

Wins. For the rewarded incongruent Stroop task, each trial was categorized as either a win (correct trials that were faster than the response time deadline), non-win (correct trials that were slower than or equal to the response time deadline), or error. A 2(Depletion: depletion vs. control) x 2 (Reward: rewarded vs. unrewarded) mixed-model ANOVA was then conducted separately on the number of wins, number of errors, and reactions times. For wins, results indicated a Reward main effect, $F(1, 97) = 24.06$, $p < .0001$, $\eta^2_p = .20$, with rewarded trials (M = 32.4, SD = 19.6) producing more wins than non-rewarded trials (M = 25.5, SD = 15.5) (see Figure 1). A Depletion main effect was not present, $F(1, 97) = 0.05$, $p = .816$, $\eta^2_p = .001$. The Reward main effect was qualified by a Reward X Depletion interaction, $F(1, 97) = 6.27$, $p = .014$, $\eta^2_p = .06$. The decomposition of this interaction revealed a marginal effect of reward for depleted participants, $t(48) = 1.92$, $p = .061$, $\eta^2_p = .07$, with rewarded trials (M = 30.9, SD = 19.4) producing more wins than non-rewarded trials (M = 26.8, SD = 16.3). The interaction was driven by the fact that the reward effect was amplified for control subjects, $t(49) = 4.72$, $p < .0001$, $\eta^2_p = .31$, (M = 33.9, SD = 19.8; reward), (M = 24.2, SD = 14.7; non-

[3] Participants who responded inappropriately to the lure items on the other questionnaires were also removed from analyses on the respective questionnaires.

reward), relative to depleted subjects. Depleted and control subjects did not differ on rewarded trials, $t(98) = 0.77$, $p = .446$, $\eta^2_p = .01$, (M = 30.9, SD = 19.4; depleted), (M = 33.9, SD = 19.78; control). More importantly, they did not differ on non-rewarded trials either, $t(97) = 0.81$, $p = .419$, $\eta^2_p = .01$, (M = 26.8, SD = 16.3; depleted), (M = 24.2, SD = 14.7; control). The lack of an influence of the depletion manipulation on unrewarded trials is at odds with a resource-depletion effect. Since past research has found that depleted participants who are rewarded do not perform any worse than unrewarded controls, we tested this as well and found that depleted participants who were rewarded actually performed better (M = 30.9, SD = 19.42) than unrewarded controls (M = 24.22, SD = 14.7), $F(1, 98) = 3.78$, $p = .055$, $\eta^2_p = .04$. However, this is less remarkable when taking into account the fact that the present data did not replicate a typical depletion effect (i.e., there was no Depletion effect on unrewarded trials). Also, as one might have expected, rewarded control participants achieved more wins (M = 33.9, SD = 19.8) than non-rewarded depleted participants (M = 26.7, SD = 16.3), $F(1, 97) = 3.86$, $p = .052$, $\eta^2_p = .04$.

Errors. Error counts were first log transformed so as to conform to a normal distribution before being subjected to testing[4]. Analyses revealed a Reward main effect, $F(1, 95) = 21.22$, $p < .0001$, $\eta^2_p = .18$, with rewarded trials (M = 15.7, SD = 11.8) producing *more* errors than non-rewarded trials (M = 12.7, SD = 10.0) (see Figure 3). This finding, along with the above finding that rewarded trials resulted in more wins, suggests the presence of a tradeoff between wins and errors. Consistent with the win data, a Depletion main effect was not present, $F(1, 95) = 1.06$, $p = .305$, $\eta^2_p = .01$. Unlike

[4] Outcomes based on log transformed scores did not differ from those based on raw scores.

the win data, there was no evidence of a Reward X Depletion interaction, $F(1, 95) = 0.18$, $p = .673$, $\eta^2_p = .00$.

Reaction Time. Median reaction times were first computed for each subject. Cell averages of these median reaction times were then log transformed before being submitted for analysis.[5] Results revealed a Reward main effect, $F(1, 98) = 26.93$, $p < .0001$, $\eta^2_p = .22$, with rewarded trials (M = 6.44, SD = 0.22) producing quicker responses than non-rewarded trials (M = 6.53, SD = 0.21) (see Figure 2). Taken with the win and error data, it appears that rewarded trials (i.e., money signs) caused participants to respond more quickly and thereby achieve more wins at the cost of committing more errors, relative to non-rewarded trials. Consistent with the win and error data, a Depletion main effect was not present, $F(1, 98) = 0.16$, $p = .686$, $\eta^2_p = .00$. Like the win data, the Reward effect was qualified by a Reward X Depletion interaction, $F(1, 98) = 6.23$, $p = .014$, $\eta^2_p = .06$. Simple effects tests revealed that for depleted participants the effect of Reward was statistically significant, $F(1, 49) = 7.14$, $p = .010$, $\eta^2_p = .13$, with rewarded trials (M = 6.47, SD = 0.24) resulting in faster reaction times than non-rewarded trials (M = 6.52, SD = 0.22). This increase in reaction times on rewarded trials (M = 6.42, SD = 0.19), relative to non-rewarded trials (M = 6.54, SD = 0.20), was larger for control participants than for depleted participants, $F(1, 49) = 25.32$, $p < .0001$, $\eta^2_p = .34$, which guided the interaction. Like wins and errors, there was no difference on unrewarded trials between the control and depletion group, $t(98) = 0.23$, $p = .635$, $\eta^2_p = .00$, again failing to find evidence for a resource depletion effect. As expected, rewarded control participants (M = 6.42, SD = .193) responded more quickly than non-rewarded

[5] Outcomes based on log transformed scores did not differ from those based on raw scores.

depleted participants (M = 6.52, SD = .223), t(98) = 2.38, p = 0.019, η^2_p = .05). Unlike the win data, there was no difference between non-rewarded controls and rewarded depleted participants, F(1, 98) = 1.50, p = .136, η^2_p = .02.[6]

Previous trial type influence. A resource-depletion effects was not observed for wins, errors, or response time on the non-rewarded trials (or the rewarded trials). This is potentially problematic, since the non-rewarded trials conceptually represent a typical resource-depletion paradigm. One possible reason for this absence could be due to the fact that rewarded and unrewarded trials were embedded within the same task. Due to this within block design, it could be the case that the boost in motivation created by the reward trials was transferred to subsequent non-rewarded trials. If this was occurring, the unrewarded trials would not be representative of the standard non-rewarded dual task paradigm. For this reason, non-rewarded Stroop trials were separated based on whether the previous trials were rewarded or non-rewarded. The trials of interest for the present research question are the non-rewarded trials that followed non-rewarded trials. These trials were submitted to a 2 (Depletion) X 2 (Reward) mixed ANOVA for wins, errors, and reaction times. Analyses did not reveal a Depletion main effect for any of the three dependent variables: wins, F(1, 97) = 0.17, p = .683, η^2_p = .00; errors, F(1, 90) = 0.78, p = .379, η^2_p = .01; reaction time, F(1, 97) = 0.10, p = .748, η^2_p = .00. Each of the three dependent variables indicated a Reward effect, with the same pattern of means found as when collapsing over both rewarded and non-rewarded previous trials (see above). None of the dependent variables revealed a Depletion X Reward interaction. These results suggest that the lack of a resource-depletion effect was not the result of previous rewarded trials obscuring the results.

Approach-Avoidance Motivation. We next examined any potential influence of approach and avoidance motivation on how the depletion and reward manipulations influenced outcomes. To do this the 6 approach and 6 avoidance motivation items were averaged to create an approach ($\alpha = .68$) and avoidance ($\alpha = .74$) motivation composite for each participant. These composites were each entered separately into the 2(Reward) X 2(Depletion) mixed ANOVA model for each of the three dependent variables (wins, errors, and reaction times). The analyses of approach motivation and wins revealed a Reward main effect, $F(1, 90) = 27.20$, $p < .0001$, $\eta^2_p = .23$, as well as a Reward X Depletion interaction, $F(1, 90) = 5.17$, $p = .025$, $\eta^2_p = .05$. However, these effects were qualified by a Reward X Depletion X Approach Motivation, (marginally significant) 3-way interaction, $F(1, 90) = 2.99$, p = . 0.09, $\eta^2_p = .03$.[7] To break down the interaction, we computed a difference score for the control group and depletion group by subtracting win performance on non-rewarded trials from win performance on rewarded trials. These difference scores were then regressed on the approach motivation scores with the 2-level depletion variable included in the model. Analyses revealed a main effect of Depletion, $F(1, 90) = 5.17$, $p = .025$, $\eta^2_p = .05$, and a marginal Depletion X Approach Motivation interaction, $F(1, 90) = 2.99$, $p = .088$, $\eta^2_p = .03$ (see Figure 4).[8] An examination of the simple slopes of approach motivation at each level of the depletion variable revealed that approach motivation did not influence the relative number of wins on rewarded and non-

[7] This interaction reached significant if an outlying data point over 2.5 standard deviations was removed. Removal of this data point also influenced the follow-up tests (see footnotes).
[8] This interaction reached significant if the outlying data point over 2.5 standard deviations was removed.

rewarded trials for depleted participants, b = .49, SE = 1.62, t(43) = 0.30, p = .765. However, approach motivation did influence wins for control participants, b = -4.19, SE = 2.19, t(47) = -1.91, p = .062 (see Figure 4).[9] Contrary to what was expected, participants who rated themselves higher on approach motivation were *less influenced* by the rewards (based on the decrease in the rewarded minus non-rewarded trial difference). Analyses involving errors and reactions times did not indicate any effects involving the approach motivation scores.

The analyses of avoidance motivation and wins revealed a marginal Depletion X Avoidance Motivation interaction, F(1, 90) = 3.39, p = .069, η^2_p = .04 (see Figure 5). Analyses revealed that the simple slopes were not significantly different from 0 for control participants, t(47) = 1.41, p = .166, η^2_p = .04, or for depleted participants, t(43) = 1.43, p = .238, η^2_p = .03. The interaction was driven by the fact that avoidance motivation had an opposing influence on control and depleted participants (see Figure 5). For depleted participants, more wins were observed as avoidance motivation increased. However, for control participants, more wins were observed as avoidance motivation decreased. For errors, results indicated a marginal Depletion X Avoidance Motivation interaction, F(1, 90) = 3.79, p = .055, η^2_p = .04 (see Figure 5). Analysis of simple slopes revealed that avoidance motivation did not influence errors for control subjects, b = -0.15, SD = .24, t(47) = -0.63, p = .532. It did, however, influence errors for depleted subjects, b = 0.52, SD = .25, t(43) = 2.09, p = .043, with increases in avoidance motivation associated with greater error commission. There was no influence of avoidance motivation on reaction times.

[9] This test reached statistical significance if the same outlying data point was removed.

Brief Mood Introspection Scale. We next examined whether the depletion manipulation affected ratings of mood. To do this we formed a pleasant-unpleasant mood composite by combining the 8 positively valenced items with the 8 negatively valenced items (reverse scored; $\alpha = .84$; Mayer & Gaschke, 1988). An arousal-calm mood composite was also created by combining 12 of the relevant items ($\alpha = .60$; Mayer & Gaschke, 1988). Results did not indicate that the depletion manipulation influenced self-reported mood for the pleasant-unpleasant composite, $t(95) = 0.20$, $p = .534$, $\eta^2_p = .00$, or for the arousal-calm composite, $t(95) = 0.69$, $p = .494$, $\eta^2_p = .00$.

Retrospective reports of motivation, task difficulty, and task enjoyability. Next we examined whether the depletion manipulation influenced retrospective self-reports of motivation to perform the Stroop task, as well as whether it influenced ratings of the task's difficulty and enjoyability. To achieve this, the 3 motivation items were combined to form a single composite ($\alpha = .83$). The same process was applied to the 4 difficulty ($\alpha = .80$) and enjoyability ($\alpha = .80$) items. Results revealed that the manipulation did not affect participant's reports of how hard they tried on the task, $t(97) = 0.50$, $p = .616$, $\eta^2_p = .00$, reports of how hard the task was, $t(97) = 0.60$, $p = .549$, $\eta^2_p = .00$, or reports of how enjoyable and engaging the task was, $t(97) = 1.15$, $p = .252$, $\eta^2_p = .01$.

Discussion

Resource-depletion occurs when performance decrements are observed on a demanding task after the prior exertion of mental effort. Limited capacity explanations of this effect (such as the Strength Model) remain popular. Theories of this sort maintain that there is a real sense in which the operations needed to perform demanding mental tasks are compromised after use (Baumeister et al., 2007; Muraven & Slessareva, 2003). This impairment is most commonly attributed to the excessive consumption of whatever vital products the mind uses to inhibit impulses and dominant response tendencies (Gailliot et al., 2007). While these theories can, and normally do, assert that motivation modulates the extent to which these operations are employed (e.g. Resource Management Model; Muraven et al., 2003), these theories are committed to the presence of a real impairment after mental work that cannot simply be corrected by increased motivation (Vohs et al., 2012). For instance, if two people are trying equally hard on an inhibition task, but one started with less control resources, this starting deficit should eventually become manifest in performance. The present experimental study tested an alternative account of "depletion" effects that relies purely on motivation related concepts. This theory does not posit depletable resources, or temporarily compromised cognitive operations more generally, and instead, appeals to shifts in the motivational priority assigned to the different activities a person can engage in at a point in time (Motivational Shifting Theory). According to this theory, depletion is better thought of as disengagement.

The commonly endorsed resource management model(RMM) makes different predictions than the Motivational Shifting Theory(MST) in regards to approach oriented behaviors directed at cognitively taxing activities. Based on the theoretical assumption that cognitive control systems are not genuinely impaired with use, and based on evidence demonstrating that non-rewarding mental labor increases the motivation to pursue activities that are associated with approach motivation (e.g. rewarded activities), MST predicts that "depleted" participants will perform *better* than non-depleted participants on a cognitive control task that is rewarded. This would be a reversal of typical resource-depletion effects. On the other hand, if there is a resource that necessarily diminished after use--regardless of whether the resource can be motivationally managed--depleted participants should perform worse than non-depleted participants when both groups have a high incentive (due to reward) to perform well.

First, our results did not replicate a resource-depletion effect. On unrewarded Stroop trials, participants who were required to monitor a sheet of text for the presence of vowels in order to determine whether to cross out the letter "e" did not perform any worse than participants who were instructed to simply cross out all of the "e"s. This was the case for all three of our Stroop dependent variables (number of wins, errors, and reaction time). This is troubling since the primary objective of the study was to test two theoretical accounts of the effect. This is noteworthy since, according to a meta-analysis, the experiment used the most common depletion manipulation and the second most common dependent task. On top of that, the hardest version of the cross at "e" task in the literature was employed and participants performed the task for 10 minutes which, rather surprisingly, is on the higher end of task duration; studies typically apply their tasks for less than 10 minutes (Hagger et al., 2010). The lack of a resource-depletion effect could be attributed to the fact that the Stroop task used in the study embedded non-rewarded trials with rewarded trials within each block. To test this, we separated non-rewarded trials based on whether they were preceded by a rewarded or non-rewarded trial. Analyses revealed that there was no difference between the depletion and control groups on non-rewarded trials preceded by a non-reward trial for wins, errors, or reaction times. Thus, the failure to replicate is likely not due to this methodological artifact. Of relevance, the results of a meta-analysis in 2010 concluded that the depletion effect is robust and medium in magnitude (d = 0.62). However, based on methods for estimating and correcting for small-study effects, Carter & McCullough (2014) found very strong signals for publication bias, along with an indication that the depletion effect was actually no different from zero. In addition, Xu et al. (2014) report a four-fold failure to replicate the resource-depletion effect using the crossing out letters protocol as well as a modified Stroop in addition to other common procedures. Further, amidst such skepticism, the Association for Psychological Science announced a direct replication effort of the effect. This effort will be published in its third Registered Replication Report. Thus, the failure to replicate might not be as anomalous as it seems.

Regarding the theoretical aims of the present study, the replication failure counts as evidence against both RR and MST, since both theories predicted the occurrence of the effect. The primary test meant to dissociate the two theories involved the comparison of the depletion and control groups on rewarded trials. The primary prediction of MST was that rewards would have a greater influence on depleted participants, due to the hypothesized boost in approach motivation after doing a dull, work-like task. While there was no difference on the mean (between-subjects) outcomes for the two groups on rewarded trials, rewards clearly had more of an influence on control participants. This was evidenced by the magnitude of the difference between rewarded and non-rewarded trials on wins and reaction times. For wins, the effect size (semi-partial correlation) was over four times larger for controls. For reaction times, the effect size was over two times larger. While this is not what MST predicted, it was also not an a priori prediction of RMM either. However, there are theoretical reasons why these data support RMM.

RMM is committed to depletion. Thus those assigned to the depletion group are hypothesized to have less resources (or less operating capacity) available for further cognitive effort. According to RMM, how much a person values the current task and the expectancies a person has regarding the likelihood of performing other valued tasks in the future, determine the degree to which the relevant mental operations underlying mental effort (in this case inhibition) are engaged. In this way, the rate of resource-depletion can be modulated so as to conserve or expend processing capacity over time. Assuming that a resource becomes more valuable as it becomes more scarce, it should take stronger incentives to mobilize the process as the process becomes more depleted. Thus, if the depletion group is genuinely depleted, the same reward should not engage the systems underlying inhibition to the same extent that it would for the control group. This is what the data show inasmuch as rewards were more influential for control participants.

However, it is not accurate to say that the reward absolutely improved performance. While the relative increase in wins between the rewarded and non-rewarded trials was greater for control participants than for the depleted participants, the relative increase in errors between the rewarded and non-rewarded trials was also greater for control participants. It was also the case that the difference in reaction time between the rewarded and non-rewarded trials was greater for control subjects. In fact, rewards decreased reaction times by 820ms for control participants (a large effect for reaction times), compared to a 300ms decrease for depleted participants. This suggests that rewards were altering participants responses strategies such that they responded faster in order to try and beat the response time deadline, resulting in the achievement of more wins at the expense of the commission of more errors. Speed-accuracy tradeoffs of this sort are quite common (for a review, see Heitz, 2014).

A second relevant theoretical claim of the MST is that the property of a task that results in performance impairment is not the type of psychological processes that are engaged to meet the task's demands--as a depleted cognitive mechanism theory such as RMM would posit. Instead, MST holds that subjective appraisals and/or motivational constructs, such as the experience of how interesting or enjoyable the task is, drive psychological fatigue. To test this, we had participants rate the difficulty and enjoyability of the task. Results indicated that while the harder version of the cross-out-letter protocol was indeed rated as more difficulty, it was not rated as less enjoyable. These outcomes lend evidence to RMM. However, getting at these constructs via self-report might be difficult since, for example, difficulty could refer to either how hard the task was or how hard it was to sustain interest and attention on the task. Nonetheless, item composites at least showed good internal reliability (difficulty: $\alpha = .70$; enjoyability: $\alpha = .82$).

Given that MST claims that approach motivation is increased after performing dull or frustrating tasks, we hypothesized that trait level of approach motivation might interact with this process. Specifically, we predicted that this increase in approach motivation (and the concomitant increased responsiveness to rewarded trials) might be accentuated for those high in trait approach motivation, or even that it may only occur in this population. Nevertheless, we found that participants who rated themselves higher on approach motivation were *less influenced* by the rewards. Further, this pattern was only observed for control participants. This latter fact that approach motivation only affected control participants might be because rewards had a greater influence on control participants in general. The finding that higher levels of approach motivation resulted in attenuated responsiveness to rewards is, prima facie, anomalous. It is important to note, however, that this effect was only present for wins, and not for errors or reaction times. Thus it is not consistent across the dependent variables and should be interpreted with caution.

It should also be noted that participants did not report being any more motivated to do well on the task, (or report that the task was more difficult or more enjoyable), if they were in the depleted group as opposed to the control group. Since MST does predict an approach motivation boost from prior "depletion", it might be expected that depleted participants would report higher levels of motivation to perform well on the task. However, nothing about the theory is committed to the claim that the boost is consciously accessible. Furthermore, since the approach elevation was only expected to be relevant to the rewarded trials, and since participants were reporting on the entire task, there is no way to determine if heightened approach was present on reward trials and confounded with decreased motivation to perform well on the control trials.

No theoretical predictions were made concerning RRM and MST for trait levels of avoidance motivation. However, since the enhanced vigilance and caution associated with this psychological attribute is often associated with enhanced conflict detection and monitoring (Boksem, Tops, Wester, Meijman, & Lorist, 2006), it was expected that greater levels of avoidance motivation might result in better performance in the form of less errors (Amodio, Master, Yee, & Taylor, 2008; Inzlicht and Gutsell, 2007). Results indicated that avoidance motivation had no influence on errors for control participants, but that it did influence errors for depleted participants, with increases in avoidance motivation associated with greater error commission. In addition, more wins were observed as avoidance motivation increased for depleted participants while the opposite held true for control participants. Thus for depleted participants, elevated levels of avoidance motivation were associated with both more wins and more errors--the same pattern observed when examining the influence of reward on responding. Unlike rewards, however, avoidance motivation did not influence reaction times. Thus a shift towards a response strategy that involves speeding up in order to beat the response deadline cannot be appealed to in the case of avoidance motivation to explain the increase in win and error rates. However, this explanation is opposed to what is theoretically known about the relationship between avoidance motivation and performance on reaction time tasks anyways. If anything, heightened avoidance motivation would be expected to be associated with a more cautious response strategy due to elevated levels of anxiety and vigilance. It remains unsettled why win and error rates increased only for depleted participants.

Further Directions and Limitations

While the evidence is more supportive of RMM than MST, there remains alternative ways to test the two. For instance, MST maintains that the element of a task that produces subsequent performance decrements is how frustrating and unpleasant it is rather than the degree of inhibition it requires. It just turns out that these are normally confounded in the dual-task paradigm. There are several ways to test this. Since the dual task paradigm involves two tasks, and since crossing the dimension of fun/boring with the dimension of simple/difficult results in 4 combinations, there are potentially 16 different condition that could be compared. In accordance with typical dual-task paradigm studies, the present experiment manipulated the first task. The first task was not selected based on the dimensions of enjoyability and difficulty and, instead, utilized the most common task used in past research. It was expected that this task confounded the two dimensions, but this was not evidenced by the data. Further research could intentionally select tasks based on where they fell on these two dimensions. Regarding the second task, the present study also manipulated (within-subjects) this task, unlike most resource-depletion studies. The researchers intended the two conditions of the task (rewarded and non-rewarded trials) to be representative of the relevant aspects of the fun/boring dimension. Since MST is stated in terms of an increase in broad appetitive-like approach motivation, (and based on past research showing that depleted participants are better at quickly identifying money signs), we thought rewards would sufficiently share the important elements of the fun dimension even if they probably fell short of eliciting enjoyment. Future research could apply gamification elements such as narrative, achievements, progression, and reward schedules, to commonly used executive functioning tasks to create a task that is truly entertaining.

One implication of MST's emphasis on the boring/fun dimension of a task is that it implies that fun but difficult mental activities should be associated with less mental fatigue than boring but simple mental activities. This prediction has strong intuitive support. Having someone continuously count to 50 and then start over may be more "exhausting" than playing an intricate action role-playing video game like Dark Souls. Further, the vast majority of psychological fatigue research prior to the development of the dual-task paradigm utilized a within-subject and within-task paradigm where a participant would perform the same task for several hours. The primary task used for this purpose was a vigilance task. These tasks require monitoring a screen (or an auditory stream) for the presence of an infrequent stimulus (Mackworth, 1948). These tasks were modeled off the demands placed on radar operators during World War II, and were specifically designed to be boring (Warm & Dember, 1998). The fact that people performed worse on these tasks over time was the sine qua non of mental fatigue research for decades (Scerbo & Holcomb, 1993; Scerbo 2001; Warm et al. 2008). The point of interest here is that while this activity does require sustained attention, it is not what a person would normally think of as mentally taxing. It may require inhibition in the sense of having to inhibit the urge to stop doing the task. But arguably this sort of self-control-related inhibition should not be confused with the type of inhibition that is required on a trial of an inhibition task like a Stroop task. The reasons (discussed previously at length) are that self-control-related inhibition is confounded with low approach motivation to do the task (low enjoyability) and that separate instances of cognitive inhibition can be embedded within an activity that is immensely enjoyable.

Relatedly, future studies could utilize more subtle distinctions between motivation types and between subjective symptoms of mental fatigue. For instance, self-determination theory claims that there are two qualitatively different types of motivation. On the one hand, intrinsic or autonomous motivation is characterized by the desire to engage in activities for self-endorsed reasons. These intrinsic reasons include the perception that the activities are valuable, worthwhile, and inherently interesting. On the other hand extrinsic or controlled motivation involves acting out of a sense of obligation or coercion. Such external pressures can include threat, social obligation, guilt, material reward, and punishment. Situations which impel people to act for these reasons do not foster spontaneous enjoyment or the sense of freely choosing on the basis of self-sanctioned reasons (Ryan & Deci, 2000). By using money as the reward, the present study falls into the extrinsic motivation category. To date, three studies have provided autonomy support during the first task within a dual-task paradigm, and have found that depletion effects are attenuated relative to those who were subjected to a controlled motivation manipulation (Legault, & Inzlicht, 2013, Muller et al., 2006; Muraven, et al., 2008). This supports MST since the theory predicts that when a task is experienced as entertaining (or at least as not boring), it should not result in depletion effects, regardless of task difficulty. In fact, autonomy support can be seen as a useful method for altering the enjoyability dimension of a task without having to modify it.

Additionally, mental fatigue is associated with low mood states (boredom, tedium weariness), unfocused mental states (distraction, restlessness), meta-cognitive states (experienced effort), and low motivational states (apathy, disinterest). This study has lumped all of these together. Disentangling how these different states are related to performance impairments over time may prove to be a fertile enterprise. For instance, while excitement and amusement are antonyms of boredom, other words like immersion, engagement, and flow also seem like plausible antonyms. However, the former seem more associated with positive valence, while the others seem more akin to meta-cognitive states. Thinking in terms of differences in arousal and valence may clarify these issues. Finally, since some pure motivational accounts of mental fatigue lend themselves to treating mental fatigue as structurally similar to primary emotions, theories of emotions that appeal to characteristic appraisal profiles which precede or constitute an emotion may also prove useful (Lerner & Keltner, 2000). For instance, just as the occurrence of fear can be explained by an appraisal that an event is a negative event of high risk, the occurrence of mental fatigue could be explained by an appraisal that the current activity is not as valuable as alternatives.

Finally, other individual differences besides approach and avoidance motivation could be examined. In particular, construct such as need for cognition, achievement motivation, learned industriousness, and I.Q. might be relevant, since there is reason to think that individuals who score high on these constructs may respond more enthusiastically to cognitive demand.

Importantly, the Motivational Shifting Theory is not the only pure motivational account of depletion effects. Others, for instance, posit that cognitive control is intrinsically costly and that these costs non-linearly increase with use (Kool & Botvinick, 2012; Kool, McGuire, Wang, & Botvinick, 2013, Inzlicht et al., 2014). And still others conceive of depletion effects as resulting from opportunity costs associated with using cognitive faculties, and from perceived increases in the value of alternative actions after the use of cognitive control (Kurzban et al., 2012). Thus, even if the predictions of MST are not supported, other pure motivation theories can still remain alternative candidates against capacity-plus-motivation theories . Nonetheless, some of these theories quickly fall into a predicament. For instance, Kool and colleagues claim that mental effort allocation possesses intrinsic disutility (Kool, McGuire, Rosen, &Botvinick, 2010). Their explanation for why this results in performance decreases over time, however, relies on the addition assumption that the "marginal cost of control varies as a function of context: A unit increment in effort carries a greater subjective cost when one is already working hard than when one is hardly working" (Kool & Botvinick, 2012). Yet, the authors do not commit to a reason why the costs of cognitive effort increase with time. They do, however, entertain the idea that the reason mental effort is inherently costly, and the reason why the costs rise with increased usage, is that controlled information processing is capacity-limited. As we mentioned previously, if resources are depleted over time, the value of those resources should increase as they become more scarce. This brings us full circle to the Resource Maintenance Model. If this explanation of the increasing costs of mental effort is endorsed, Kool et al.'s framework simply appends a more proximate explanation to the resource management model, explaining how resources are husbanded, namely through the calculation of costs associated with the activation of the systems underlying mental effort and through the input of those calculated costs into the decision process. Note that this theory differs from MST in that MST does not claim that cognitive effort is intrinsically aversive or inherently associated with costs. Although, at this point, one has to be careful to separate subjective effort--in the sense of an increasing feeling of having to try harder and harder to remain focused--from objective effort, in the sense of the objective demands of a task. MST does claim that subjective effort is what is relevant to depletion effects.

Additionally, it is important to keep in mind that there are *non-motivational* theories that explain resource-depletion effects without appealing to depletion. Such accounts have a cognitive flavor. These include theories that emphasize the role of beliefs and expectancies regarding whether mental effort is limited (Job, Dweck, & Walton, 2010; Job, Walton, Bernecker, & Dweck, 2013; Vohs, Baumeister, & Schmeichel, 2012), theories that think of self-control as a cognitive schema or knowledge structure and that thereby utilize concepts related to priming such as spreading activation, accessibility, and facilitation (Baumeister et al., 2008), as well as theories appealing to shifts in construal level (Bruyneel & Dewitte, 2012; Wan & Agrawal, 2011).

Conclusion

While pure motivational theories of psychological fatigue are difficult to separate experimentally from mental impairment accounts that posit depletion, they differ drastically in theoretical respects. If certain cognitive operations become impaired with repeated use, a developed research program should include an exhaustive search for the physiological basis of this impairment, whether it involves a metabolic chemical or a more intricate biophysical process. In this respect, the research program would be similar to the approach many exercise scientists take towards understanding physical fatigue, such as looking for increasingly intricate metrics of heart performance (Levine, 2008). On the other hand, if mental fatigue is an adaptive phenomenon that prevents fixation on a single activity for too long (Dodge, 1917; Hockey 2011; Lorist et al. 2005), it would be misguided to search for physical substrates of cognitive impairment since such an impairment would not exist; the relevant cognitive systems should be able to perform just as well on theoretically specified alternative tasks (Kurzban et al., 2012).

In a recent review paper that attacks the "willpower-as-resource" model, Kurzban et al. (2012) express surprise that not one commentator defended the glucose model, and almost none defended a resource view more generally. And yet, the theory has become ubiquitous--maybe partly due to the sheer intuitiveness it gains from the physical fatigue analogy. For instance, Barack Obama reported in *Vanity Fair* that he uses the theory to guide how he makes decisions throughout the day, and a book espousing the theory has become a *New York Times* bestseller (Baumeister & Tierney, 2011). The present study is the only study that we know of attempting to directly test a pure motivation theory against a depletion theory. The results, overall, provide more support for the depletion theory. However, the outcomes should be interpreted with caution since the key phenomenon underlying the debate--two-task resource-depletion--was not replicated. Further research needs to be conducted in order to gain more traction on the issue, and to determine if the psychological phenomenon to be explained actually exists in the first place.

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Figures

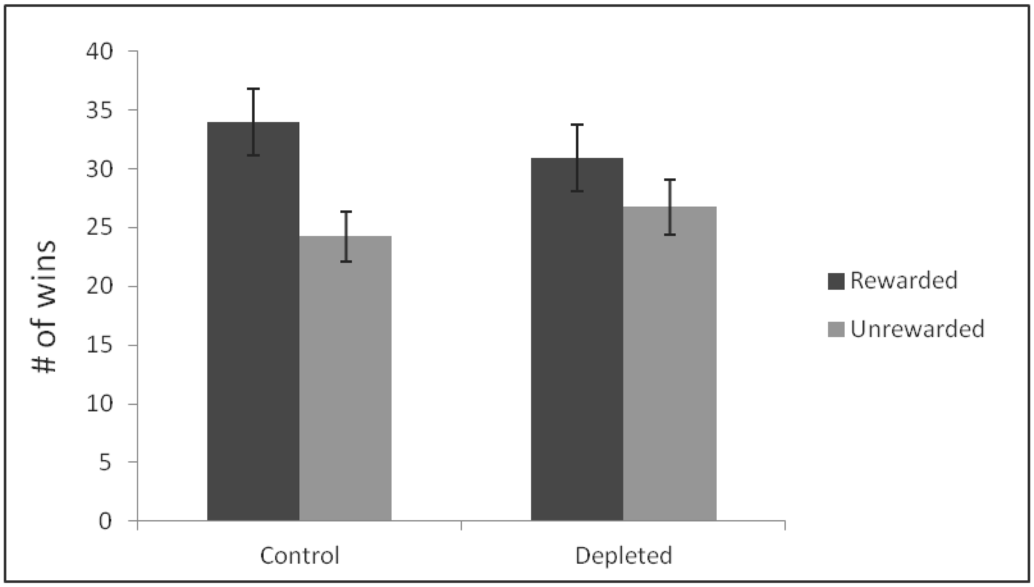

Figure 1. The number of correct trials on the Rewarded Incongruent Stroop Task that were faster than the reaction time cut-off (i.e., wins) for each condition.

Note: Error bars represent standard errors.

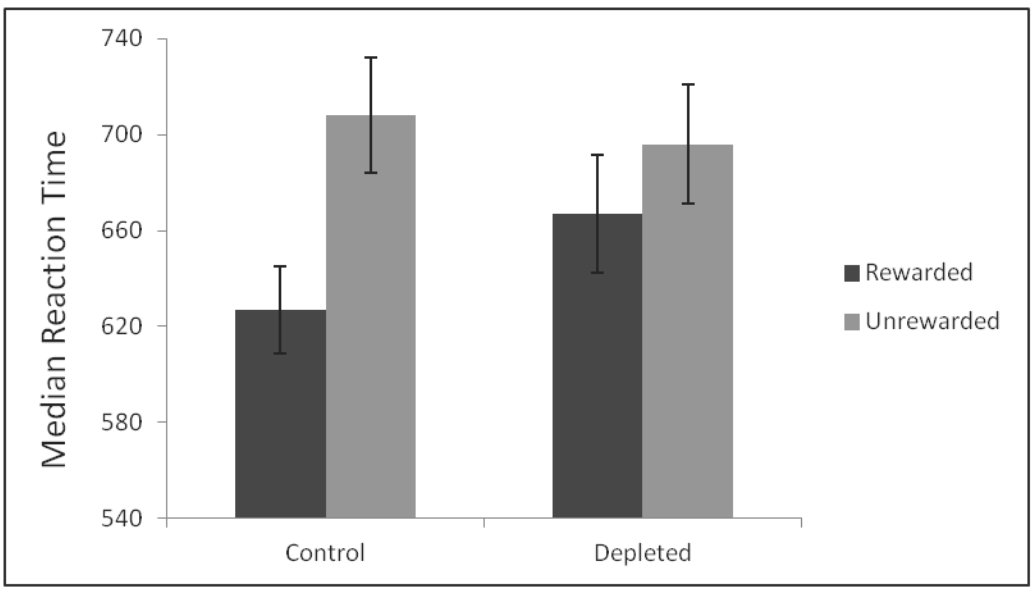

Figure 2. Median reaction times on the Rewarded Incongruent Stroop task for each condition.

Note: Log transformed scores were used in data analysis, but non-transformed scores are presented here for ease of interpretation.

Note: Error bars represent standard errors.

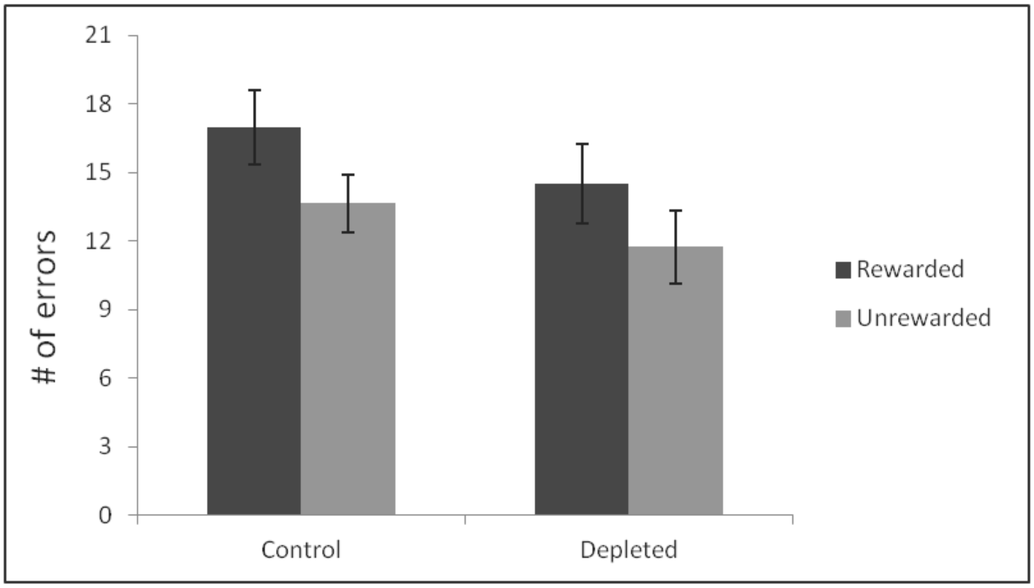

Figure 3. Number of errors on the Rewarded Incongruent Stroop task for each condition.

Note: Log transformed scores were used in data analysis, but non-transformed scores are presented here for ease of interpretation.

Note: Error bars represent standard errors.

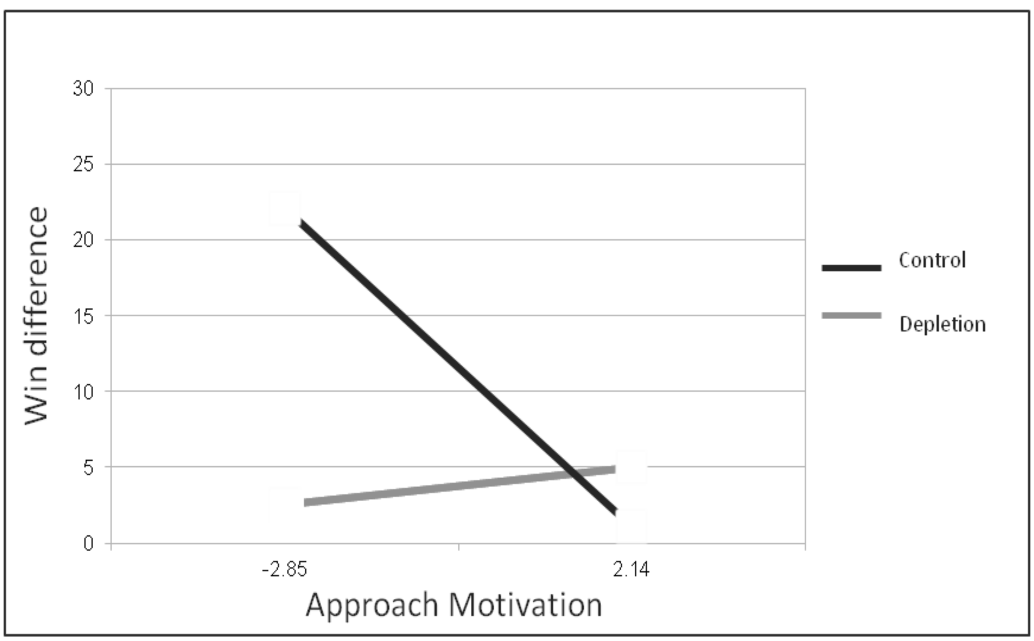

Figure 4. The difference in wins between rewarded and non-rewarded trials as a function of approach motivation for control and depleted participants.

Note: Approach motivation scores represent standardized values.

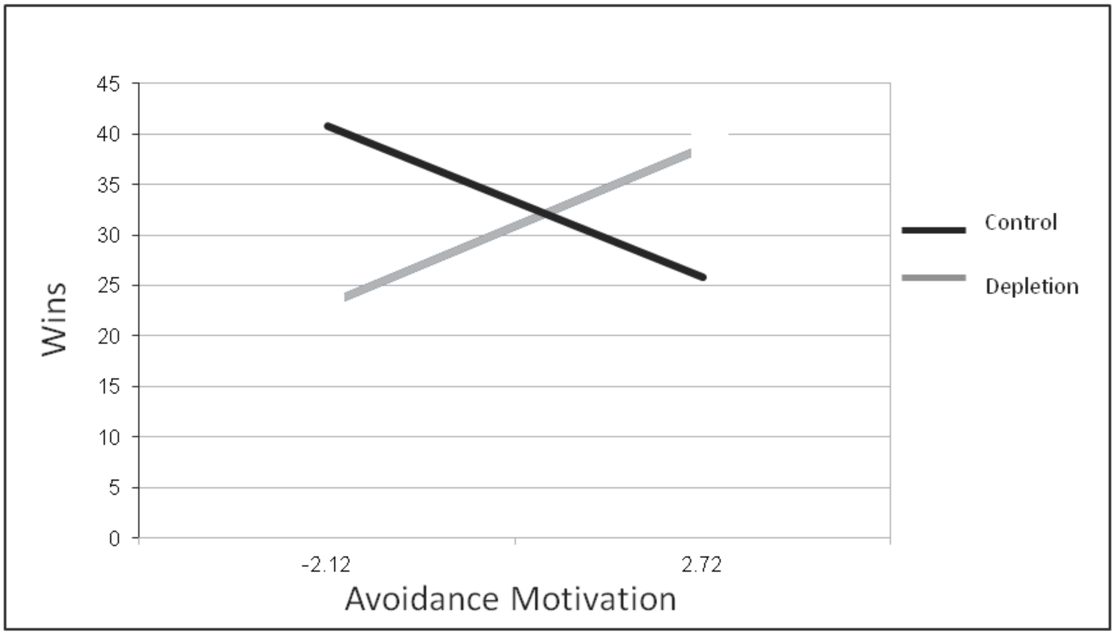

Figure 5. Wins as a function of avoidance motivation for control and depleted participants.
Note: Avoidance motivation scores represent standardized values.

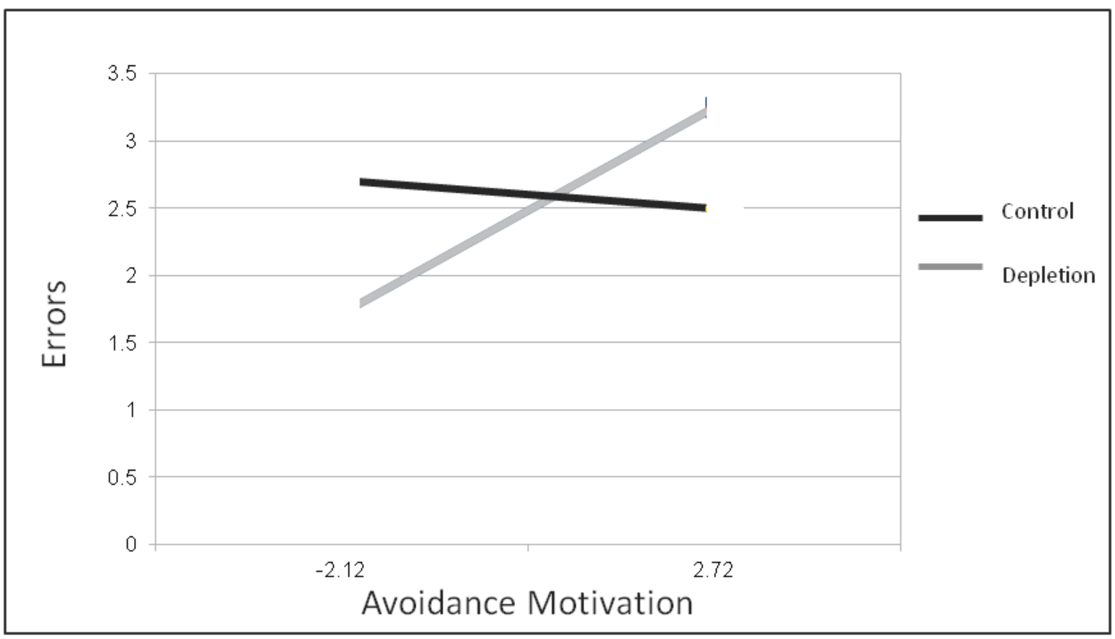

Figure 6. Errors as a function of avoidance motivation for control and depleted participants.
Note: Avoidance motivation scores represent standardized values.
Note: Errors are log transformed.

Rewarded Stroop Task

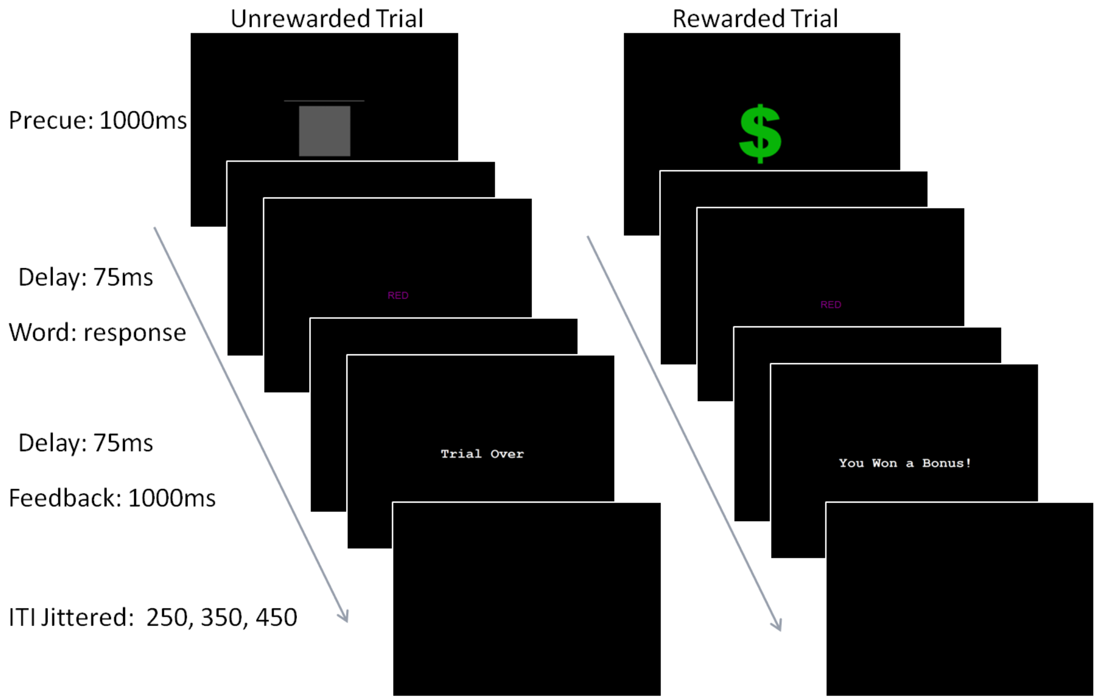

Figure 7. The primary dependent measure of the study. Rewarded and unrewarded trials were randomly intermixed within 4 blocks of 48 trials each. On rewarded trials, if participants responded faster than the response deadline, and got the answer correct, then the feedback read, "You Won a Bonus!". If they answered correctly but were not quick enough, the feedback read, "Trial Over". Unrewarded trial feedback read, "Trial Over", regardless of whether the response was faster than the deadline. Error feedback was the same for both trial types.