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Self-Control: Is Glucose a Constraint or an Input?

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Abstract

Many researchers have claimed that self-control relies on a limited resource (e.g. Baumeister, Vohs, & Tice, 2007). Recently, Gailliot et al. (2007) suggested that self-control does, in fact, rely on a limited resource: glucose. However, facts about brain metabolism (e.g. Clarke & Sokoloff, 1998; Gibson, 2007) suggest that this is not likely to be plausible. Further, a recent study revealed that rinsing a glucose beverage in the mouth was enough to increase task performance, relative to placebo (Chambers, Bridge, & Jones, 2009). This suggests that results in Gailliot et al. (2007), as well as other recent studies testing the relationship between glucose and self-control performance (e.g. Gailliot, Peruche, Plant, & Baumeister, 2008; Dewall, Baumeister, Gailliot, & Maner, 2008), might be driven by the sensation of sugar acting as a reward. The motivation for the present studies was to demonstrate the “depletion effect” such that the experiment(s) could be used in future studies to test the carbohydrate sensing hypothesis. Two studies were conducted using the dual-task paradigm, each using two different tasks identified in the self-control literature. Both studies failed to demonstrate the depletion effect.

Introduction

Individuals are routinely tempted to act in ways that are immediately gratifying, but that have negative long-term consequences. These are frequently described as “self-control” or “self-regulation” problems. Self-control is defined in a variety of ways in the literature, but one common definition is that it is a process of overriding impulses. For example, Gailliot et al. (2007) state: “Self-control (or self-regulation) is the ability to control or override one’s thoughts, emotions, urges, and behavior” (p. 325). A more expansive definition is found in Baumeister, Vohs, & Tice (2007): “Self-control refers to the capacity for altering one’s own responses, especially to bring them into line with standards such as ideals, values, morals, and social expectations, and to support the pursuit of long-term goals” (p. 351). Commonly cited examples of self-control problems include criminal behavior (Gottfredson & Hirschi, 1990), addiction (Bickel & Marsch, 2001), gambling (Holt, Green, & Myerson, 2003), and savings behavior (Thaler, 1981). All of these phenomena reflect success or failure at inhibiting impulses for immediate benefits in the service of future benefits.

*The Limited Resource Model of Self-Control*

What is the nature of self-control? Researchers have suggested multiple possible answers to this question. The most prominent view in social psychology, also intuitively appealing, is that self-control relies on a limited resource (Baumeister, Vohs, & Tice, 2007). On this view, self-control draws from a common pool resource leaving less to draw from for future acts of self-control. The limited resource model of self-control is also used interchangeably with the view that self-control is like a muscle: exercising self-control gets more difficult when done repeatedly, just as lifting weights gets more difficult with repetition. Hagger, Wood, & Stiff (in press) describe the strength model as follows: “The strength model offers an explanation for self-control that transcends cognitive and associative-learning models (Baumeister et al., 1998). It predicts that acts of self-control draw from a common, global resource. The resource is limited and vulnerable to becoming depleted over time, just as a muscle becomes tired after a period of exertion” (p. 6). For the purposes of the present project, this model will be referred to only as the limited resource model.

Until recently, the limited resource model of self-control was underspecified, serving metaphorical purposes only. Perhaps for that reason the necessary conditions for demonstrating that self-control relies on a limited resource have also remained underspecified. If self-control relies on a limited resource, what is it?

*Is Glucose the Limited Resource of Self-Control?*

Gailliot et al. (2007) make explicit one possible candidate for the limited resource of the limited resource model: glucose.[[1]](#footnote-1) They report a series of studies attempting to demonstrate a relationship between acts of self-control and decrements in glucose, using the dual-task paradigm common to the self-control literature. Study 1 is the most relevant to the present inquiry. In Study 1, subjects first had their glucose levels assessed. (These subjects were asked not to eat anything for three hours prior to the experiment.) Subjects then watched a film of a woman being interviewed, while common words appeared every 10 seconds on the bottom of the screen. Subjects were assigned to one of two conditions. They were either given no instructions about how to watch the video, or they were instructed to attend only to the woman being interviewed, while ignoring the words as they appeared on the screen. Glucose levels were then measured once again. The researchers predicted that glucose would drop further in the attention control condition than in the control condition. Participants in the attention control condition showed decreased levels of glucose over the two time periods, while those in the control condition did not. The authors conclude that “[t]hese results are consistent with the notion that exerting self-control uses up a relatively large amount of glucose” (p. 327).

A handful of other studies have subsequently examined the relationship between glucose and self-control performance. Gailliot, Peruche, Plant, & Baumeister (2008) examined the relationship between glucose and prejudice. Subjects were randomly assigned to the sugary beverage condition or the non-sugary beverage condition. They were then presented with a picture of a man, “Sammy,” said to be a homosexual. Participants were then instructed to write for five minutes about Sammy’s activities on any given day. Judges blind to the condition then counted the number of times traits associated with stereotypes of homosexual men were mentioned. They found a main effect of the condition; participants who consumed the sugary beverage used fewer stereotypes than did participants in the non-sugary beverage condition. The authors claim that “these findings suggest a link between glucose levels and the expression of prejudice and the use of stereotypes such that people with lower glucose levels are more likely to use stereotypes when describing others . . . These data are consistent with evidence that low levels of glucose impair self-control” (p. 290).

Masicampo & Baumeister (2008) examined the relationship between glucose and reliance on heuristics for decision-making. Subjects were randomly assigned to the sugary beverage condition or the non-sugary beverage condition (sweetened with Splenda). Participants then rated the drink for pleasantness and other characteristics. After several minutes had passed, the subjects watched a silent video of a woman being interviewed while large words appeared. Approximately half the subjects were given no instructions for how to watch it, while the other half of subjects were instructed to focus their attention on the woman only. Then subjects were asked to complete a second task, though under the false pretense that it was for another study. The second task was described by the authors as follows: “Instructions printed on a sheet of paper told participants to imagine that they were searching for a new apartment for the coming school year. They were to choose among three options. All participants saw the main options B and C, plus one of two decoys, A or D. . . . Decoy A resembles B but is inferior to it on both dimensions, whereas decoy D resembles C and is inferior on both dimensions” (p. 258). Rational individuals should rule out the decoy, as it is dominated by both available alternatives, but the researchers hypothesized based on previous research that subjects would be swayed by its existence. This is called the “attraction effect.” The argument is that the attraction effect is a result of automatic, intuitive decision processes overriding more deliberate, reasoned decision processes. Masicampo & Baumeister (2008) hypothesized that sugar intake should reduce reliance on more intuitive reasoning processes. They found that, for the attention control condition, subjects in the glucose group showed a significantly lower attraction effect. That is, these subjects were less swayed by the dominated alternatives. The authors suggested that “this finding supports the hypothesis that glucose intake eliminates the effect of ego depletion on decision making and restores effortful choice” (p. 258).

In Study 2 of Dewall, Baumeister, Gailliot, & Maner (2008), participants were randomly assigned to a sugary beverage condition or a non-sugary beverage condition, and then asked to watch the same video of a woman being interviewed described above. All participants were then given an opportunity to volunteer hours of their time (0 to 9 or more) to help the woman in the interview, which served as the dependent measure. The authors predicted that subjects in the attention control condition would volunteer fewer hours than subjects in the control condition, but that glucose would reduce this effect. Indeed, the researchers found that subjects in the attention control condition volunteered more time if they were in the glucose group than subjects in the placebo group.

In a meta-analysis of self-control studies, Hagger, Wood, & Stiff (in press) provided statistical evidence that administering glucose (relative to a placebo) had a large effect size across the four studies just described. But it is not clear whether changes in peripheral blood glucose, measured in the previously described studies, could reflect glucose consumption by the brain.

In a discussion of energy metabolism of the brain, Clarke & Sokoloff (1998) state that “[a] common view equates concentrated mental effort with mental work . . . [but] there appears to be no increased energy utilization by the brain during such processes” (p. 664). Further, “the areas that participate in the processes of such reasoning represent too small a fraction of the brain for changes in their functional and metabolic activities to be reflected in the energy metabolism of the brain” (p. 675). Reviewing the evidence on carbohydrates and mental function, Gibson (2007) states that “[r]ecent developments in understanding the regulation of energy supply (principally glucose) for neuronal function suggest that it is too simplistic to assume that ingesting carbohydrates will inevitably improve cognitive function. There is a damping or buffering seen between glucose changes in blood and brain extracellular ﬂuid, and even evidence for an acute dissociation of these glucose changes during task performance in speciﬁc brain regions” (p. 71). Further, he goes on to say, “*overall brain function appears to be quite insensitive to . . . ﬂuctuations in blood glucose*, other than in controlling autonomic activity dealing with glucose homeostasis. *This may be partly owing to buffering of the brain against large changes in glucose availability*” (p. 80, emphasis added). In short, it is unlikely that commonly cited self-control tasks, often only minutes in duration, could be responsible for even modest amounts of glucose metabolism by the brain that then result in worse performance on subsequent tasks.

*Glucose Sensing as an Input to the Reward System*

If glucose ingestion and subsequent brain metabolism are not driving the results in studies testing the glucose-based limited resource model of self-control, then what other possibilities exist? Chambers, Bridge, & Jones (2009) examined the effect of a glucose beverage (relative to placebo), first rinsed in subjects’ mouths and then spit out, on subjects’ performance in a physical exercise. They described the motivation for the study as follows: “The primary taste cortex and orbitofrontal cortex are believed to have projections to the dorsolateral prefrontal cortex, anterior cingulate cortex and ventral striatum, brain regions believed to mediate the behavioural and autonomic responses to rewarding stimuli, including taste (Rolls, 2007). It has therefore been suggested that activation of these taste-related brain regions can inﬂuence emotion and behaviour (Kringelbach, 2004) and this might, for instance, have an impact on exercise performance” (p. 1780). They found that subjects’ exercise performance improved simply by rinsing the glucose beverage in their mouths. They conclude that “improvement in exercise performance that is observed when carbohydrate is present in the mouth may be due to the activation of brain regions believed to be involved in reward” (p. 1779).

Given the evidence cited above, in addition to what is known about brain metabolism, it may be the case that carbohydrate sensing—anticipated reward—and not ingestion, is driving the results in studies that have examined the relationship between glucose and self-control performance. That is, it may be the case that self-control failure (or success) does not reflect the depletion (or replenishment) of a limited resource, in this case glucose. Instead, it might reflect the operation of a system weighing the costs and benefits of the present activity and generating an output—the feeling of mental effort, or lack thereof—that motivates the person to disengage (or persist). This explanation better accords with the computational theory of mind.

According to this view, urges and impulses can be understood as “prepotent responses” mediated by mechanisms involved in immediate reward-seeking behavior, while mechanisms associated with executive function inhibit these mechanisms. Based on this view, self-control failure can be thought of as a conflict between (a) “now” mechanisms designed to bring about benefits immediately rather than in the future, and (b) mechanisms whose operation inhibits the “now” mechanisms. This model of self-control relies on costs and benefits of the current activity as a function of (at least) these two cognitive mechanisms. In this sense, it is similar to optimal foraging models in the animal behavior literature (e.g. Gallistel, 1994) or the habituation paradigm in developmental psychology (Baillargeon, Spelke, & Wasserman, 1985). Foraging in one patch carries opportunity costs of marginal calories not consumed in other patches. Similarly, babies’ interest in a stimulus, measured by looking time, is determined by how much information can be gained by paying attention to the current stimulus, or moving to a new one.

The Present Research

If carbohydrate sensing is sufficient to cause increased performance on a difficult task, interpretations of results from Gailliot et al. (2007)—and other studies examining the relationship between glucose and self-control performance—can be scrutinized empirically. The motivation for the present studies was to demonstrate the “depletion effect” such that the experiment(s) could be used in future studies to test the carbohydrate sensing hypothesis. If it could be shown, for example, that the depletion effect was attenuated in *both* the ingestion version of a glucose-based self-control experiment *and* the rinse-and-spit version of the same experiment, those results would be evidence against the glucose-based limited resource model of self-control. First, however, the depletion effect itself must be demonstrated.

Study 1

The purpose of Study 1 was to demonstrate the phenomenon of decreased performance on a second task following a putatively taxing first task. This phenomenon is now widely described as the “depletion effect” or the “ego-depletion effect” (e.g. Muraven, Tice, & Baumeister, 1998), and is elicited using the commonly employed dual-task paradigm. The motivation for demonstrating the effect was to identify an experiment that used the dual-task paradigm that could later be used to test the glucose-based limited resource model of self-control.

There is a wide range of tasks employed in dual-task self-control studies (Hagger, Wood, & Stiff, in press), and the serial position of each task is in many cases interchangeable (one cognitively taxing task followed by another). As such, the present study did not attempt to replicate any single study. Rather, Study 1 used tasks from two separate previous self-control studies. Task 1 was drawn from the typing task of Experiment 3 in Muraven, Gagné, & Rosman (2008). In that experiment, all subjects were shown a paragraph on a computer screen; subjects in the treatment condition were asked to re-type the paragraph without typing any e’s or spaces. Crossed with these tasks was a Pressure/No Pressure manipulation. For subjects in the Pressure condition, “the time spent typing was displayed in a very large font at the top of the screen and the number of e’s typed (for participants in the No E’s condition). Participants in this condition were continually reminded of their need for speed and accuracy” (p. 581). Finally, subjects completed a concentration task and their scores on this task were recorded. Only the typing task was used for the present study.

Task 2 of the present study is based on the Stroop task in Study 3 of Gailliot et al. (2007). Subjects were told that the experiment was related to physiology and task performance. Experimenters assessed subjects’ baseline glucose levels. All subjects were then instructed to watch a silent video of a woman being interviewed while words appeared in large font in one of the corners of the screen. Subjects were asked to maintain attention on the woman and were instructed to avoid looking at the words. Glucose levels were assessed again. Finally, subjects completed 80 incongruent Stroop trials without stopping. The dependent measures were response times and errors on the Stroop. (In Study 7 of the same paper, Gailliot et al. [2007] also use the Stroop task to elicit dependent measures for Task 2 performance, but the Stroop was broken up into four separate blocks of 20 trials.)

Based on the dual-task paradigm of previous self-control studies, the prediction for the present study was that subjects in the *inhibition* condition (no e’s and spaces) would perform worse on the incongruent Stroop trials relative to subjects in the *no inhibition* condition (re-type everything in the paragraph).

*Method*

*Participants.* One hundred and five participants (47 male, average age = 21.9 years) were recruited from Experiments@Penn, a web-based experiment registration system at the University of Pennsylvania. The sample was about 41% Caucasian, about 33% Asian, about 10% African American, and about 6% Hispanic; 75% of participants self-identified as native English speakers. After data omission, 98 observations were used for analysis. The experiment description, intentionally vague to avoid demand characteristics, stated: “Experiment subjects will complete computer tasks.” All subjects were told before the experiment (and in the experiment description) that they would receive $10.00 for completion of the experiment; all subjects received $10.00 for completion of the experiment.

*Procedure.* Ten sessions were run. All but one of these sessions were run with groups of subjects, with group sizes ranging from 7 to 17. Prior to each session, before any subjects entered the lab, the experiment was set up on several computers. The experiment was created and implemented using E-Prime, a commonly used programming tool for experiment design and data collection. The computer monitor was then turned off to prevent subjects from seeing any part of the experiment until the experimenter turned on their monitor. After signing in, subjects were seated at a computer terminal in a cubicle. Depending on the number of subjects in the session, there were up to three rows of computer terminals occupied by subjects. Each subject was seated at a computer terminal in the order that they arrived, and were each individually instructed by the experimenter “please do not touch the keyboard or the monitor until further instruction.” The experimenter then waited until the specified start time of the experiment to close the door and begin the experiment. All subjects were asked to sign a consent form, which indicated that performance data would be linked to other information they provided, such as GPA and SAT scores, but would not be linked to their identity. Once all consent forms were collected, the experimenter read the following statement: “We are now going to turn on your monitors one at a time, at which point you may begin the experiment. All instructions are on the computer screen. If you have any questions, please raise your hand and an experimenter will assist you. Please do not talk or use your cell phone during the experiment. Once you are finished, please sit quietly and wait for further instructions.” The experimenter then turned on each of the subjects’ monitors one at a time, and told the subjects that they could begin the experiment.

The experiment used a 2 (*Task 1:* *inhibition* or *no inhibition*) X·2 (*Task 2:* *congruent* or *incongruent* Stroop) design. As per Muraven, Gagné, & Rosman (2008), all subjects first did a typing task (Task 1). When the experimenter turned on the monitor, subjects began reading the experiment instructions on the computer screen. All subjects were instructed to type the 149-word paragraph[[2]](#footnote-2) as quickly and as accurately as possible (see Appendix A for the relevant experimental content that appeared to participants). Subjects in the *inhibition* condition were instructed to type the paragraph without typing any e’s or spaces. The paragraph contained 149 spaces and 85 e’s, for a total of 234 e’s and spaces. Subjects in the *no inhibition* condition were not given any specific instructions other than to re-type the paragraph as quickly and accurately as possible. In both conditions subjects could see the paragraph they were to re-type but could not see what they were typing. Muraven, Gagné, & Rosman (2008) describe the logic of the manipulation as follows: “Typing is a highly automatic task for many people and therefore regulating what one types should require a good deal of inhibition and self-stopping. Thus, the No E’s condition should deplete more strength than the Type All condition” (581).

After subjects finished re-typing the paragraph, the computer program instructed them that that portion of the experiment had concluded, and that they should proceed to the next task. Task 2 was a Stroop task. The next screen had detailed and color-coded instructions on how to do the Stroop. The instructions were the same for both *congruent* and *incongruent* conditions: their task was to respond with the color of the word, not what the word says. For example, if the word said GREEN, but was presented in the color red, the subjects were instructed to respond with the button that corresponds to the color red, because the word was red. Conversely, if the word said GREEN, and was presented in the color green, the subjects were instructed to respond with the button that corresponded to the color green. Subjects were also instructed that, “as soon as the word appears on the screen, please respond with the color of the word as fast as you can by pressing the button that corresponds to that color.” All subjects then proceeded to do 12 practice trials before they began the real trials. Subjects practiced only Stroop trials that matched their condition; subjects in the *congruent* condition practiced Stroop trials that were congruent only, and subjects in the *incongruent* condition practiced Stroop trials that were incongruent only. Subjects then had an opportunity to ask questions, followed by the real Stroop trials. All subjects completed 96 Stroop trials.

After subjects had completed all 96 Stroop trials, they were asked several questions (e.g. “At this moment, how bored are you?”), and given a 7-point scale to answer them (e.g. 1 = Not bored at all; 7 = Extremely bored). Finally, subjects were asked a variety of questions about their personal characteristics (e.g. sex, age, race, GPA).

*Results[[3]](#footnote-3)*

*Data omission.* Seven observations were removed from the dataset, all of which came from the inhibition conditions where subjects were asked to re-type the paragraph without typing the letter ‘e’ or the spacebar. Upon observing the individual-level data for each subject, it appeared that these seven subjects failed to comply with the instructions. They either typed the paragraph without inhibiting both e’s *and* spaces, or they inhibited typing one but not the other.

*Manipulation checks.* Many self-control studies, especially those using the dual-task paradigm, implement manipulation checks between each of the tasks (e.g. Muraven, Shmueli, & Burkley, 2006), including the experiment on which Task 1 of this study is based (Muraven, Gagné, & Rosman, 2008). Given the heterogeneity of effect sizes in this literature (Hagger, Wood, & Stiff, in press) additional stimuli prior to any dependent measures may introduce noise into the results. For that reason, explicit manipulation checks were introduced at the end of the experiment.

Observation-level data suggest that subjects in the *inhibition* condition did indeed comply with instructions to inhibit typing e’s or spaces. (See Table 1 for Study 1’s relevant descriptive statistics.) An ANOVA confirmed that subjects complied with the instructions, *F*(1, 96) = 30,916, p < 0.001; subjects in the *inhibition* condition typed significantly fewer e’s and spaces than did subjects in the *no inhibition* condition. Subjects in the *inhibition* condition also spent more time re-typing the paragraph than subjects in the *no inhibition* condition, as indicated by an ANOVA, *F*(1, 96) = 19.46, p < 0.001.

*Dependent measures.* The dependent measures, as used in Gailliot et al. (2007), were response times and errors on the Stroop. At first glance, the group means and standard deviations suggest that the samples were drawn from the same population. An ANOVA revealed that, indeed, the typing instructions had no effect on response times, *F*(1, 94) = 0.000004539, p = 0.998. For response times, there was also no interaction between the typing instructions (*inhibition* vs. *no inhibition*) and the Stroop (*congruent* vs. *incongruent*), *F*(1, 94) = 0.04, p = 0.83. An ANOVA also revealed that Stroop response times were not statistically different between congruent and incongruent conditions, *F*(1, 94) = 1.15, p = 0.29.

What about differences in performance on errors? First, the number of errors did not differ significantly for those subjects in the congruent or incongruent conditions, as revealed by an ANOVA, *F*(1, 94) = 1.37, p = 0.25. There were no significant differences in errors between the typing instructions, *F*(1, 94) = 0.003, p = 096. For errors, there was also no interaction between typing instructions (*inhibition* vs. *no inhibition)* and Stroop (*congruent* vs. *incongruent*), *F*(1, 94) = 0.31, p = 0.58.

*Subjective reports of effort*. Although Task 1 clearly had no effect on Task 2 performance, perhaps typing instructions or other variables affected self-reported feelings of effort, as measured at the end of the experiment. First, a series of ANOVAs were run to see if typing instructions had an effect on each of the effort measures (see Appendix A for effort measures). Typing instructions had no significant effect on subjective reports of tiredness, boredom, frustration, or how much they felt obligated to exert effort. However, based on an ANOVA, there was an interaction between typing instructions (*inhibition* vs. *no inhibition*) and Stroop condition (*congruent* vs. *incongruent*), *F*(1, 94) = 5.21, p < 0.05; subjects in the *no inhibition* X *incongruent* group reported significantly higher ratings of exerted effort than did other groups.

*Discussion*

Performance on the Stroop, as measured by response times and errors, did not differ significantly among the groups. Inhibiting an ostensibly automatic response to type e’s and spaces did not result in lower performance on the Stroop relative to controls. In fact, the dependent measures were strikingly similar between inhibition conditions. Also important, response times on the two Stroop conditions were not significantly different; subjects were able to respond as fast to incongruent Stroop trials as they were to congruent Stroop trials. Further, the number of errors was also not significantly different among groups of subjects.

How should these results be interpreted, other than that they did not support the prediction? Given the voluminous literature supporting many different versions of the Stroop effect (see MacLeod, 1991, for an extensive review), the insignificant differences between Stroop conditions—regardless of the inhibition condition—are somewhat puzzling. Although the results of Study 1 do not support the prediction of worse Task 2 performance following a task requiring inhibition, there are reasons to suspect that the dependent measure was simply insufficient to capture potential effects of the manipulation. There is some evidence that manipulating expectations about the proportional content of Stroop stimuli influences the magnitude of the Stroop effect.[[4]](#footnote-4) Using a spatial analog of the Stroop task, Logan and Zbrodoff (1979) varied the frequency of compatible and incompatible trials (the words “above” or “below” appeared above or below a fixation point) from 10% to 90%. They found that “[c]ompatible stimuli were processed faster when conflicting trials were rare, *but conflicting stimuli were processed faster when they were frequent*” (emphasis added). This implies that response times on these kinds of stimuli depend on the proportional makeup of the trials, regardless of whether they are congruent or incongruent. In the case of the present study, the incongruent condition had 100% of the same *type* of stimuli as the congruent condition, thus minimizing any possible between-subjects differences. Making the incongruent condition easy in this way may have dropped the response times to a floor that made it comparable with the response times for the congruent condition.

Study 2

Because no main effects or interactions were found in Study 1, a second study was conducted to demonstrate the decreased performance on a second task following a taxing first task. Task 1 was drawn from Study 1 of Gailliot et al. (2007). In that experiment, subjects were asked to watch a soundless 6-minute video of a woman talking (itself a modified version of a video used in Gilbert, Krull, & Pelham, 1988). Every 10 seconds a new word in large letters appeared in the bottom right-hand corner of the screen. Subjects were randomly assigned to one of two conditions. Subjects in the treatment condition were instructed to focus attention only on the woman, and to avoid looking at the words as they appeared. Further, if they looked at the words, they were instructed to shift their attention back to the woman as fast as they could. Subjects in the control condition were simply asked to watch the video, with no particular instructions.

Task 2 was drawn from Study 2 of Muraven, Tice, & Baumeister (1998). In Study 2 of their experiment, the researchers used unsolvable anagrams. The dependent measure of interest was persistence on the unsolvable anagrams. As noted by the authors, persistence at unsolvable puzzles has often been used to measure “frustration tolerance” (see, e.g, Glass, Singer, & Friedman, 1969). The results of Study 1 demonstrated that Task 2 should be more difficult. In self-control studies, persistence on a variety of tasks has been successfully used as a dependent measure (e.g. Baumeister, Bratslavsky, Muraven, & Tice, 1998; Muraven, Tice, & Baumeister, 1998; Vohs, Baumeister, & Ciarocco, 2005). The method in Muraven, Tice, & Baumeister (1998) was not replicated exactly in the present study. In that study, subjects were given a list of anagrams that were unsolvable.[[5]](#footnote-5) The dependent measure was simply the persistence time on that list. The authors argued: “what mattered was that persistence required the person to override an easy, appealing response (i.e., quitting) and hence constituted self-regulation. Participants with less regulatory capacity—presumably, the ones who had depleted their capacity by the previous thought suppression exercise—should therefore quit the task sooner than other participants” (p. 779). Subjects rang a bell when they wanted to stop doing the anagram task and “the experimenter noted the time and reentered the room”; although it is somewhat unclear from their language, it appears that subjects did this in the presence of all of the other subjects. In order to avoid noise that might be introduced by public signals of finishing the anagram task, subjects in the present study completed all aspects of the experiment privately. Finally, only five anagrams were given, they were each given separately, and only two of them were impossible.

For the present study, the prediction was that subjects in the *inhibition* condition would persist on impossible anagrams for less time than subjects in the *no inhibition condition*.

*Method*

*Participants.* Forty-nine participants (29 male) were recruited from Experiments@Penn, a web-based experiment registration system at the University of Pennsylvania. The sample was about 53.1% Caucasian, about 34.7% Asian, and about 12.2% African American. About 88% of participants self-identified as native English speakers. After data omission, 46 observations were used for analysis. The title of the experiment on the Experiments@Penn website was “How people respond to different stimuli.” The experiment description, also intentionally vague to avoid demand characteristics, stated: “Participants will do two computer tasks.” All subjects were told before the experiment (and in the experiment description) that they would receive $10.00 for completion of the experiment; all subjects received $10.00 for completion of the experiment.

*Procedure.* Five sessions were run. All of these sessions were run with groups of subjects, with group sizes ranging from 8 to 14. Prior to each session before any subjects entered the lab, the experiment was set up on several computers. The experiment was created and implemented using Qualtrics, a web-based survey and experiment software. The computer monitor was then turned off to prevent subjects from seeing any part of the experiment until the experimenter turned on their monitor. After signing in, subjects were seated at a computer terminal in a cubicle. Depending on the number of subjects in the session, there were up to two rows of computer terminals occupied by subjects. Each subject was seated at a computer terminal in the order that they arrived, and were each individually instructed by the experimenter “please do not touch the keyboard or the monitor until further instruction.” The experimenter then waited until the specified start time of the experiment to close the door and begin the experiment. All subjects were asked to sign a consent form, which indicated that performance data would be linked to other information they provided, such as GPA and SAT scores, but would not be linked to their identity. Once all consent forms were collected, the experimenter read the following statement: “We are now going to turn on your monitors, at which point you may begin the experiment. All instructions are on the computer screen. If you have any questions, please raise your hand and an experimenter will assist you. Please do not talk, use your cell phone, or the internet during the experiment. Also, please do not talk, use your cell phone, or use the internet after the experiment has concluded. An experimenter will let you know when everyone is finished and it is time to leave. Once you are finished, please sit quietly and wait for further instructions.” The experimenter then turned on each of the subjects’ monitors one at a time, and told them that they could begin the experiment.

The experiment used a 2 (*Task 1:* *inhibition* or *no inhibition*) X·1 (*Task 2:* *anagram persistence*) design. As in Gailliot et al. (2007), and also based on the procedure used in Gilbert, Krull, & Pelham (1988), subjects were randomly assigned to two conditions. Approximately half of the participants were instructed to watch a silent video of a woman talking while words appeared in the bottom right-hand corner; the other half of participants were told to watch the same video, but were instructed to do so while only attending to the woman in the video. (See Appendix B for material that was presented to subjects.) For these subjects, they were also instructed to redirect their gaze to the woman if they found themselves looking at the words. The video was seven minutes long, with 30 seconds of a blank grey screen at the start, followed by 6 minutes and 30 seconds of the woman talking while words appeared onscreen approximately every 10 seconds. For the present study, participants started the video 15 seconds into the blank grey screen, so subjects all saw 15 seconds of blank grey screen followed by the video.

After subjects finished the video, they were presented with instructions for Task 2. Task 2 consisted of five anagrams, two of which were unsolvable (the third and the fifth). The instructions were worded carefully to avoid demand characteristics.[[6]](#footnote-6) One portion of the instructions, in particular, was highlighted:

**This is not a test. There is no time limit, and you do not have to answer if you don’t want to. If you wish to proceed to the next anagram, you may do so without entering an answer.  
  
After the five anagrams there are a few questions to answer. You may proceed to these questions whenever you want, but you will not be able to go back to the anagrams.**

(See Appendix B for the entire set of instructions.)

After subjects had proceeded past the fifth anagram, they were asked several questions (e.g. “How difficult was it to follow the instructions for watching the video?” and “How much did you have to concentrate to comply with the instructions for watching the video?”) and given a 7-point scale to answer them (e.g. 1 = Not difficult at all; 7 = Extremely difficult). Finally, subjects were asked a variety of questions about their personal characteristics (e.g. sex, age, race, GPA).

*Results*

*Data omission.* Three observations were removed from the dataset, two of which came from control condition where subjects were given no particular instructions about how to watch the video, except to watch the entire video. These two subjects failed to comply with these instructions, as indicated by the amount of time spent watching the video, which in both cases was less than half the actual duration of the video. (Qualtrics was programmed to record the amount of time spent on every single page of the experiment; this was important to secure the dependent measure of anagram persistence, but secondarily allowed unobtrusive monitoring of instruction compliance.) The third observation that was removed was for a subject whose persistence on one of the impossible anagrams was greater than four standard deviations from the group mean. Thus, after data omission 46 observations were used for analysis.

*Manipulation checks.* For reasons discussed in this section under Study 1, manipulation checks were introduced at the end of the experiment. All questions were asked on a visual 1-7 scale, where the left-most bubble represented the lowest possible value for that question and the right-most bubble represented the highest possible value. (See Table 2 for Study 2’s relevant descriptive statistics.) For the question “How difficult was it to follow the instructions for watching the video?” an ANOVA revealed no significant difference between the *inhibition* and *no inhibition* conditions, *F*(1, 44) = 1.26, p = 0.27. For the question “How much did you have to concentrate to comply with the instructions for watching the video?” an ANOVA revealed a significant difference between the two conditions, *F*(1, 44) = 10.21, p < 0.01; subjects in the *inhibition* condition reported significantly higher levels of concentration to comply with the instructions than did subjects in the *no inhibition* condition.

*Dependent measures.* Because timing data were collected for every single screen of the experiment, the dependent measure of persistence could be parsed several different ways. Using the simple persistence measure used in Muraven, Tice, & Baumeister (1998), which was total time spent on the anagrams, an ANOVA revealed that there was no significant difference in persistence between the two groups, *F*(1, 44) = 0.0003, p = 0.99. Given that result, it was unsurprising that there was also no significant difference between the two conditions when persistence on the third or fifth anagram (both impossible) was considered separately, *F*(1, 44) = 0.52, p = 0.47, and *F*(1, 44) = 0.50, p = 0.48, respectively.

*Subjective reports of effort*. As was done for Study 1, a secondary analysis was conducted to examine whether self-reported feelings of effort, as measured at the end of the experiment, were affected by the conditions or even by outcome variables such as persistence. Differences between the two conditions in self-reported measures of tiredness, frustration, and boredom did not approach significance. For the question “How much effort did you feel obligated to exert during the anagram task?” an ANOVA revealed a significant difference between the two groups, *F*(1, 44) = 3.36, p < 0.1. However, this was in the opposite of the predicted direction; subjects in the *no inhibition* condition reported significantly greater feelings of effort obligation than did subjects in the *inhibition* condition. For the question “How much effort did you exert during the anagram task?” there was no significant difference between the two groups, as indicated by an ANOVA, *F*(1, 44) = 0.06, p = 0.80.

*Discussion*

Compared to subjects in the *no inhibition* condition, subjects in the *inhibition* condition reported having to concentrate significantly more, but the groups did not differ significantly on self-reports of instruction difficulty. It is unclear, therefore, whether the manipulation had its intended effect. The question about the difficulty of instructions compliance is potentially dissociable in the minds of subjects from the level of mental effort required by the task itself. For example, a person might say that it is an easy decision whether to comply with the law and do their taxes, but that has little bearing on the level of mental effort required to actually do them. In the example, then, people might have variable responses to the concentration question contingent on actual properties of their taxes (not complicated, very complicated). For this reason, one might conclude tentatively that the manipulation was in fact successful based on the higher amounts of reported concentration for subjects in the *inhibition* condition. Unfortunately, absent eye-tracking software or other direct or indirect measures of instruction compliance, there are no means of assessing whether subjects followed the instructions in the *inhibition* condition, and therefore there is no way to know whether the manipulation was successful. (For the same reason it is also impossible to know what subjects did in the *no inhibition* condition.)

There were no significant differences in persistence between the *inhibition* and *no inhibition* conditions, regardless of whether persistence was measured as total time on all anagrams, or persistence on anagram 3 or 5. This result was puzzling because of the numerous persistence effects in dual-task studies (e.g. Baumeister, Bratslavsky, Muraven, & Tice, 1998, where resisting temptation to eat cookies resulted in less persistence on unsolvable geometric puzzles; Muraven, Tice, & Baumeister, 1998, where not thinking of a white bear resulted in less persistence on unsolvable anagrams). There seemed to be at least two possible interpretations of the null results: (1) the effects of an inhibitory Task 1 on Task 2 persistence are not robust, or (2) the *inhibition* condition was not cognitively taxing relative to the *no inhibition* condition. Given the multiple studies that find an effect of a cognitively taxing first task on persistence on a second task, including physical tasks, it seems unlikely that the effects are not robust.

The most likely reason for null results is that persistence is not a measure of self-control or self-regulation. Why exactly should any participant persist, particularly given the purposefully nebulous directions given at the outset? Subjects’ confusion or more likely ambivalence about the putative purpose of the task may introduce considerable noise into the persistence measure, regardless of which initial condition they were in. Finally, it is possible the manipulation was simply unsuccessful; as discussed previously, although subjects in the *inhibition* condition reported significantly higher rates of concentration for complying with the instructions, there were no direct means of assessing whether subjects followed the instructions in either condition because of the nature of the task.

Future Directions

The next step is to identify a dual-task experiment that demonstrates the depletion effect, and then to test the glucose-based limited resource model directly as described in the Introduction.

Second, there is surprisingly little existing agreement or even consideration of what should constitute a self-control task. The null results of Studies 1 and 2 raise questions about the nature of results and tasks in dual-task paradigm self-control studies. In a helpful meta-analysis, Hagger, Wood, & Stiff (in press) demonstrated significant effects across a wide range of 82 self-control studies. But the effect sizes are incredibly heterogeneous, ranging from quite small to insignificant (e.g. positive affect) to quite large (e.g. effect on second task performance of a cognitively taxing first task). Further, they found that “[t]he effect size was moderated by depleting task duration, task presentation by the same or different experimenters, inter-task interim period, dependent task complexity, and use of dependent tasks in the choice and volition and cognitive spheres” (p. 2). If “self-control” is driving the hugely variable results across all of the tasks and domains in the self-control literature, a theory of self-control must be able to account for this variability. At present, there is no theory that does so. In large part this is because “self-control” is the behavioral outcome of a computational process, not a causal entity. Like all computational processes, it has inputs and outputs.

It would be fruitful to identify and clarify what sorts of tasks used in this literature actually reflect the phenomenon of self-control problems as experienced in everyday life, as a way of identifying the relevant inputs to computational processes that result in self-control failure or success. This endeavor would be greatly aided by identifying neural mechanisms common to intuitively obvious self-control problems, such that one could distinguish at the neural level between mechanisms that are primarily overlapping with the feeling of mental effort that accompanies self-control problems, and those which are only partially overlapping with feelings of mental effort. As indicated by the motivation for this project, however, there are a number of theoretical clarifications that first need to be made, and behavioral studies to be conducted that could potentially make progress on the problem of self-control.

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|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Inhibition** | | | | **No Inhibition** | | | |
|  | Congruent (n = 21) | | Incongruent (n = 24) | | Congruent (n = 27) | | Incongruent (n = 26) | |
|  | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* | *Mean* | *SD* |
| **Response time (ms)** | 652 | 97 | 669 | 90 | 649 | 109 | 674 | 101 |
| **Errors (out of 96)** | 1.9 | 2.1 | 2.1 | 2.2 | 1.7 | 1.4 | 2.4 | 2.2 |
| **# e's/spaces** | 11.0 | 5.8 | 12.8 | 11.4 | n/a | n/a | n/a | n/a |
| **Time (s) - total** | 516 | 76 | 531 | 92 | 422 | 68 | 477 | 99 |
| **Time (s) - paragraph** | 258 | 61 | 263 | 80 | 180 | 59 | 214 | 80 |
| **Tired** | 3.9 | 1.4 | 4.6 | 1.3 | 4.4 | 1.2 | 4.6 | 1.5 |
| **Bored** | 4.0 | 1.4 | 4.0 | 1.3 | 4.3 | 1.4 | 3.8 | 1.3 |
| **Frustrated** | 2.6 | 1.4 | 2.8 | 1.5 | 2.9 | 1.5 | 2.6 | 1.6 |
| **Effort (obligated)** | 4.4 | 1.3 | 4.9 | 1.4 | 4.7 | 1.8 | 4.3 | 1.3 |
| **Effort (exerted)** | 4.1 | 1.3 | 5.3 | 1.2 | 4.3 | 1.7 | 4.1 | 1.5 |

**Table 1.** *Study 1 Descriptive Statistics*

**Table 2.** *Study 2 Descriptive Statistics*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Inhibition** (n = 25) | | **No Inhibition** (n = 21) | |
|  | *Mean* | *SD* | *Mean* | *SD* |
| **Anagram 3 persistence (s)** | 20.8 | 15.4 | 17.8 | 12.4 |
| **Anagram 5 persistence (s)** | 65.8 | 43.9 | 74.8 | 41.0 |
| **Total persistence (s)** | 249.3 | 134.4 | 249.9 | 114.5 |
| **Instructions (difficult)** | 3.7 | 2.0 | 3.0 | 2.0 |
| **Instructions (concentration)** | 5.0 | 1.7 | 3.3 | 1.9 |
| **Tired** | 4.7 | 1.6 | 4.7 | 1.7 |
| **Bored** | 4.9 | 1.4 | 4.7 | 2.0 |
| **Frustrated** | 2.3 | 1.5 | 2.9 | 1.4 |
| **Effort (obligated)** | 4.8 | 1.6 | 5.7 | 1.4 |
| **Effort (exerted)** | 5.5 | 1.5 | 5.5 | 1.4 |

Appendix A

*Study 1 Materials*

*Task 1 Instructions (*inhibition *condition in [[brackets]])*

Welcome to today’s experiment.

There will be a paragraph on the next screen. Your task is to re-type the paragraph as QUICKLY and ACCURATELY as possible [[WITHOUT typing the letter ‘e’ or the SPACEBAR]].

You will not be able to see what you are typing as you type it, but your keystrokes will be recorded.

When you have completed typing the paragraph, make sure to type the # symbol which appears at the end of the paragraph.

If you have any questions, please raise your hand now.

When you are ready, press the SPACEBAR to begin.

*Paragraph*

In order to be cryptic, an animal’s color pattern must appear to its predators as a random sample of the background. Any deviation from the background in the distribution of color patch size, color frequency, or brightness distributions will make an animal’s pattern conspicuous, and the degree of conspicuousness is proportional to the deviation from the background distributions. As predation intensity increases, the match between animal and background should improve. Poeciliids are small fishes which live in streams in North, Middle, and South America. Guppies are ideal for color pattern studies. They are found in northeastern South America, and their ecology and behavior are well known. Color pattern frequencies at a particular locality represent a balance between visual selection by predators (favoring crypsis) and sexual selection (favoring conspicuous color patterns). The diet and number of predator species varies from place to place and allows sampling along predation intensity gradients.#

*Task 2 Instructions*

For this task, you will see words in different colors. Your task is to respond with the color of the word, not what the word says.

For example, for the word GREEN, you should respond with the button that corresponds to the color red, because the word is red.

Another example: For the word RED, you should respond with the button that corresponds to the color green, because the word is green.

As soon as the word appears on the screen, please respond with the color of the word as fast as you can by pressing the button that corresponds to that color.

If the color is YELLOW, please press 4 (there is a yellow sticker on this button).

If the color is RED, please press 5 (there is a red sticker on this button).

If the color is GREEN, please press 6 (there is a green sticker on this button).

If the color is BLUE, please press 7 (there is a blue sticker on this button).

*Post-Experiment Questions*

You will be asked some questions in the next section. You will be presented with a rating scale. Press the ‘0’ key to move the scale to the right. Press the ‘1’ key to move the scale left. Press the spacebar to submit your rating.

Please press the SPACEBAR to continue.

1. At this moment, how tired are you? (1-7, Not tired at all; Extremely tired)

2. At this moment, how bored are you? (1-7, Not bored at all; Extremely bored)

3. At this moment, how frustrated are you? (1-7, Not frustrated at all; Extremely frustrated)

4. How much effort did you feel obligated to exert during this task? (1-7, No effort; A lot of effort)

5. How much effort did you exert during this task? (1-7, No effort; A lot of effort)

6. How old are you?

7. What is your sex? (M/F)

8. What is your race?

9. What is your native language?

10. Are you right or left-handed? (R/L) (If ambidextrous, type ‘A’)

11. What is your combined SAT score (if you know it)?

12. What is your cumulative GPA (if you know it)? (To one decimal place, e.g., 2.9 or 3.1)

*Final Screen*

Thank you for participating. Please sit quietly for further instructions, and please do not press any keys or use the mouse.

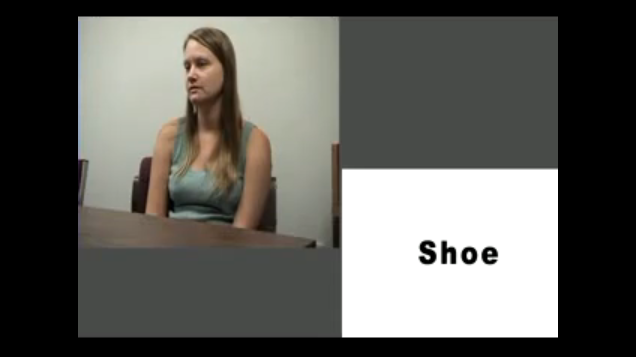
Appendix B

*Study 2 Materials*

*Task 1 Instructions (*inhibition *condition in [[brackets]])*

Welcome to today’s experiment.  
  
On the next screen you will see a video. The video is of a woman being interviewed. The video is muted, so there is no sound. For the first 15 seconds the video will be a blank gray screen. The entire video is about 7 minutes long. Please watch the entire video from start to finish. When the video ends, proceed to the next screen.  
  
**[[The following instructions are important so please read them carefully.  
  
Different words will appear every 10 seconds in the bottom right-hand corner of the video. Do NOT read or look at any words that may appear on the screen. Pay attention only to the woman being interviewed. If you find yourself looking at the words, please redirect your gaze to the woman being interviewed.]]**  
  
If you have any questions, please raise your hand. When you are ready to proceed, please go to the next screen and press the play button in the middle of the screen to start the video.

*Video Screenshot*



*Task 2 Instructions*

Now it is time for something different. On each of the next five screens you will be asked to solve an anagram. There are five total anagrams. An anagram is a scrambled word. For example, you might see the following:  
  
WATLLE  
  
These letters can be rearranged to spell “WALLET.” To enter your answer, simply type it in the blank text box and proceed to the next screen.  
  
**This is not a test. There is no time limit, and you do not have to answer if you don't want to. If you wish to proceed to the next anagram, you may do so without entering an answer.  
  
After the five anagrams there are a few questions to answer. You may proceed to these questions whenever you want, but you will not be able to go back to the anagrams.**  
  
Whether or not you choose to try the anagrams, please do not use cell phones, pencil and paper, or internet to help solve the anagrams.  
  
If you have any questions, please raise your hand. Otherwise continue to the first anagram.

*Anagrams (appeared on separate screens)*

Anagram 1:

ALRMAS

Type in your answer below, or proceed to the next anagram if you wish.

Anagram 2: EOFCEF

Anagram 3: TECRXE (impossible)

Anagram 4: RETUUF

Anagram 5: RHOCOS (impossible)

*Post-Experiment Questions*

1. How difficult was it to follow the instructions for watching the video? (1-7, Not difficult at all; Extremely difficult)

2. How much did you have to concentrate to comply with the instructions for watching the video? (1-7, Not much at all; A lot)

3. At this moment, how tired are you? (1-7, Not tired at all; Extremely tired)

4. At this moment, how bored are you? (1-7, Not bored at all; Extremely bored)

5. At this moment, how frustrated are you? (1-7, Not frustrated at all; Extremely frustrated)

6. How much effort did you feel obligated to exert during the anagram task? (1-7, No effort; A lot of effort)

7. How much effort did you exert during the anagram task? ? (1-7, No effort; A lot of effort)

8. What is your age?

9. What is your sex? (male; female)

10. What is your race? (White/Caucasian; African American; Hispanic; Asian; Native American; Pacific Islander; Other)

11. Is your native language English? (yes; no)

12. If you know it, what is your combined SAT score (math, writing, critical reading)? (If you took the SAT when it was out of 1600, please simply use that score.)

13. If you know it, what is your cumulative GPA?

*Final Screen*

You have now completed the experiment. After you proceed to the next screen, please sit quietly and await further instructions. Please do not use cell phones, the internet, or your computer. An experimenter will let you know when everyone is finished and it is time to leave. You may now proceed to the final screen.

1. In the few studies that have tested the glucose-based limited resource model, it is unclear whether researchers are claiming that glucose is the resource on which self-control relies, or whether it is implicated in a lesser (or some other) role. For example, Gailliot & Baumeister (2007) state that “[p]ast research indicates that self-control relies on some sort of limited energy source. This review suggests that blood glucose *is one important part of the energy source of self-control*” (p. 303, emphasis added). Statements such as these are common in the self-control literature, specifically in those studies that test the relationship between glucose and self-control, but they leave unclear what the researchers are claiming. Is glucose the resource on which self-control relies? Or, alternatively, is it implicated in the exercise of self-control in some other way? [↑](#footnote-ref-1)
2. The paragraph was drawn from John A. Endler’s 1982 paper “Convergent and divergent effects of natural selection on color patterns in two fish faunas,” *Evolution, 36*, 178-188. See Appendix A for the paragraph in its entirety. [↑](#footnote-ref-2)
3. All data analyses were conducted using the R statistical environment. [↑](#footnote-ref-3)
4. It should be noted that for the present study, no within-subjects measures of the Stroop effect were obtained, because in both congruent and incongruent conditions subjects saw only one type of trial, congruent or incongruent. [↑](#footnote-ref-4)
5. Based on the language in their study, there is no indication that any of the anagrams were solvable. However, Muraven sent by email the list of anagrams, several of which were actually solvable. It is unclear what precisely was used for their study. [↑](#footnote-ref-5)
6. Mark Muraven (personal communication, Feb 25, 2010), who had previously used unsolvable anagrams in a self-control experiment, and who also provided a list of unsolvable anagrams for use in this experiment, said the following about unsolvable anagrams: “In general, I recommend careful pilot testing of your instructions, because it takes a delicate touch to motivate people to try but make quitting seem acceptable too. For that reason, I have moved away from using these persistence tasks to more cognitive measures of inhibition, like the stop signal, stroop, or vigilance.” [↑](#footnote-ref-6)