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Improved Self-Control Associated with Using Relatively Large Amounts of Glucose: Learning Self-Control Is Metabolically Expensive

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The current study examined whether changes in glucose during a self-control task would predict changes in self-control performance later on. Participants attended two experimental sessions, spaced two weeks apart. During each session, they had their glucose measured, completed the Stroop task as a measure of self-control, and then had their glucose measured again. Larger decreases in glucose (from before to after the Stroop task) during the first session predicted larger increases in improvement on the Stroop task during the second session, in the form of increased speed. Learning self-control might benefit from using larger amounts of glucose. Learning self-control is metabolically expensive. These findings raise the possibility that self-control fatigue occurs because metabolic energy is depleted during the learning of self-control.

Keywords: Self-Control; Self-Regulation; Glucose; Metabolism; Learning; Fatigue; Energy; Memory

Introduction

Humans are metabolic organisms. Every thought, behavior, and biological process requires the use of metabolic energy. Some processes are metabolically expensive, however, and consume more energy than do others (Aiello, 1997; Aiello, Bates, & Joffe, 2001; Aiello & Wheeler, 1995; Gailliot, Hildebrandt, Eckel, & Baumeister, 2009). The current study tested whether learning self-control is metabolically expensive, such that improved learning would be associated with using larger amounts of one metabolic energy source—glucose.

Past work suggests that cognitive learning is metabolically expensive. Children use a relatively large amount of glucose for the brain, disproportionately more than adults do (Haymond, 1989), and childhood is a time of learning large amounts of information. Several studies demonstrate that memory is improved when glucose levels are optimal, such as after having a glucose drink (for reviews, see Riby, 2004; White, 1991). Memory is one form of learning, as the individual encodes, stores, and retrieves information for later recall or recognition. If glucose benefits learning among children and memory, then glucose might benefit learning self-control.

Learning can be viewed as a form of growth, because learning occurs partly through neuronal spreading or the growth of neurons. Growth is metabolically expensive.

Cancer cells are one form of growth, and they use a relatively large amount of metabolic energy, relative to non-cancerous cells (Schoen et al., 1999; Weber et al., 2003; Younes, Lechago, Somoano, Mosharaf, & Lechago, 1996). Other forms of biological growth, such as sperm production (Pitnick, Jones, & Wilkinson, 2006), can also be metabolically expensive. To the extent that learning self-control entails growth, such as among neurons, then glucose would be expected to improve learning self-control.

Using self-control is metabolically expensive, suggesting that learning self-control might be also. Several studies have found that, after using self-control in one domain (e.g., thought suppression), self-control is impaired in any other domain (e.g., emotion regulation) (for reviews, see Baumeister, Gailliot, DeWall, & Oaten, 2006; Baumeister, Vohs, & Tice, 2007; Gailliot, 2009; Muraven & Baumeister, 2000). This effect appears to occur because self-control is impaired when glucose is low, and using self-control reduces glucose in the bloodstream (DeWall, Baumeister, Gailliot, & Maner, 2008; Fairclough & Houston, 2004; Gailliot et al., 2007; Gailliot & Baumeister, 2007; Gailliot, Peruche, Plant, & Baumeister, 2009; Masicampo & Baumeister, 2008). Other work shows that self-control is impaired by other metabolic problems, such as low brain glycogen, diabetes, glucose-6-phosphate dehydrogenase deficiency, and glucose intolerance (DeWall, Gailliot, Deckman, & Bushman, 2009; Gailliot, 2008; Gailliot & Baumeister, 2007).

Thus, people might be better at learning self-control when they use larger amounts of glucose while exerting self-control. Using more glucose might indicate more effective learning or growth.

Participants in the current study attended two experimental sessions, spaced 2 weeks apart. During each session, participants completed the Stroop task as a measure of self-control, before and after which their blood-glucose levels were assessed. If glucose reductions benefit learning, then using more glucose during the first session should predict greater improvements on the Stroop during the second session.

Method

Participants

The final sample included 50 college undergraduates (30 women, 20 men) who participated in exchange for credit to-

ward a course requirement. The final sample excluded 11 participants who did not return for the second experimental session and 3 participants for whom procedural errors by an experimenter precluded analyzing their data.

Procedure

Participants attended two experimental sessions, spaced 2 weeks apart. During each session, participants first completed a questionnaire packet unrelated to the current investigation. They then had their blood-glucose levels measured, completed the Stroop task, and then had their glucose levels measured again.

Blood samples were taken with single-use blood sampling lancets. Blood glucose levels were measured (mg/dL) using an Accu-chek compact meter.

Participants completed the Stroop task for 20 minutes. For the Stroop task, participants were given a list in which the words *red*, *blue*, and *green* appeared in an incongruent font color (either red, blue, or green). Participants were instructed to state aloud the color of the ink and to ignore the meaning of the word, and to do this as quickly and accurately as possible. The experimenter recorded the number of errors and speed (number of trials completed).

Results

Speed on the Stroop

The change in glucose (from the first to the second glucose reading) during the first session predicted change in speed on the Stroop (number of trials completed) from the first to the second session, $r(50) = -.30$, $p < .05$. Larger decreases in glucose during the first session predicted larger increases in the number of trials completed. Thus, larger drops in glucose were associated with greater improvements in performance.

Errors on the Stroop

The change in glucose (from the first to the second glucose reading) during the first session did not predict change in errors on the Stroop from the first to the second session, $p > .58$. The relationship between glucose changes during the first session and changes in speed across sessions did not appear attributable to errors, such as if a speed-accuracy tradeoff existed. Specifically, glucose changes during the first session and changes in speed remained significantly correlated when controlling for changes in errors, $r(47) = -.29$, $p < .05$.

Glucose Changes during the Second Session

Changes in glucose (from the first to the second glucose reading) during the second session did not predict change in performance across the two sessions for either speed or accuracy, $ps > .80$. This is inconsistent with the alternative explanation that people prone to experience glucose drops during the Stroop task also are prone to improve their performance.

Discussion

The current study found that larger decreases in glucose while performing the Stroop task predicted larger increases in improvement in speed on the Stroop during a second experi-

mental session. Presumably, glucose is used during the Stroop as participants learn how to perform the task, and larger amounts of glucose consumption indicate greater learning.

These findings are consistent with past work on glucose and metabolism. Glucose enables learning (e.g., among children, during memory tasks) and growth (e.g., in cancer cells), and is strongly linked to self-control. Glucose seems to enable effective learning of self-control, perhaps through neuronal growth occurring while learning how to perform well on the Stroop.

The exertion of self-control in specific ways is difficult at first but may eventually become automatized (Bargh, 1994; Bargh & Chartrand, 1999). Initial attempts at quitting smoking, for instance, can be effortful, but eventually people might learn how to avoid smoking automatically. If so, then the initial development of self-control is metabolically costly but eventually might require less metabolic energy as the capacity is automatized.

It is plausible that people perform worse on self-control tasks after having used self-control (Baumeister et al., 2007; Gailliot, 2009; Muraven & Baumeister, 2000) because glucose decreases (Fairclough & Houston, 2004; Gailliot et al., 2007) during the initial self-control task as people learn how to perform it. Hence, self-control impairments after initial self-control might be considered as harmful aftereffects of learning. People who learn the self-control task most effectively might be the most likely to show impairments on later self-control tasks. Learning self-control could be metabolically expensive because neurons must not only fire as usual but also expand and grow.

Studies on the aftereffects of using self-control have found little or no evidence that general individual differences moderate the effects of self-control on later self-control. Individual differences that have emerged tend to be related to the relevant self-control domain, such as differences in eating restraint moderating eating consumption (Kahan, Polivy, & Herman, 2003; Vohs & Heatherton, 2000), the motivation to respond without prejudice moderating effects of stereotype suppression (Gailliot, Plant, Butz, & Baumeister, 2007), the temptation to drink alcohol moderating alcohol consumption.

(Muraven, Collins, & Nienhaus, 2002), sex drive moderating sexual restraint (Gailliot & Baumeister, 2007), and attachment style moderating interpersonal functioning (Vohs, Baumeister, & Ciarocco, 2005). It is possible that individual differences in learning might moderate self-control fatigue effects across different self-control domains, because learning tendencies can be domain general.

Gailliot et al. (2007) found (but did not report) that decreases in glucose predicted impaired performance on later self-control tasks, though glucose levels more reliably predicted self-control performance. Whereas past work thus highlights the link between glucose levels and self-control (Fairclough & Houston, 2004; Gailliot et al., 2007), the current work suggests that changes in glucose levels also are influential.

People with diabetes and other metabolic problems tend to exhibit impaired self-control (e.g., DeWall et al., 2009; Gailliot & Baumeister, 2007). Their problems with self-control could stem from difficulties learning to effectively exert self-control. They might form self-control intentions and act upon them much like individuals without metabolic deficits, yet experience problems with learning.

Metabolic energy use is limited (Kleiber, 1961), suggesting that metabolites used for one processes can be diverted away from others (Gailliot et al., 2009). If so, then metabolism used

for learning might at times be diverted from other processes and viceversa. Immune functioning and reproduction are metabolically expensive, and so learning might exhibit metabolic trade-offs with health and reproductive capacity, for instance.

Demands to learning self-control could be related to metabolism in ways aside from causing decreases in glucose. For example, increased demands to learn self-control might lead to increased metabolic energy intake, such as gaining weight in novel environments.

Future work could focus on why learning self-control might be a metabolically costly part of self-control. Learning might entail greater changes in neuronal firing and connections, thus requiring more energy than more simple neuronal activity. Change requires growth and the additional metabolites to support that growth, which is above the typical rate of glucose use during that same amount of time.

Failures in self-control might stem from failures in learning how to exert self-control as much as they stem from failures in exerting self-control. People might lack the glucose needed to effectively learn superior self-control strategies, for instance, such as a dieter failing to learn how to walk away from the kitchen and engage in an activity other than eating. The individual might experience thoughts helpful toward successful self-control, but without sufficient glucose, fail to learn from them.

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