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Beyond The Breakfast Club: The Influence of Breakfast Type on Cognition

Jillian D. Saccogna
The College of Wooster, jsaccogna18@wooster.edu

The College of Wooster

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by

Jillian D. Saccogna

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Supervised by

Evan A. Wilhelms

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Abstract

The glycemic index ("GI") of a food refers to the magnitude with which the food elevates an individual's blood glucose levels, and this value can be used to calculate the glycemic load ("GL") of a specific portion of food. Some evidence suggests that blood glucose levels may play a key role in self-control. Emerging research suggests that consuming low GI or GL breakfasts may enhance memory performance and result in greater levels of positive affect compared to high GI or GL breakfasts. Participants in the present study were randomly assigned to consume either a low GI/GL breakfast or a high GI/medium GL breakfast. Later in the morning, participants completed a memory task, a Stroop task to assess self-control, and a PANAS questionnaire to assess mood. Breakfast condition did not influence memory performance or self-control; however, participants who consumed the high GI/medium GL breakfast indicated significantly higher levels of positive affect than those who consumed the low GI/GL breakfast. Effects of semester on self-control performance and positive affect were observed and are discussed. While contrary to previous research, the present study suggests no comparative cognitive benefit of a low GI breakfast and that a high GI breakfast, when consumed according to serving size recommendations, may not be detrimental to cognitive functions.

Keywords: breakfast, glucose, glycemic index, glycemic load

Introduction

The benefits of eating breakfast are so often touted that nearly everyone is familiar with the saying, “Breakfast is the most important meal of the day.” Breakfast can be defined as the first meal of the day within two to three hours of waking up and consists of a food or beverage from at least one food group; however, noncaloric beverages such as water, tea, or black coffee are not considered a form of breakfast (O’Neil et al., 2014). Including a morning meal in one’s diet can increase the likelihood of meeting the recommended daily values of crucial nutrients such as calcium, fiber, iron, and B-vitamins, among various others (O’Neil et al., 2014; Williams, 2014). Additional research has found that breakfast consumption is associated with improved weight management and lower levels of obesity among breakfast-eaters (Leidy, 2013; Williams, 2014). In addition to the various physiological benefits of consuming breakfast, evidence purports cognitive benefits as well. Some findings suggest that eating breakfast may be associated with improved mental well-being (Williams, 2014) and enhanced cognitive functioning (O’Neil et al., 2014; Williams, 2014), the latter of which is especially important for young children who must spend much of their day at school.

While breakfast has appeared to earn its title of being the most important meal of the day, it is worth noting the controversies surrounding the credibility of these benefits being attributed to breakfast alone. For example, some studies have observed that regular breakfast-eaters tend to partake in other health-promoting behaviors such as engaging in more vigorous exercise (Chen et al., 2014; Reeves, Halsey, McMeel, & Huber, 2013) directing more focus to their personal nutrition, and sustaining enhanced interpersonal relationships and methods for combatting stress (Chen et al., 2014). Since the act of eating breakfast is often used in one’s daily life in conjunction with other health-promoting activities, it is possible that other uncontrolled healthful habits could play a role in some of the touted benefits of consuming breakfast in the morning. While this is certainly an important avenue for future research to explore, when an individual does choose to consume a morning meal, not all breakfasts are created equally. Recent findings assert that specific characteristics of one's morning meal may play an important role regarding its influence on the breakfast-consumer. In particular, certain contents of a breakfast may benefit or hinder a breakfast eater's cognition.

In order to better examine what this meal could bring to the table, research has resorted to several different methods of measuring a given breakfast and the effects it could have on the cognition of breakfast eaters. Due to the presence of many breakfast-related variables, common methods seen in the literature include examining the size of a breakfast (Lloyd, Rogers, Hedderley, & Walker, 1996; Michaud, Musse, Nicolas, and Mejean, 1991), the number of food groups present (Herrero & Fillat, 2006; O'Dea and Mugridge, 2012), the macronutrient content of the breakfast (Kaplan, Greenwood, Winocur, & Wolever, 2001; Dye, Lluch, & Blundell, 2000; Nabb & Benton, 2006), and the glycemic index ("GI") or load of the given breakfast. Due to the importance of glucose for general brain functioning in addition to the relationship between glycemic index and an individual's blood glucose levels, the glycemic index of a breakfast will remain the primary focus of this paper.

Glycemic Index

The GI of a food refers to the magnitude with which the food elevates an individual's blood glucose levels (Ingwersen, Defeyter, Kennedy, Wesnes, & Scholey, 2007). A food that is considered to have a high GI tends to cause a sharp spike in blood glucose levels followed by a sharp drop-off because it is absorbed and metabolized quickly in the body; however, on the other hand, a food that has a low GI results in more gradual and sustained changes in one's blood glucose levels (Englyst, Liu, & Englyst, 2007; Ingwersen et al., 2007; Leeds, 2002). A food item is identified as having a high or low GI by the number it has been given on a scale of one through 100. These numbers have been derived from the comparison of volunteers' average blood glucose levels after consuming 50 grams of carbohydrates of pure glucose to volunteers' average blood glucose levels after consuming 50 grams of carbohydrates of any given food (Jenkins et al., 1981). Since the blood glucose response curve will always be smaller after consuming 50 grams of carbohydrates of a specific food than the response curve after consuming 50 grams of carbohydrates from glucose, GI values represent the percentage form of a given food's blood glucose response curve out of 100 (the response curve of pure glucose) (Jenkins et al, 1981). A food with a low GI is one that has been given a number from one to 55, medium GI foods have been given a number from 56 to 69, and a high GI food has been given a number anywhere from 70 to 100 (Atkinson, Foster-Powell, & Brand-Miller, 2008).

There are several characteristics that may be used to help identify high and low GI food items. The type of carbohydrates present in a food can determine whether the given food has a high or low GI. For example, food items largely comprised of available carbohydrates (commonly known as simple carbohydrates) such as sugar tend to result in a greater increase in blood glucose levels (Crapo, Reaven, & Olefsky, 1976); therefore, these foods tend to result in higher GIs (Balay, 2009; Gangwisch et al., 2015). On the other hand, the rise in blood glucose levels tends to be lower for food items comprised largely of resistant carbohydrates (commonly known as complex carbohydrates) such dietary fiber (Gangwisch et al., 2015; Topping, 2007); therefore, these foods have been associated with a food item being lower in GI (Balay, 2009; Gangwisch et al., 2015). This relationship occurs because fiber can be either poorly digested and metabolized or not digested at all in the small intestine (Englyst et al., 2007), resulting in a slower metabolism of carbohydrates (Gangwisch et al., 2015), and, therefore, more gradual changes in blood glucose levels. Additional factors, such as a food being more highly processed, and increasing the serving size of a food, can increase the associated glycemic response (Balay, 2009), whereas vitamin E supplements have the potential to counteract this effect, as they have been shown to improve glucose tolerance (Paolisso et al., 1993).

Evidence suggests that following a diet that relies on low-GI foods has more favorable effects on long-term health than a diet that relies on high-GI foods. For example, a diet consisting of high-GI foods has been linked to a decreased level of high-density lipoprotein cholesterol concentration, a phenomenon that has been shown to increase the probability of developing coronary heart disease (Ford & Liu, 2001). Even when caloric intakes were accounted for, several studies found that a diet comprised of high-GI foods elevated an individual's risk of developing diabetes (Salmerón et al., 1997a; Salmerón et al., 1997b) and other complications such as increased free radical production (Ceriello et al., 1998), a phenomenon which can accelerate aging and results in a detrimental imbalance of the products of the metabolism (Valko et al., 2007). Following a diet rich in high-GI foods has also been shown to place an individual at a heightened risk for developing certain types of cancer, such as colorectal cancer (Franceschi et al., 2001) and breast cancer (Augustin et al., 2001), even after caloric intakes were equalized. While the reviewed research has presented many physiological effects of a long-term diet relying on high-GI foods, evidence suggests that psychological effects occur as well. In a three-year observational study, post-menopausal women whose diets tended to include high-GI foods displayed a greater risk of developing depression than those whose diets tended to include low-GI foods (Gangwisch et al., 2015).

It is important to note, however, that simply being labeled as having a high GI does not immediately designate a given food as unhealthful. Other considerations should be taken into account when evaluating the healthfulness of a food item. For example, when the ratio of other beneficial components such as vitamins and minerals to carbohydrates is high, consuming a food containing a higher GI may be a sacrifice worth making (Jenkins et al., 2002). For instance, carrots, parsnips, and broad beans are all examples of food items that are high in GI (Foster-Powell, Holt, & Brand-Miller, 2002); however, each of these items can be characterized as healthful because they contain high levels of antioxidants and other essential micronutrients.

There are several other important considerations to be made regarding the GI. Firstly, there may be inconsistencies between the typical portion size of a food and the portion size of 50 grams' worth of carbohydrate in the same food. Some foods may require a serving size much larger than typically eaten in order to obtain the 50 grams of carbohydrates necessary to reach the blood glucose response percentage indicated in the GI. One way this has been addressed is through the development of the glycemic load ("GL"), which integrates the individual portion size that is consumed into the calculation of the impact on one's blood glucose levels (Salmerón et al., 1997b). This calculation involves multiplying the GI of the food by the number of grams of available carbohydrates present in the serving to be eaten and dividing the product by 100 (Atkinson et al., 2008). Foods containing a low GL are those with values from zero to 10, those with a medium GL are from 11 to 19, and those with a high GL have values 20 and over (Mendosa, 2003).

Newer research reveals that blood glucose responses to different foods are not completely universal. Since blood glucose responses are unique to each individual, complete reliance on the GI may not be optimal for individuals whose blood glucose responses deviate from the widely accepted “average” GI values (Whelan, Hollar, Agatson, Dodson, & Tahal, 2010). Individual variation of glycemic responses to the same food item could be attributed to differences in age, sex, body mass index, ethnicity, and can even be random (Whelan et al., 2010). This phenomenon highlights the importance of obtaining a large sample size to reduce the bias that could be inflicted by individual variations in glycemic response.

Neurochemical Effects of Glucose

Although individual glycemic responses vary, one universal aspect of glucose is that it remains the dominant source of energy for every living cell in the body (Soty, Gautier-Stein, Rajas, & Mithieux, 2017) and serves almost exclusively as the fuel required for brain-related functioning (Marty, Dallaporta, & Thorens, 2007; Steinbusch, Labouèbe, & Thorens, 2015; Weiss, 1986). The brain itself has a very limited capacity for glucose storage; therefore, it is heavily reliant on the cerebral circulation of blood sugar (McNay, McCarty, & Gold, 2001; Weiss, 1986) to sustain its functioning. Once glucose from the blood enters neural tissue, it is continuously employed by cells within the brain (Wakabayashi, Myal, & Kiyatkin, 2015), and its metabolism occurs in the regions of the brain that are involved in the specific task being carried out (Gailliot & Baumeister, 2007).

Brain cells that are especially receptive to fluctuations in glucose levels in the body include those found in the hypothalamus and the brainstem (Steinbusch et al., 2015). The nourishment provided by glucose in these areas is crucial for maintaining control of the sympathetic and parasympathetic divisions of the autonomic nervous system and the homeostatic regulation of insulin and glucagon secretion (Steinbusch et al., 2015), whole-body homeostasis, and hunger regulation (Marty et al., 2007). In hunger regulation specifically, brain regions related to processing the reward cues of food such as the nucleus accumbens, central amygdala, and orbitofrontal cortex have shown activation following glucose delivery (Delaere, Akaoka, De Vadder, Duchampt, & Mithieux, 2013; Soty et al., 2017). The observed activation of these areas suggests survival implications, since it has been demonstrated that a decrease in blood sugar levels tends to result in the drive to eat and subsequent experience of reward in response to the act of eating (Marty et al., 2007). For example, one study found that infusing glucose into rats prevented their blood sugar levels from naturally declining and postponed the rats' act of eating their next meal (Campfield, Brandon, & Smith, 1985).

While all regions of the brain metabolize glucose, some regions are more metabolically-active than others (Mergenthaler, Lindauer, Dienel, & Meisel, 2013). Furthermore, when a specific brain region is activated, it metabolizes glucose at a faster rate (Mergenthaler et al., 2013). Mental processes that involve the prefrontal cortex, such as memory, attention, decision-making, and control of emotion (Banfield, Wyland, Macrae, Munte, & Heatherton, 2005) tend to require large amounts of effort and control and appear to demand more glucose than elementary and automatic processes (Gailliot & Baumeister, 2007). Some research has indicated that the hippocampus may also be sensitive to glucose supply within the brain (Gibson, 2007).

Recent evidence supports the necessity of glucose for brain processes that are reliant on the prefrontal cortex. For example, participants showed a greater decline in blood-glucose levels following a Stroop task containing incongruent color-text stimuli (considered effortful) as opposed to a Stroop task containing congruent color-text stimuli (considered not effortful; Fairclough & Houston, 2004). Gailliot and Baumeister (2007) have noted that some studies observed glucose to improve performance on very demanding attention-control tasks but not on less-demanding attention-control tasks. A study that implemented cognitively-demanding tasks observed that 20 minutes after consuming a pure glucose drink, participants had faster reaction times on a Rapid Information Processing Task and performed better on a Stroop task as opposed to participants who consumed a placebo drink (Benton, Owens, & Parker, 1994). On the other hand, a study that used the Test of Variables of Attention, a task requiring less effort, found no improvement in the performances of participants 15 minutes following consumption of a glucose drink as opposed to a placebo drink (Flint & Turek, 2003). A plausible explanation for the results of these studies is that the flow of glucose to the brain is restricted during states of hyperglycemia (characterized as high blood glucose levels); therefore, having an excess of glucose required for the task at hand should not result in any cognitive benefits (Gailliot & Baumeister, 2007).

The brain's utilization of glucose from the blood supports the idea that blood glucose levels derived from consuming a food high or low in GI influence brain functioning. As it is normal for blood glucose levels to vacillate throughout the day, the brain is generally equipped to adjust to these changes. For example, when a fasting state occurs, one's metabolism adjusts to decrease the body's glucose usage in an attempt to preserve as much of this energy source as possible (Soty et al., 2017). Although many cognitive processes can still function well during daily rises and dips in blood glucose levels, more effortful cognitive processes are thought to be sensitive to even these minor fluctuations (Gailliot et al., 2007). This paper will seek to examine the effect of blood glucose levels resulting from different kinds of breakfasts upon effortful cognitive processes such as memory and self-control.

Memory

Some research has shown that consumption of caloric energy, regardless of its carbohydrate content or GI, has been shown to positively impact one's memory. For example, when participants were given either a pure protein drink, a pure fat drink, a carbohydrate (glucose) drink, or a calorie-free placebo, all participants except for those in the placebo group displayed an enhancement in their memory performance 15 minutes after consuming the drink (Kaplan et al., 2001). Researchers Jones, Sünram-Lea, and Wesnes (2012) observed a similar result when implementing a comparable design, although they found no increase in memory performance in the group who consumed a pure fat drink. Interestingly, it is important to note that Kaplan and colleagues (2001) found that only participants who consumed a glucose drink displayed an improved memory performance at 60 minutes, whereas Jones and colleagues (2012) found that only participants who consumed a protein drink displayed an improved memory performance at 60 minutes. Since carbohydrates are the sole macronutrient that can directly elevate one's blood glucose levels, these findings are particularly important because they show that elevated blood glucose levels may not be the only reason for improved memory performance. While these studies exhibit evidence for an effect of a pure carbohydrate-containing meal on memory, more research is clearly needed to address the conflicting nature of the current research in the literature.

Instead of consisting of one macronutrient alone, a typical meal contains some amount of carbohydrates, protein, and fat. Several studies examining memory in participants have focused on examining a typical breakfast containing all three macronutrients instead of isolating the effects of the macronutrients, as in Kaplan et al. (2001) and Jones et al. (2012). One such study (Smith, Clark, & Gallagher, 1999) found that participants who consumed breakfast cereal (containing carbohydrates) and semi-skimmed milk (containing both protein and fat) in the morning performed better on a mid-morning spatial memory task than participants who did not consume any breakfast. It was explained that participants could choose one cereal to eat from a selection of several cereals. Another study (Pivik, Tennal, Chapman, & Gu, 2012) examined the neural activity in children as they completed mathematical arithmetic tasks. The neural networks of children in the “ate breakfast” condition appeared more efficient than those of the children in the “skipped breakfast” condition, indicating that demands on the working memory processes involved in mathematical calculations were facilitated in fed children (Pivik et al., 2012). This piece of evidence, along with the results from Smith et al. (1999), offers a compelling argument for the cognitive benefits of consuming breakfast. Regardless of their GI, breakfasts in these studies appeared to have a positive influence on performance on effortful memory tasks. While these are encouraging findings, emerging evidence has brought to light a distinction in memory performance between individuals who have consumed high GI breakfasts as opposed to low GI breakfasts, a characteristic that was not examined in the studies done by Pivik et al. (2012) and Smith et al. (1999).

When participants were provided with either a low GL breakfast or a high GL breakfast, those who were given the former showed a superior effortful memory performance compared to those who consumed a high GL breakfast 150 minutes and 210 minutes after eating (Benton et al., 2002). A critical detail about this study remains that both high GL and low GL groups showed similar elevated memory scores at 30 minutes that remained stable 90 minutes after eating the breakfast. This result is consistent with the findings from Kaplan et al. (2001), where memory was supported an hour after pure glucose consumption. Even though memory was supported for 90 minutes in both low GL and high GL groups, glucose levels and memory scores of the participants in the high GL group decreased at 150 and 210 minutes, whereas those of the low GL group did not (Benton et al., 2002). These findings provide evidence that when compared with breakfasts with a high GL, breakfasts with a low GL could have a more positive impact on longer-term memory performance but not necessarily on shorter-term memory performance. Interestingly, a similar reaction to glucose has been displayed in rats. Rats who were fed a low GL diet performed significantly better on a learning task three hours after eating than did rats who were fed a high GL diet (Benton et al., 2002).

The implications of the relationship between GI and memory performance is highly relevant in an educational setting. Schoolchildren have demonstrated a similar cognitive response following consumption of breakfasts varying in GI. In one study (Ingwersen et al., 2007), after eating either Coco Pops (cereal with a high GI) or All Brain (cereal with a low GI), children were subject to memory and attention tests. Children who consumed the low GI cereal exhibited a significantly smaller decline in both secondary memory and accuracy of attention over the course of the morning when compared with children who consumed the high GI cereal (Ingwersen et al., 2007). These results bring to salience the importance of the GI of a breakfast because of its potential impact on students' performance in school. As memory and attention are both crucial skills for students of any age, these findings are compelling.

The examined studies are of great importance because the results suggest that children and adults alike may benefit in terms of their memory performance and other forms of cognition if they select a breakfast lower in GI as opposed to a breakfast higher in GI. While the consumption of any form of caloric energy in the morning has been shown to provide the consumer cognitive benefits, this may be taken a step further by refining one's breakfast choice to a meal with a low GI for maximum, longer-lasting cognitive performance. The implications of such a selection could extend to include increased workplace productivity and enhanced performance in school.

Fuzzy-Trace Theory. While the studies discussed do lend focus to memory, it may be valuable to implement components of the fuzzy-trace theory of memory. Fuzzy-trace theory acknowledges dual-opponent processes in the formation of memories: verbatim processing and gist processing (Brainerd & Reyna, 2002; Brainerd, Reyna, & Zember, 2011), which are said to occur simultaneously when experiencing a stimulus and are stored as dissociated memory representations (Brainerd & Reyna, 2002). Verbatim memory traces refer to representations of the surface form of an experience (Brainerd & Reyna, 2002), such as specific facts and figures, for example. On the other hand, gist memory traces refer to one's interpretations of the meanings and patterns culminating from verbatim memory traces (Brainerd & Reyna, 2002). Examining verbatim and gist components of memory separately could be interesting because the nature of verbatim memories may require more effort to hold in one's memory. Gist memories, on the other hand, may be more closely-related to implicit memory processes that occur unconsciously and require less effort than verbatim memories.

Research concerning fuzzy-trace theory has tended to focus on applications such as false memories, decision-making tendencies, forgetting, and memory retrieval (e.g. Reyna & Brainerd, 1995; Blalock & Reyna, 2016). However, because the retrieval of both verbatim and gist memory traces contributes to one's overall memory performance (Brainerd & Reyna, 2002), it could be worthwhile to examine the impact of differing blood glucose levels on both of these processes given prior studies that show glucose to be important for general memory performance. The present study will seek to address this gap in the literature by directly measuring both verbatim and gist facets of memory.

Self-Control

While the specific definitions of self-regulation, self-control, and the mechanisms behind them are often debated among researchers, most acknowledge that these key processes are important and involved in many facets of life (Fujita, Trope, Liberman, & Levin-Sagi, 2006).

While many researchers use self-regulation and self-control as interchangeable terms, they may refer to unique phenomena (Baumeister, Vohs, & Tice, 2007). Self-regulation can be defined as the use of control to prevent the problematic consequences of following through with an impulse (Baumeister & Heatherton, 1996). On the other hand, self-control is a unique type of self-regulation in that the control exhibited in overriding an impulse must be conscious, whereas self-regulation could refer to homeostatic processes within the body (Baumeister et al., 2007). Applications of self-control are seen in many aspects of day-to-day life, such as attempts to curb an addiction, avoidance of overspending one's monetary resources, perseverance on difficult tasks, or adherence to a specific diet (Tice & Bratslavsky, 2000). When individuals are successful at maintaining their self-control, they are often met with copious benefits for themselves and those around them, such as reduced instances of drug abuse and criminal behavior, enhanced interpersonal relationships, improved mental and physical well-being, and school- or career-related achievements (Hagger, Wood, Stiff, & Chatzisarantis, 2010).

In a perfect world, self-control would constantly be maintained, as it often appears to result in an individual's prosperity; unfortunately, recent research has proposed that one's ability to maintain self-control is a limited, albeit renewable, resource (Baumeister & Heatherton, 1996). For instance, when presented with a plate containing radishes and a plate containing chocolate chip cookies, participants who were instructed to consume radishes and no cookies gave up sooner on an impossible drawing task than did participants who were instructed to consume only cookies or participants who were not presented with any food at all (Baumeister, Bratslavsky, Muraven, & Tice, 1998). This finding provides support for the assertion that one's self-control can be expended, as participants who were told to consume radishes and no cookies had to exert self-control to avoid eating the cookies. While this claim seems promising, the tendency for one's self-control to diminish following earlier acts of self-control, often referred to as "ego depletion" (Baumeister et al., 1998), is quite controversial and far from conclusive at the present time.

Ego depletion has previously been likened to a muscle during exercise, as the capacity for self-control appears to grow with practice and be renewed with rest (Hagger et al., 2010). Past studies have frequently implemented a dual-task paradigm to directly observe one's ability to maintain self-control. This design involves presenting participants with a primary task that demands self-control followed by a second task that also requires a large amount of self-control (Hagger et al., 2010). One study that employed such a structure found that participants who were asked to suppress their emotions during an unpleasant movie showed decreased stamina on a handgrip task when compared with participants who were allowed to show their emotions during the movie (Muraven, Tice, & Baumeister, 1998). Those who had to suppress their emotions were expected to rely on self-control to prevent a natural emotional reaction; therefore, the effort required by this task could have depleted their reservoirs of self-control and may explain why they experienced decreased stamina on the following handgrip task.

In another dual-task paradigm study, participants who made a series of deliberative decisions about several products (a process that relies on self-control) performed significantly worse on a cold pressor task than participants who simply gave their opinions about several advertisements (a process that does not rely on self-control) (Vohs et al., 2008). Participants' decreased performance on a cold pressor task, a task characterized by holding one's hand in painfully cold water for as long as possible, suggests a depletion of self-control that may have been caused by an effortful decision-making process in the first task.

A third study executing a dual-task paradigm found that participants who were asked to remember a string of 13 random digits and letters displayed significantly higher levels of aggression when provoked compared to participants who were only asked to remember three random digits (Bartlett, Oliphant, Gregory, & Jones, 2016). It is anticipated that participants who had to remember the long string of random numbers relied on higher levels of self-control in order to block out distractions and concentrate on remembering the numbers. The amount of effort necessary for this task may have depleted the participants' ability to control their emotions when provoked in a frustrating situation.

Taken together, the results of Muraven et al. (1998), Bartlett et al. (2016), and Vohs et al. (2008) offer compelling support for the assertion that self-control is a limited resource that can be depleted with use. However, as mentioned earlier, the concept of ego depletion remains frequently debated as some investigators (e.g. Lurquin et al., 2016) have experienced difficulty in replicating the results of studies that claim to have found an effect.

Since glucose serves as the main energy source for all brain functions (Marty et al., 2007; Steinbusch et al., 2015; Weiss, 1986), it is often assumed that glucose should also fuel self-control processes.[1] While most psychological events appear to use small and relatively inconsequential amounts of glucose, Gailliot & Baumeister (2007) hypothesize that the process of self-control might be unique relative to other psychological processes in that it may demand large amounts of energy for its functioning. As described in a study (Fairclough & Houston, 2004) earlier, participants who had to exhibit more self-control on an effortful Stroop task displayed a significantly larger decrease in blood glucose levels than participants who exhibited less self-control on an easier Stroop task. The effortful condition involved suppressing the

[1] The specific mechanism through which glucose brings about changes in cognitive functioning is still unclear (Gibson, 2007). Gibson (2007) presents several possible models that could explain this relationship.

impulse to push a button consistent with the name of a color presented on the screen instead of the actual color of the text on the screen. The easier Stroop task did not require suppression of an impulse because the color in which each word was presented mirrored the semantic meaning of the word. The significant decrease in blood glucose levels following the effortful condition suggests that self-control may require larger amounts of glucose than other brain processes. Researchers speculate that the expansiveness of self-control necessary for day-to-day life, including the roles of self-regulation, decision-making, and the ability to actively respond to life events could explain why self-control may demand more energy (and glucose) than other psychological processes (Gailliot & Baumeister, 2007).

Although the glucose model of self-control appears convincing, some researchers express disagreement with this concept. The findings of Fairclough and Houston (2004) are particularly interesting in light of brain imaging studies which have suggested that increases in blood flow to activated brain regions seldom alter the entire rate of blood flow throughout the brain, even during strenuous perceptual or motor tasks (Raichle & Mintun, 2006). Compared to the total energy consumption of the brain, relative energy consumption in a certain area of the brain during a specific task can be a very small percentage of the brain's total energy consumption — as low as 1% (Raichle & Mintun, 2006), weakening the hypothesis that brain uptake of glucose from the blood can reduce blood glucose levels in the rest of the body (Messier, 2004). Furthermore, since the brain in its entirety tends to use one-fourth of a calorie each minute (Clarke & Sokoloff, 1999), the caloric cost of a self-control task should be even smaller, relying upon a minute and possibly trivial amount of glucose (Kurzban, 2010).

Despite the major contradictions present in the literature, quite a few studies have found evidence of self-control as mediated by glucose. Investigators (Gailliot et al., 2007) measured participants' blood glucose levels after an initial self-control task and observed that those who had low levels of glucose persisted less on an impossible figure-tracing task, even after controlling for participants' starting blood glucose levels. These findings remained robust even when the initial self-control task was manipulated to be (1) an attention-control task, (2) a Stroop task, or (3) an emotion-regulation task (Gailliot et al., 2007) and connote that a lower level of blood glucose may have led to a diminished level of cognitive resources available to remain focused on the task.

In a study of children, it was observed that schoolchildren who consumed a glucose drink performed better on a reaction time task than the schoolchildren who consumed a placebo (Benton, Brett, & Brain, 1987). Since a task relying on reaction time requires self-control to avoid becoming distracted by other environmental stimuli, it is possible that glucose enhanced the performance ability of these children by preventing a depletion in self-control. After they completed the reaction time task, the children were instructed to play a very challenging computerized game in which speed and concentration were important. The children in the glucose drink condition were more likely to maintain robust quiet concentration during the challenging game, whereas the children in the placebo drink condition were more likely to talk, show signs of frustration, and fidget in the later trials of the game (Benton et al., 1987). This result is crucial because the differences in performance between the two conditions imply that the reaction time task was especially mentally taxing for the children who received the placebo drink and could indicate that the presence of glucose in the glucose drink condition "replenished" children's ability to maintain self-control and composure.

While the studies discussed in this section (Baumeister et al., 1998; Gailliot et al., 2007; Muraven et al., 1998; Bartlett et al., 2016; Benton et al., 1987) act as a cornerstone for the implications of self-control and its relationship with blood glucose levels, additional skepticism has been garnered surrounding the reported significant effects of glucose on self-control. One analyst (Schimmack, 2012) concluded that the statistical power in the monumental glucose studies performed by Gailliot et al. (2007) was too low for the number of significant results they indicated. Therefore, it is possible that these results were swayed by publication bias or *p*-hacking (Vadillo, Gold, & Osman, 2016), which can be characterized as the manipulation of *p*-values through methods such as excluding certain outliers or stopping data collection prematurely in order to obtain a significant result (Leggett, Thomas, Loetscher, & Nicholls, 2013). Furthermore, an analysis of the significant *p*-values obtained from a collection of different studies examining the effect of glucose on self-control revealed suspicious results. The distribution of the p-values reported by these studies resembled a flat distribution instead of the typical right-skewed distribution expected when examining a true effect (Vadillo et al., 2016). A flat distribution is characterized by the tendency for significant p-values to be equally likely and is reflective of a nonexistent effect, whereas a right-skewed distribution of p-values is indicative of an effect because most experiments examining an effect should obtain very small p-values (Vadillo et al., 2016).

In addition to the statistical criticism, many researchers have experienced difficulty in replicating the results of studies that indeed found a significant relationship of glucose on self-control. After obtaining an especially large sample size to counteract small-study effects that likely occurred in other studies, Lurquin and colleagues (2016) observed no effect of ego depletion following a commonly-used video-viewing task. In this task, participants viewed a silent video of a woman talking and were asked to inhibit the impulse to give attention to distracting words that flashed at the bottom of the screen. Another study (Kelly, Sünram-Lea, &

Crawford, 2015) failed to observe any benefit of glucose consumption on an antisaccade task following an initial Stroop task. Antisaccade task performance was determined by how quickly and accurately participants directed their eyes away from a circular target that appeared on a computerized screen. Although this task relies on self-control to remain focused on exhibiting an accurate and quick response, the performance of participants who consumed a glucose drink did not differ from those who consumed a placebo drink (Kelly et al., 2015). This result indicates that the presence or absence of glucose did not affect self-control.

Findings from yet another experiment (Job, Walton, Bernecker, & Dweck, 2013) further cloud a direct understanding of the relationship between glucose and self-control. Job and colleagues (2013) identified that regardless of whether they consumed a glucose drink or a glucose-free placebo, participants who believed willpower was an unlimited resource performed better on a Stroop task than those who believed willpower was a limited resource. Interestingly, participants in the placebo condition who believed willpower was a limited resource performed significantly worse on the Stroop task than those in the glucose drink condition who believed willpower was limited. Since participants were made aware of the type of drink they consumed, Job and colleagues (2013) speculate that participants who believed willpower was a limited resource came to rely more heavily on glucose to help fuel their performance in the Stroop task after completing an initial difficult task. The outcomes of this study purport a possible interplay between one's mindset and resulting self-control that cannot be explained by glucose alone.

The combination of numerous studies with extremely inconsistent results along with possible instances of publication bias and *p*-hacking serve to hinder a clear understanding of self-control and its relationship with glucose. While asserting that all studies that found an effect of glucose on self-control were subject to *p*-hacking is quite bold, the evidence presented in favor of this claim is strongly backed by statistical analyses. On the other hand, it could be possible that the effect of ego-depletion is so small that it simply does not always manifest itself in statistical results; hence, a considerable reason for the many occurrences of significant effects and effects that are not significant. It is one goal of the present study to assist in clarifying whether glucose manipulations can significantly influence self-control processes in a manner as unbiased as possible.

Mood and Affect

The impact of general breakfast consumption on one's subjective well-being has been studied in the literature. Past research has illustrated several benefits of regular breakfast consumption upon one's wellbeing as opposed to regular breakfast-skipping, such as decreased levels of mental health problems and lower levels of stress, anxiety, and depression (Williams, 2014). For instance, in a 14-day study of children who either consumed no breakfast or consumed a high carbohydrate cereal of Corn Flakes, Rice Krispies, or Rice Krispie Multi-Grain each day, children who ate cereal reported higher levels of alertness and lower levels of depression, emotional distress, and fatigue, both during the seventh day and during the 14th day (Smith, 2010). A similar effect has also been observed in adults. In an observational study, regular breakfast eating habits in adults were associated with decreased levels of stress, depression, and emotional distress, as opposed to adults who did not habitually eat breakfast (Smith, 1998). Although those who regularly consumed breakfast cereal were also more likely to take part in other health-promoting behaviors such as eating a generally healthier diet, smoking less, and ingesting less alcohol, it was noted that these other health-promoting behaviors could not entirely account for the positive effects observed on mood (Smith, 1998). This distinction is important because it insinuates a particular relevance of breakfast on one's mood state; however, it is still unclear as to whether eating breakfast could enhance one's mood state or if those who have better mood states tend to breakfast more often (Smith, 1998).

This research has focused heartily on eating breakfast in general rather than the mood effects of specific contents of a breakfast; however, other researchers have taken to directly observing the effect of carbohydrates. GI aside, it has been noted that the direct effect of carbohydrates on an individual's mood is dependent on the amount of time following consumption of the carbohydrates (Benton & Nabb, 2003). Short-term studies have identified a reported increase in energy 15, 30, or 60 minutes following general carbohydrate consumption and a decrease in subsequent energy two hours after carbohydrate consumption (Benton & Nabb, 2003). This could be attributed to the typical rise and fall of one's blood glucose levels in response to the consumption of carbohydrates. When participants' blood glucose levels were directly manipulated with a glucose clamp, a state of hypoglycemia, or low blood glucose, was associated with a state of more negative affect, an increase in tense arousal, and a decrease in energetic arousal as opposed to having a state of normal blood glucose levels (Gold, MacLeod, Frier, & Deary, 1995). These pieces of research further emphasize a possible direct effect of glucose on one's mood state.

These parameters have been expanded upon by examining mood as a function of the GI respective to the meal. In a six-month study of participants who were trying to lose weight, those who consumed a high GL diet showed more detrimental changes in self-reported depression, whereas those who consumed a low GL diet showed no significant changes in response to self-reported depression (Cheatham et al., 2009). A similar effect on mood was found in another study, where participants who consumed a diet high in GL displayed significantly higher scores on total mood disturbance (computed by combining scores for the

POMS subscales of tension-anxiety, depression-dejection, anger-hostility, fatigue-inertia, and confusion-bewilderment, along with the reverse-scored vigor-activity subscale), fatigue, and depressive symptoms than did participants who consumed a low GL diet after 28 days (Breymeyer, Lampe, McGregor, & Neuhouser, 2016). Furthermore, a survey found that postmenopausal women who indicated having a diet higher in GI were more likely to suffer from depression as opposed to those who indicated having a lower GI diet (Gangwisch et al., 2015). These findings provide strong support for the mood-related benefits of maintaining a long-term diet lower in GI.

Mood-related benefits of a low GI meal have also been observed in a short-term time frame. When healthy male participants were provided with a breakfast containing a high ratio of complex carbohydrates to simple carbohydrates (typical of a low GI), they felt significantly less fatigued three hours later than those who consumed a breakfast containing a high ratio of simple carbohydrates to complex carbohydrates (typical of a high GI) (Pasman, Blokdijk, Bertina, Hopman, & Hendriks, 2003). This finding provides support for the consistent effects of GI after the passage of a variety of time periods.

While the study by Gold et al. (1995) explores the immediate effects of a reduction in blood glucose levels, its resulting symptoms of increased negative affect, tense arousal, and decreased energetic arousal are consistent with the mood results found in long-term studies of those who continually consumed either a breakfast or maintained a diet that relied on high GI foods (e.g. Breymeyer et al., 2016; Cheatham et al., 2009; Gangwisch et al., 2015). These consistencies might be attributed to the sharp decrease in blood glucose levels of these participants following each sharp increase derived from a high GI meal. Since these participants continued to consume high GI meals over long periods of time, they likely frequently experienced sharp increases and subsequent rapid decreases in blood glucose levels, which may account for the decline in mood state that was observed by the researchers.

Additional characteristics of one's diet have been identified as having a possible effect on mood states. Dietary fiber content, for example, has been argued to influence mood states and behavior because its presence in one's dietary regime is an indicator of other nutrients and antioxidants associated with well-being (Logan, 2006). In one study, it was noted that after both seven and 14 days, participants who consumed a high-fiber breakfast expressed lower levels of fatigue and emotional distress compared with those who consumed a low-fiber breakfast (Smith, Bazzoni, Beale, Elliott-Smith, & Tiley, 2001). Gangwisch et al. (2015) also found that diets containing a higher fiber content were associated with lower instances of depression in postmenopausal women. Since a high fiber content present in a food is associated with a lower GI (Balay, 2009; Gangwisch et al., 2015), these findings could relate to other mood effects specific to a low GI. As mentioned earlier, a low GI correlates with a decreased level of fatigue, mood disturbance, and emotional distress (Breymeyer et al., 2016; Cheatham et al., 2009; Gangwisch et al., 2015).

In contrast, diets high in added sugar increased the chances of depression in postmenopausal women (Gangwisch et al., 2015). The finding by Gangwisch et al. (2015) is consistent with the tendency for foods with high amounts of added sugar to have a higher GI (Balay, 2009). As described earlier, the observed consequences of a high GI diet on mood include increased levels of depression (Cheatham et al., 2009; Gangwisch et al., 2015), fatigue (Pasman et al., 2003), and negative affect (Breymeyer et al., 2016).

Although these findings tend to reveal the benefits of following dietary patterns consistent with a diet relying on low GI foods, one study served as a particularly interesting contrast. Among participants who were randomly assigned to one of several “equi-caloric” breakfast conditions, those who consumed a low-fat, high-carbohydrate (LFHC) breakfast experienced lower levels of fatigue and uneasiness as opposed to those who consumed either no breakfast, a medium-fat, medium-carbohydrate (MFMC) breakfast, or a high-fat, low-carbohydrate (HFLC) breakfast (Lloyd et al., 1996). This result is especially intriguing in light of prior research regarding the positive influence of low GI foods on mood states. Although Lloyd and colleagues (1996) did not explicitly provide GI values for each of the three breakfasts, because the LFHC breakfast in the study contained a larger quantity of added sugars, it is reasonable to expect that the GI value was the highest for this breakfast. The authors (Lloyd et al., 1996) speculated that their results could be attributed to the fact that the participants tended to consume a breakfast similar in macronutrient composition to the LFHC breakfast in their everyday lives, and that a deviation from one’s normal habits could result in a decreased mood state. It remains unclear how such results can be explained in relation to studies that have shown opposite effects. Lloyd and colleagues (1996) suspect that that methodological differences between studies may account for disparities and that the effect of breakfast composition on mood states could be small.

Though the reviewed research regarding mood states generally suggest that a diet relying on low GI foods could enhance one’s subjective well-being, additional research is needed in order to better comprehend the relationship between mood states and blood glucose levels. In many of the studies discussed (e.g. Breymeyer et al., 2016; Cheatham et al., 2009; Gangwisch et al., 2015; Pasman et al., 2003; Smith et al., 2001) the observed decline of mood states related to consuming high GI breakfasts or partaking in high GI diets provides support that glucose could play a role in emotion regulation. Some research indeed suggests that emotion regulation is closely tied with self-control (Bartlett et al., 2016; Gailliot & Baumeister, 2007). For example, after participants were asked to suppress the impulse to read the text at the bottom of a six-minute video, they listed more death-related thoughts regarding an ambiguous painting as opposed to participants who were allowed to watch the video normally (Gailliot, Schmeichel, & Baumeister, 2006). This interesting proposition suggests an intimate relationship between self-control and mood states. Since some previous, though disputed, research involving ego-depletion proposes that self-control may be reliant on glucose, it is possible that the decreased levels of emotion regulation in individuals who consume high GI foods is attributed to weakened self-control by the crash in blood glucose levels that tends to accompany these kinds of foods.

The Present Study

The tendency of breakfast-eaters to engage in other health-promoting behaviors makes it difficult to determine whether consuming breakfast in the morning is superior to skipping it; however, the examined research puts forth strong evidence that if one is to consume breakfast in the morning, the type of breakfast selected matters. The present study seeks to examine the impact of high GI and low GI breakfasts on gist and verbatim memory, self-control, and mood state. As discussed earlier, while previous research has examined the effect of the GI of breakfast on memory, there is a gap in the literature regarding the effect of GI on specific memory components such as gist and verbatim memory. Research in this area could serve to enhance the literature in regard to the specific mechanisms of memory that might be affected by differing levels of glucose in one's breakfast. Since previous research has indicated a favorable effect of low GI breakfasts on effortful memory task performance (e.g. Benton et al., 2002; Ingwersen et al., 2007), one hypothesis of the present study is that participants who consume a low GI breakfast will display superior performance on verbatim measures of memory performance as opposed to participants who consume a high GI breakfast. On the other hand, due to its potential overlap with implicit memory and less effortful nature, it is predicted that performance on gist measures of memory will not differ between participants who consume either a high GI or a low GI breakfast.

In addition to identifying a positive influence of foods low in GI on memory performance, other investigators have propounded that glucose could play a crucial role in self-control functioning (e.g. Benton et al., 1987; Gailliot et al., 2007). Despite the sizeable body of research focusing on self-control and its relationship to an individual's blood glucose levels, findings have been quite inconsistent. The discrepancies observed in this area of research have resulted in confusion and skepticism about the role of glucose in precluding self-control. Further investigation of this phenomenon in the present study will enhance the evidence base of the current literature and may aid in clarifying whether or not glucose manipulations influence self-control. To date, there has not yet been an examination of the GI of a morning meal and its resulting influence of self-control later in the day; therefore, the present study will act as a pioneer for future investigation in this area. Since a low GI meal results in more sustained blood glucose levels as opposed to the sharp blood glucose increases and decreases typically following a high GI meal, it is hypothesized that participants who consume a low GI breakfast will display improved levels of self-control than will participants who consume a high GI breakfast.

Mood-related research involving GI manipulations among the literature have revealed fairly consistent results, although it appears that the majority of this research has addressed long-term diets as opposed to the manipulation of one breakfast. Thus, the present study may contribute to this area. Since a high GI diet or meal has been shown to result in increased levels of fatigue (Breymeyer et al., 2016; Pasman et al., 2003), mood disturbance (Breymeyer et al., 2016), and depressive symptoms (Breymeyer et al., 2016; Cheatham et al., 2009; Gangwisch et al., 2015), it is hypothesized that participants who consume a high GI breakfast will report higher levels of negative mood states than those who consume a low GI breakfast in the present study.

Method

Participants

The participants included 59 male and female college-aged students (16 males, 42 females, and one who did not disclose their biological sex), ranging from 18 to 22 years old (M = 20.1695 years old). The reported ethnicities of the participants included Asian (11 participants; 18.6%), Black or African American (eight participants; 13.6%), and Caucasian (38 participants; 64.4%), with two participants indicating that they preferred not to answer (3.4%) and one participant indicating they were of a race not listed (1.7%). Participation in the study was spread across the fall (N = 26) and spring (N = 33) semesters of the 2017-2018 school year.

All participants were screened for diabetes and any dietary restrictions that may have prevented their consumption of cereal and either dairy milk or soy milk. Such restrictions included, but were not limited to, gluten intolerance and celiac disease.

Participants were asked not to consume anything other than the provided breakfast and water on the day of testing until after they had completed the experiment. This parameter served to prevent participants' blood glucose levels from being altered by additional food items or snacks that were not controlled for. In addition, participants were asked to avoid ingesting caffeine until the conclusion of the study. Although there is limited research regarding the impact of caffeine on self-control, caffeine has been shown to improve explicit memory performance in college students during the morning (Sherman, Buckley, Baena, & Ryan, 2016).

Furthermore, caffeine intake has been shown to affect mood by its association with increased levels of depression, anxiety, and stress in an individual (Rogers, 2007).

Materials

Breakfast materials included a single serving of cereal (either one single-serving box [23g] of Kellogg's Corn Flakes ["Corn Flakes"] or one serving [30g] of Kellogg's All-Bran Bran Buds ["All-Bran"]) and eight fluid ounces of either 2% milk ("reduced-fat milk") or Silk Original Soymilk. The nutritional characteristics of these cereals are presented in Table 1. Corn Flakes was chosen for use in the present study because it has a high GI (Atkinson et al., 2008). On the other hand, All-Bran has a low GI (Atkinson et al., 2008) and has been used in several studies that have demonstrated benefits associated with a low GI, high fiber cereal on measures cognitive performance (e.g. on effortful memory processes, Ingwersen et al., 2007) and on mood state (e.g. lower levels of fatigue, Smith et al., 2001). In line with a few previous studies (e.g. Lloyd et al., 1996; Mahoney, Taylor, Kanarek, & Samuel, 2004; Pasman et al., 2003; Smith, 2010) caloric values for both high GI and low GI breakfast conditions were kept similar.

Table 1

Nutritional characteristics for one serving of Corn Flakes and All-Bran.

	GI	GL	Serving	kcal	Carbohydrates	Protein	Fat	Fiber
Corn Flakes	81	15	23	80	19	2	0	<1
All-Bran	44	5	30	80	24	3	1	13

Note. Serving = weight of cereal in grams. Carbohydrates, protein, fat, and fiber, are all presented in grams. GI values were obtained from an international table of glycemic indexes (Atkinson et al., 2008).

Reduced-fat milk was used in the present study, as other research in the literature tended to include either unspecified, skim, or semi-skimmed milk with the breakfast provided to their participants (Breymeyer et al., 2016; Ingwersen et al., 2007; Mahoney et al., 2004; Pasman et al., 2003; Smith, 2010). Although the GI of milk itself is low (Atkinson et al., 2008), the frequency with which milk is included in the prior research designs in both high GI and low GI conditions suggests that the impact milk has on the GL of these conditions is not large.

In order to increase the number of participants who could contribute to the present study, a soy milk option was made available for those who had a preference or need for a dairy-free milk alternative. Plain soy milk was chosen because it tends to have a macronutrient profile similar to reduced-fat 2% milk. Furthermore, like dairy milk, plain soy milk has also been found to have a low GI (Atkinson et al., 2008; Blair, Henley, & Tabor, 2006); therefore, the glycemic response of participants who consume soy milk with their breakfast should not differ largely from the glycemic response of participants who consume dairy milk with their breakfast.

The cognitive measures used in the present study were chosen based on their replicability and successful or frequent usage in the literature. The gist and verbatim memory manipulation used in Flores, Hargis, McGillivray, Friedman, & Castel, (2017) was selected for the present study on account of its prior success in measuring performance differences between gist and verbatim memory among participants. Moreover, the authors generously provided the materials used in manipulation. Testing was facilitated because these materials could conveniently be used in any silent setting, given that a computer was available. These materials also provided a direct comparison of gist and verbatim memory performance in the context of one task. Present in the PowerPoint were 12 categories of common food items found at the grocery store, where each category represented a specific type of food item (e.g. orange juice, yogurt, jam, etc.). Each category contained two different images representing two unique brands (e.g. in the orange juice category, one image showed a carton of Minute Maid orange juice, whereas the second image showed a carton of Tropicana orange juice). The first half of the PowerPoint presented the images one at a time, allotting five seconds per slide. Images were centered and accompanied by a price just above the picture. The second half of the PowerPoint presented both images in each of the categories side-by-side without their prices. Participants were allowed to advance through these slides at their own pace.

Within the literature, the Stroop task has often been used for measuring self-control in participants and it has been frequently implemented in examining performance differences as a function of one's blood glucose levels (Benton, et al., 1994; Gailliot et al., 2007; Gailliot & Baumeister, 2007); therefore, this task appeared appropriate for examining self-control in the present study. An online version of the Stroop task was selected for the present study and was obtained from http://opencoglab.org/stroop/. This task involved presenting the name of a color on a computer screen and required one to press the key on a keyboard that corresponded to the first letter of the color in which each word was presented (e.g. if the word "green" appeared and the color of the text was orange, one must press the "o" key to advance to the next trial) as quickly and as accurately as possible. The task instructed that one place his or her fingers on the spacebar and the "r", "g", "b", "o", and "p" keys. The task was comprised of 85 trials.

The Positive and Negative Affect Schedule (PANAS) was used to assess the mood states of the participants in the present study. This measure was chosen because the PANAS has been determined to provide a reliable measure of positive and negative affect in large, non-clinical samples (Crawford & Henry, 2004). In addition, the PANAS has been a widespread choice within the literature to measure mood states in those participating in experiments which seek to influence participants' stress responses (Rossi & Pourtois, 2012), which is a characteristic that is reflective of the present study. The questionnaire consisted of 20 unique affective adjectives (e.g. "Irritable", "Attentive", "Enthusiastic", etc.), where participants rated the extent to which they felt each adjective described them at the present moment. Ratings were based on a five-point scale, with one being "Very slightly or not at all" and five being "Extremely".

Additional materials that were incorporated into the experiment were a response sheet to record answers from the memory manipulation PowerPoint, a demographics and manipulation check questionnaire, and a computer to display the Stroop test, PowerPoint presentation, and questionnaires.

Procedure and Design

The day before the scheduled experiment, participants met with the experimenter to pick up the breakfast assigned to them. Participants were given eight fluid ounces of either 2% milk or Silk Original Soymilk, depending on their preference. Participants were randomly assigned to receive either one single-serving box of Kellogg's Corn Flakes (high GI/medium GL condition) or one serving of Kellogg's All-Bran Bran Buds (low GI/medium GL condition). Participants were instructed to consume their provided breakfast by 9:00 am the next morning and to abstain from supplementing their assigned breakfast, eating any snacks, and drinking coffee on the morning of the experiment until after they had completed testing.

Participants were tested roughly two hours following breakfast consumption. This two-hour interval was selected because a two-hour time frame has been used as a yardstick within the literature to gauge the GI of a food item and allows the peak of blood glucose levels in response to eating the food item to be reached (Foster-Powell et al., 2002). Although one study was unable to find significant differences in memory performance between high GL and low GL breakfasts until two and a half hours following breakfast consumption (Benton et al., 2003), several studies have found significant cognitive changes within two hours of high GL or low GL breakfast consumption (Ingwersen et al., 2007; Mahoney et al., 2005). Therefore, for the purposes of the present study, a two-hour minimum between breakfast consumption and cognitive testing was chosen because it would allow for the previously-observed minimum amount of time necessary for blood glucose levels to potentially translate to differences in cognition.

Upon entering the lab at 11:00 am on the morning of the experiment, participants were directed to a computer to take part in the memory manipulation PowerPoint used in Flores et al. (2017). During the testing portion of this manipulation, participants reported on a piece of paper with a pen the prices of each item along with a separate indication of which item was cheaper for each of category of food. After concluding the memory task, participants completed an online Stroop task followed by the PANAS questionnaire. Finally, participants completed a brief demographics and manipulation check questionnaire online. The manipulation check was designed to gauge how well participants adhered to the instructions provided regarding the breakfast provided to them. This questionnaire included several questions assessing which cereal participants were given, whether participants ate anything in addition to the cereal and milk, when participants ate that morning, and if the participant in question typically drinks coffee in the morning.

Participants were then debriefed and thanked for their time. Participants earned SONA credits and bonus points for a class or were purchased a snack of their choice for their participation in the study.

Analyses were performed on all dependent measures using independent t-tests between breakfast conditions. The study facilitated a quasi-experimental design, as the data collection process included participants who were tested at the end of the fall semester and at the beginning of the spring semester. Since it is possible that the students experienced different amounts of stress and academic burdens depending on the time of semester, the dependent measures of the present study were also evaluated using two-way factorial analysis of variances between breakfast conditions and semester.

Results

Demographic Variables

Random assignment was used to determine the breakfast condition in which each participant would partake. The Corn Flakes condition included 29 participants and the All-Bran condition included 30 participants. Several chi-square tests of independence were performed to examine the validity of the random assignment of participants to breakfast condition. These analyses revealed that there was no significant relation between breakfast condition and participants' biological sex, X^2 (2, N = 59) = 2.08, p = 0.354, age, X^2 (4, N = 59) = 2.36, p = 0.669, ethnicity, X^2 (2, N = 59) = 3.06, p = 0.217, or race, X^2 (4, N = 59) = 2.58, p = 0.63. Therefore, the random assignment of participants was successful, because the distributions of sexes, ages, ethnicities, and races were comparable between the Corn Flakes and All-Bran conditions.

Gist Measures of Memory

Gist memory scores were calculated by determining the number of categories (out of 12) in which a given participant correctly circled on the response sheet which item in each category was cheaper. Data from three of the participants were excluded because they appeared to misunderstand this portion of the instructions and did not indicate with a circle which items were cheaper. An independent samples t-test was run to compare the gist memory performance between participants in the Corn Flakes and All-Bran conditions. There was no significant difference in gist memory scores as reported for Corn Flakes ($M = 9.11$, $SD = 1.73$) and All-Bran ($M = 8.71$, $SD = 1.78$) conditions, $t(54) = -0.84$, $p = 0.406$; as expected, gist memory performance was similar between Corn Flakes and All-Bran conditions.

Gist memory data from 11 participants indicated contradictory gist-verbatim memories. A contradiction refers to an instance in which a participant circled “Item A” as being cheaper (gist memory) but provided a higher price guess for “Item A” than “Item B” (verbatim memory). Since these contradictions may have been merely unintentional, a secondary analysis was run with “corrected” gist answers, which were obtained by adjusting one’s gist memory score to be congruent with their verbatim memory price estimate. The corrected scores were then analyzed in conjunction with the scores of the other participants that were not contradictory. An independent samples t-test was used to compare the corrected gist memory scores between Corn Flakes and All-Bran conditions. There was no significant difference in corrected gist memory scores between Corn Flakes ($M = 9.14$, $SD = 1.74$) and All-Bran ($M = 8.82$, $SD = 1.74$) conditions, $t(54) = -0.69$, $p = 0.492$; therefore, even accounting for gist-verbatim corrections, gist memory performance was comparable between Corn Flakes and All-Bran conditions.

Verbatim Measures of Memory

Verbatim memory error scores were determined by computing the absolute value of the difference between the remembered price of each item and the true price of the item for all 24 items. All 24 absolute values were averaged together to create a mean absolute value of error for each participant. This indicated the average amount of money by which each participant deviated from the true price of the item. Of the 59 participants, a group of 11 participants misunderstood the instructions and did not provide prices for all 24 items. The mean absolute values of error were calculated for these participants based on the prices they did provide. An independent samples t-test was run to compare the mean absolute values of error between Corn Flakes and All-Bran conditions. Verbatim error scores between participants in the Corn Flakes (*M* = 0.74, *SD* = 0.22) and All-Bran (*M* = 0.77, *SD* = 0.29) conditions were not significantly different, *t*(57) = 0.41, *p* = 0.687. Since these results indicate that verbatim memory performance was the same between conditions, the hypothesis that those who consumed All-Bran would perform better on verbatim measures was not supported.

Verbatim memory performance was also evaluated in accordance with the analysis strategy used by Flores and colleagues (2017). The frequency with which each participant accurately guessed the exact price of an item was determined. This value reflected the total number of guesses in which the participant was correct (out of 24 possible guesses). An independent samples t-test was performed to compare the mean frequency of accuracy between the Corn Flakes and All-Bran conditions. Verbatim accuracy between participants in the Corn Flakes (*M* = 2.10, *SD* = 1.52) and All-Bran (*M* = 2.87, *SD* = 2.19) conditions was not significantly different, *t*(57) = 1.55, *p* = 0.127. This finding did not support the hypothesis that those who consumed All-Bran would perform better on verbatim memory performance.

Stroop Task

Results of the Stroop task are summarized in Table 2. The Stroop task recorded the reaction times (in milliseconds) of each participant both when the word and color of the word were congruent and when these stimuli were incongruent. Data from one participant was excluded from the congruent and incongruent Stroop task analyses because the participant indicated that he was colorblind. An independent samples t-test was used to compare the mean congruent reaction times of Corn Flakes and All-Bran conditions. As expected, there was no significant difference in congruent reaction times between those in the Corn Flakes and All-Bran conditions, $t(56) = 0.99$, $p = 0.322$. An independent samples t-test was also used to compare the mean incongruent reaction times of Corn Flakes and All-Bran conditions. No significant difference in reaction times between Corn Flakes and All-Bran conditions was observed, $t(56) = 1.51$, $p = 0.137$; therefore, there is no evidence to support the hypothesis that participants who consumed All-Bran would perform better on the portion of the Stroop task requiring self-control.

Table 2

Means and standard deviations for Stroop task reaction times (in milliseconds) for Corn Flakes and All-Bran conditions.

	Congruent Stimuli		Incongruent Stimuli	
	M	*SD*	*M*	*SD*
Corn Flakes	941.69	184.91	1197.69	280.99
All-Bran	991.10	191.76	1312.34	297.18

Note. Congruent Stimuli = reaction time when the color of a word and semantic meaning of the word matched; Incongruent Stimuli = reaction time when the color of a word and semantic meaning of the word did not match.

PANAS Questionnaire

Results of the PANAS questionnaire analysis are presented in Figure 1. The PANAS was scored by categorizing each question as a measure of positive or negative affect and then determining a participant's average score for both categories. The means of the average positive affect scores of Corn Flakes and All-Bran conditions were compared using an independent samples t-test. A significant difference in average positive affect score was found between Corn

Flakes (*M* = 2.75, *SD* = 0.73) and All-Bran (*M* = 2.33, *SD* = 0.70) conditions, $t(57) = -2.21$, $p = 0.031$. Contrary to the hypothesis, participants in the Corn Flakes condition experienced greater levels of positive affect than participants in the All-Bran condition. An independent samples t-test was also used to compare the means of the average negative affect scores of Corn Flakes and All-Bran conditions. No significant difference in average negative affect score was found between Corn Flakes (*M* = 1.54, *SD* = 0.55) and All-Bran (*M* = 1.45, *SD* = 0.59) conditions, $t(57) = -0.59$, $p = 0.557$. Participants in the Corn Flakes and All-Bran conditions reported similar levels of negative affect, contrary to the prediction that participants in the Corn Flakes condition would experience higher levels of negative affect.

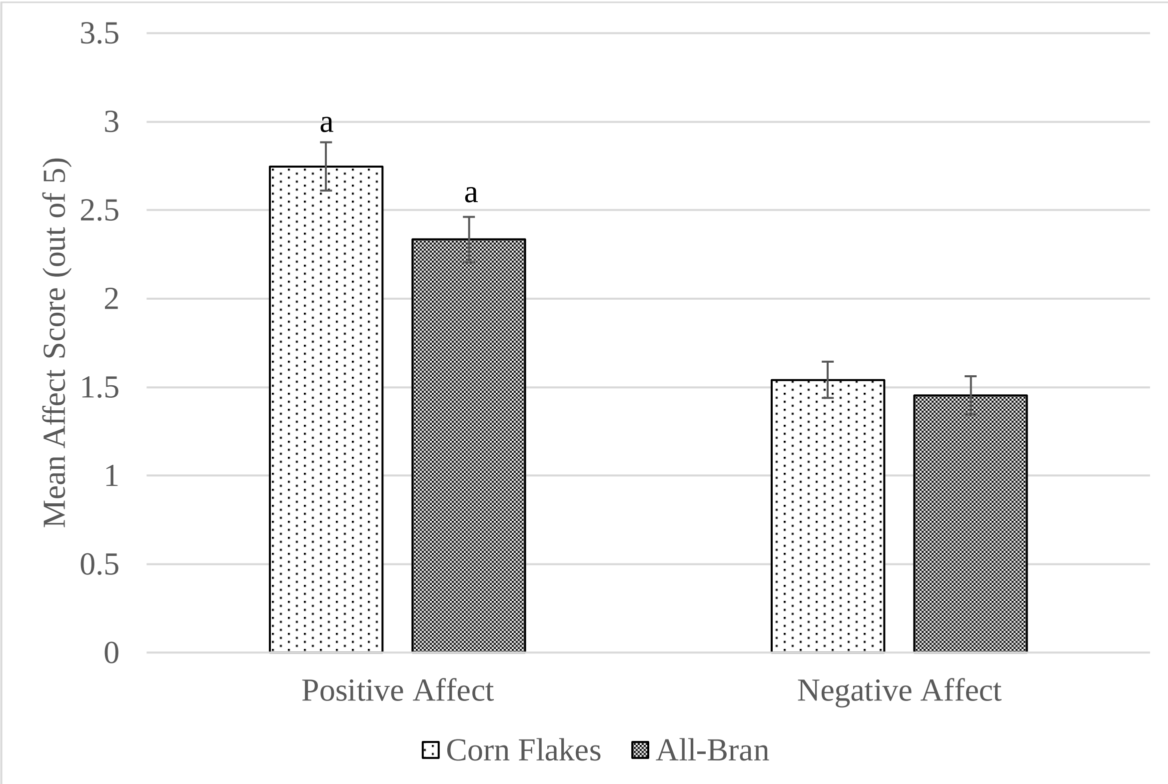

Figure 1. Cereal condition and mean affect score for positive and negative affect subscales of the PANAS. Standard error bars are included. a = significant difference ($p < 0.05$) between mean affect scores.

Semester Effects

The data collection process took place during the end of the fall semester and the beginning of the spring semester. The distribution of participants between the two breakfast conditions throughout the testing duration is summarized in Table 3.

Table 3

Number of participants in each condition who took part in the study during the fall and spring semesters.

	Fall Semester	Spring Semester
Corn Flakes	13	16
All-Bran	13	17
Total	26	33

Gist Measures of Memory. A two-way factorial analysis of variance was performed to examine the effect of semester and breakfast condition on uncorrected gist measures of memory. The semester level contained two levels: fall semester and spring semester, and the breakfast condition level contained two levels: Corn Flakes and All-Bran. Neither the Corn Flakes condition, F (1, 52) = 0.01, p = 0.934, η^2 = 0.00, nor the All-Bran condition, F (1, 52) = 0.30, p = 0.584, η^2 = 0.006, revealed a significant effect of semester. Therefore, the gist memory performance of those who ate Corn Flakes in the fall (M = 9.08, SD = 1.75) did not differ from the gist memory performance of those who ate Corn Flakes in the spring (M = 9.13, SD = 1.77). Likewise, the gist memory performance of participants who consumed All-Bran in the fall (M = 8.50, SD = 2.15) did not differ from the performance of those who consumed All-Bran in the spring (M = 8.88, SD = 1.50). Pairwise comparisons of Corn Flakes and All-Bran conditions in the fall, F (1, 52) = 0.65, p = 0.423, η^2 = 0.012, and spring, F (1, 52) = 0.16, p = 0.689, η^2 = 0.003, revealed no significant interaction. Therefore, the gist scores between participants in both breakfast conditions did not differ when compared between the fall and spring semesters.

Furthermore, another two-way factorial analysis of variance revealed no effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on corrected gist measures of memory in Corn Flakes, F (1, 26) = 0.00, p = 0.976, η^2 = 0.00, or All-Bran conditions, F (1, 26) = 0.03, p = 0.854, η^2 = 0.001. Corrected gist performance neither differed between Corn Flakes eaters in the fall (M = 9.15, SD = 1.73) and the spring (M = 9.13, SD = 1.81) nor All-Bran eaters in the fall (M = 8.75, SD = 2.05) and the spring (M = 8.88, SD = 1.54). Pairwise comparisons of Corn Flakes and All-Bran conditions in the fall, F (1, 52) = 0.32, p = 0.572, η^2 = 0.006, and spring, F (1, 52) = 0.16, p = 0.687, η^2 = 0.003, revealed no significant interaction. Therefore, the corrected gist scores between participants in both breakfast conditions did not differ when compared between the fall and spring semesters.

Verbatim Measures of Memory. The effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on verbatim memory error scores was investigated using a two-way factorial analysis of variance. No effect of semester was found on verbatim error scores in either the Corn Flakes condition, F (1, 55) = 0.27, p = 0.607, η^2 = 0.005, or the All-Bran condition, F (1, 55) = 1.27, p = 0.266, η^2 = 0.022. The verbatim error scores of those who ate Corn Flakes in the fall (M = 0.72, SD = 0.21) did not differ from those who ate Corn Flakes in the spring (M = 0.77, SD = 0.23). Furthermore, the verbatim error scores in participants who ate All-Bran did not differ, regardless of whether they participated in the fall (M = 0.83, SD = 0.32) or the spring (M = 0.72, SD = 0.27). Pairwise comparisons of the verbatim error scores of Corn Flakes and All-Bran conditions in the fall, F (1, 55) = 1.30, p = 0.26, η^2 = 0.023, and spring, F (1, 55) = 0.21, p = 0.646, η^2 = 0.004, revealed no significant interaction. Therefore, the verbatim memory performance between participants in both breakfast conditions did not differ when compared between the fall and spring semesters.

The effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on verbatim memory accuracy scores were also evaluated with a two-way factorial analysis of variance. No effect of semester was found on verbatim accuracy scores in either the Corn Flakes condition, F (1, 55) = 0.21, p = 0.648, η^2 = 0.004, or the All-Bran condition, F (1, 55) = 1.04, p = 0.313, η^2 = 0.019. The verbatim accuracy scores of those who consumed Corn Flakes in the fall (M = 1.92, SD = 1.38) did not differ from those who consumed Corn Flakes in the spring (M = 2.25, SD = 1.65). Likewise, the verbatim accuracy scores of those who ate All-Bran in the fall (M = 2.46, SD = 2.40) did not differ from those who ate All-Bran in the spring (M = 3.18, SD = 2.04). Pairwise comparisons of verbatim accuracy of the two breakfast conditions in the fall, F (1, 55) = 0.52, p = 0.474, η^2 = 0.009, and spring, F (1, 55) = 1.95, p = 0.168, η^2 = 0.034, revealed no significant interaction. Therefore, the verbatim memory performance between participants in both breakfast conditions did not differ when compared between the fall and spring semesters.

Stroop Task. A two-way factorial analysis of variance was performed to examine the effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on congruent Stroop task reaction times. The results are presented in Table 4. A significant effect of semester was found on congruent stimuli reaction times in the All-Bran condition, F (1, 54) = 4.85, p = 0.032, η^2 = 0.082, but not in the Corn Flakes condition, F (1, 54) = 0.36, p = 0.549, η^2 = 0.007. Participants who consumed Corn Flakes during the fall semester had similar congruent reaction times to those who consumed Corn Flakes during the spring. Participants who consumed All-Bran in the spring, however, had faster reaction times to congruent stimuli than the participants who consumed All-Bran in the fall. A pairwise comparison of Corn Flakes and All-Bran conditions in the fall, F (1, 54) = 4.67, p = 0.035, η^2 = 0.08, revealed a significant interaction between cereal condition and the fall semester. This result indicates that during the fall semester participants in the Corn Flakes condition had significantly faster reaction times than participants in the All-Bran condition. A pairwise comparison of Corn Flakes and All-Bran conditions in the spring, F (1, 54) = 0.32, p = 0.574, η^2 = 0.006, revealed no significant interaction. Therefore, the reaction times of participants in both breakfast conditions did not differ from each other in the spring.

Table 4

Means and standard deviations for congruent Stroop task reaction times (in milliseconds) for Corn Flakes and All-Bran conditions.

	Fall Semester		Spring Semester	
	M	*SD*	*M*	*SD*
Corn Flakes	918.92[b]	209.13	960.19	167.39
All-Bran	1074.23[ab]	210.54	923.56[a]	149.42

Note. Fall Semester = participation during the end of the fall semester; Spring Semester = participation during the beginning of the spring semester. [a, b] = significant difference ($p < 0.05$) between reaction times.

A two-way factorial analysis of variance was also performed to measure the effect of semester on incongruent Stroop task reaction times in Corn Flakes and All-Bran conditions. The results are presented in Table 5. A significant effect of semester was found on incongruent stimuli reaction times in the All-Bran condition, F (1, 54) = 6.31, p = 0.015, η^2 = 0.105, but not in the Corn Flakes condition, F (1, 54) = 3.26, p = 0.077, η^2 = 0.057. Participants in the All-Bran condition had faster reaction times to incongruent stimuli during the spring semester than those in the same condition did during the fall semester. However, the reaction times of participants in the Corn Flakes condition were relatively stable regardless of whether they were tested during the fall semester or spring semester. A pairwise comparison of the reaction times of Corn Flakes and All-Bran conditions in the fall, F (1, 54) = 11.618, p = 0.002, η^2 = 0.172, revealed a significant interaction between cereal condition and the fall semester. This result indicates that during the fall semester participants in the Corn Flakes condition had significantly faster reaction times to incongruent stimuli than participants in the All-Bran condition. A pairwise comparison of Corn Flakes and All-Bran conditions in the spring, F (1, 54) = 0.72, p = 0.40, η^2 = 0.013, revealed no significant interaction. Therefore, the reaction times of participants in both breakfast conditions did not differ from each other in the spring.

Table 5

Means and standard deviations for incongruent Stroop task reaction times (in milliseconds) for Corn Flakes and All-Bran conditions.

	Fall Semester		Spring Semester	
	M	*SD*	*M*	*SD*
Corn Flakes	1096.77[b]	286.71	1279.69	256.17
All-Bran	1452.77[ab]	322.19	1198.25[a]	225.47

Note. Fall Semester = participation during the end of the fall semester; Spring Semester = participation during the beginning of the spring semester. [a, b] = significant difference ($p < 0.05$) between reaction times.

PANAS Questionnaire. A two-way factorial analysis of variance was used to measure the effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on mean positive affect scores. There was a significant effect of semester on positive affect in Corn Flakes conditions, F (1, 55) = 4.24, p = 0.044, η^2 = 0.072, such that those who participated in the fall (M = 2.45, SD = 0.82) indicated lower levels of positive affect than those who participated in the spring (M = 2.99, SD = 0.57). However, there was no significant effect of semester on positive affect in All-Bran conditions, F (1, 55) = 1.39, p = 0.243, η^2 = 0.025, because those who participated in the fall (M = 2.16, SD = 0.67) indicated comparable levels of positive affect to those who participated in the spring (M = 2.46, SD = 0.72). A pairwise comparison of the mean positive affect in Corn Flakes and All-Bran conditions in the spring, F (1, 55) = 4.64, p = 0.036, η^2 = 0.078, revealed a significant interaction between cereal condition and the spring semester. This result indicates that during the spring semester participants in the Corn Flakes condition had significantly higher positive affect scores than participants in the All-Bran condition. A pairwise comparison of Corn Flakes and All-Bran conditions in the fall, F (1, 55) = 1.12, p = 0.29, η^2 = 0.02, however, revealed no significant interaction. Therefore, positive affect scores of participants in both breakfast conditions did not differ from each other in the fall.

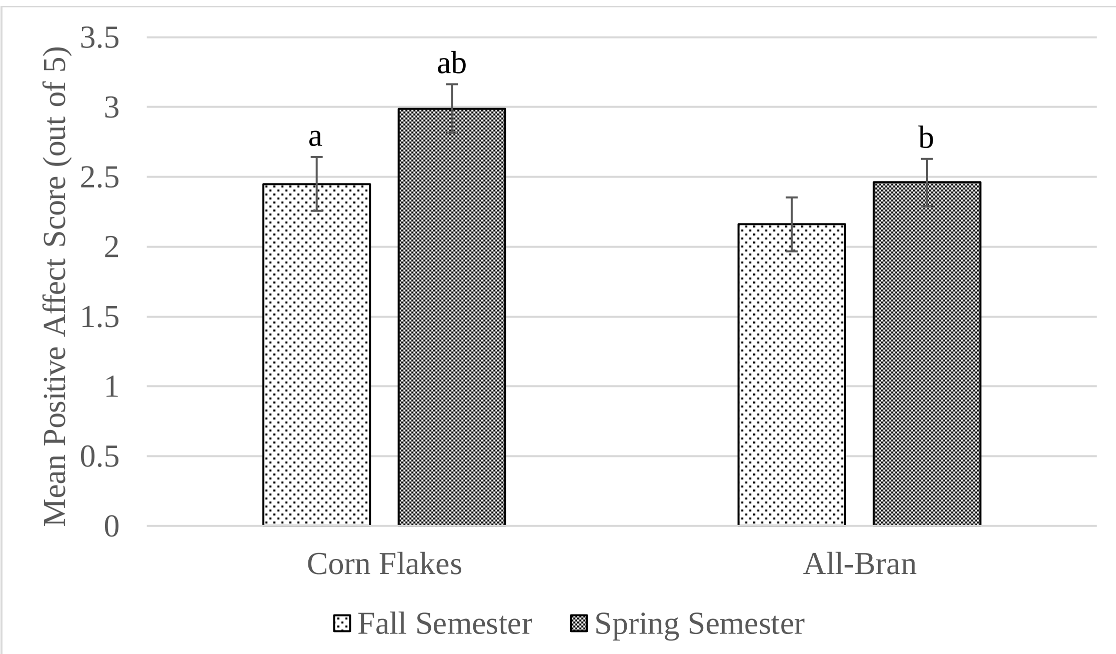

Figure 2. Cereal condition by semester and mean affect score for positive affect subscales of the PANAS. Standard error bars are included. a, b = significant difference ($p < 0.05$) between mean positive affect score.

The effect of semester (fall, spring) and breakfast condition (Corn Flakes, All-Bran) on the mean negative affect scores was also investigated using a two-way factorial analysis of variance. No significant effect of semester was found on the mean negative affect scores of Corn Flakes conditions, F (1, 55) = 1.14, p = 0.291, η^2 = 0.02, and All-Bran conditions, F (1, 55) =

0.59, $p = 0.447$, $\eta^2 = 0.011$. Participants in the Corn Flakes condition indicated comparable mean negative affect scores in the fall semester ($M = 1.42$, $SD = 0.38$) and in the spring semester ($M = 1.64$, $SD = 0.66$). Likewise, those in the All-Bran condition had similar mean negative affect scores in the fall semester ($M = 1.36$, $SD = 0.41$) and in the spring semester ($M = 1.52$, $SD = 0.70$). Pairwise comparisons of negative affect in Corn Flakes and All-Bran conditions in the fall, $F(1, 55) = 0.06$, $p = 0.812$, $\eta^2 = 0.001$, and spring, $F(1, 55) = 0.36$, $p = 0.55$, $\eta^2 = 0.007$, revealed no significant interaction. Therefore, mean negative affect scores between participants in both breakfast conditions did not differ when compared between the fall and spring semesters.

Discussion

To address the mixed findings within the literature, the objective of the present study was to investigate whether a breakfast lower in GI and GL would result in superior verbatim memory and self-control performance compared to a breakfast higher in GI and GL. Additionally, the present study examined whether consuming a breakfast lower in GI and GL would result in reduced levels of negative affect. The observed findings provided no indication of enhanced verbatim memory or self-control performance respective to a given breakfast condition. The results revealed no effect of the GI or GL of a breakfast on negative affect; however, participants who consumed a breakfast higher in GI and GL tended to experience greater levels of positive affect than those who consumed a lower GI breakfast. Several analyses also indicated that the time of year in which participants completed the experiment affected self-control and mood states.

The finding that gist memory performance did not differ between Corn Flakes and All-Bran eaters was as predicted. This task was designed to be less effortful than the verbatim memory task in the present study and was expected to draw upon fewer cognitive resources. The consistent gist memory performance between the two breakfast conditions could suggest that glucose levels in all participants were high enough to allow for similar performances, regardless of whether participants consumed a lower or higher GL breakfast.

Although the similarity in gist memory performance between breakfast conditions was anticipated, the finding that verbatim memory performance remained unchanged between Corn Flakes and All-Bran eaters was unexpected. Given that past research identified that a low GI breakfast could prevent a performance decline in effortful memory tasks (e.g. Benton et al., 2003; Ingwersen et al., 2007), it was anticipated that participants who consumed All-Bran would, on average, remember specific prices of grocery items more accurately than participants who consumed Corn Flakes. However, is possible that the serving sizes of the cereals used in the present study in comparison with the serving sizes used in Benton et al. (2003) and Ingwersen et al. (2007) merit thoughtful consideration as an explanation for the deviation in results.

While the present study was initially inspired by examining the differences between a cereal of low GL and a cereal of high GL, reaching a high GL value for Corn Flakes would have necessitated increasing the serving size beyond the recommendation present on the single-serving nutrition label, even though Corn Flakes was chosen for use in the present study because its GI is already very high (Atkinson et al., 2008). From a practical standpoint, it could be called into question as to why increasing a portion beyond its recommended serving size should be used to extrapolate to the cognitive performance of a typical individual who consumes a reasonably expected breakfast. Unless certain individuals habitually consume portions larger than those recommended by the nutrition facts panel, results obtained by studies that oversize breakfast portions might not reflect memory performance or any other measure of cognition in the general population. This being considered, the present study focused on providing participants with a typical breakfast that one might reasonably consume in the morning; therefore, one serving was determined by the amount recommended on the nutrition label of the cereal. This decision resulted in using a serving of All-Bran that had both a low GI and a low GL and a serving of Corn Flakes that had a high GI and a medium GL, instead of an unnaturally-high GL that may have no ecological value for the average person who does not consume inflated portions.

Although they did not indicate the specific recommended serving sizes for the food products used in their breakfasts, Benton and colleagues (2003) did indicate that they used 50g of four different cereal-based foods for their breakfast conditions. Since the mass of the serving size of many cereal-based products varies and is seldom exactly 50g, it is likely that portions were altered in this experiment. Along the same line, Ingwersen and colleagues (2007) included that they provided their participants with either a 35g serving of Coco Pops or a 35g serving of All-Bran, both of which are larger portions than the recommended serving sizes indicated on the nutrition labels for these products. Though Benton et al. (2003) and Ingwersen et al. (2007) indeed found results of memory performance differences among those who consumed breakfasts differing in GL, the practicality of such manipulations for the average person could be questionable due to the inflated portion sizes. The present results are certainly preliminary, but could suggest that some high GI foods, when consumed in conjunction with serving size recommendations, may not be detrimental to memory performance.

An alternative explanation for the disparity in results between the present study and the results of Benton et al. (2003) and Ingwersen et al. (2007) could be that GL only affects select memory components, and as a result, only influences performance on certain memory tests. Benton and colleagues (2003) found that memory performance on an abstract word recall task was enhanced in participants who consumed a low GL breakfast, and Ingwersen and colleagues

(2007) found a low GI breakfast to enhance secondary memory, but not working memory. Thus, it may be that GL influences certain memory processes differently. It could therefore be conducive for future studies to consider comparing performance on a large assortment of memory tasks to reach an improved understanding of the relationship of GL on memory.

Regarding the Stroop task, the lack of variation in reaction times between breakfast conditions was unsurprising in the context of congruent stimuli. Along the same lines as the gist memory task, it is thought that all participants maintained the blood glucose levels necessary to comparably react to congruent Stroop stimuli regardless of whether they consumed All-Bran or Corn Flakes. However, of particular interest given mixed findings in the past, the present study did not find evidence that a glucose manipulation could influence self-control with respect to incongruent Stroop stimuli.

Previous studies examining the metabolic effects of glucose on self-control (e.g. Benton et al., 1987; Job et al., 2013; Kelly et al., 2015; Lurquin et al., 2016) tend to implement glucose and placebo drinks as a means of manipulating participants' blood glucose levels; however, the present study opted to manipulate blood glucose levels through two typical breakfasts one might normally consume. While it cannot be concluded that glucose does not fuel self-control, the fact that participants who consumed high GI Corn Flakes were able to demonstrate comparable levels of self-control to participants who consumed low GI All-Bran presents a challenge to the hypothesis that typical variations in blood glucose levels can substantially influence self-control. Although the role glucose plays in self-control is not at all conclusive, if an effect indeed exists, perhaps the high GI of the Corn Flakes condition did not lend itself to a large enough decrease in blood glucose levels to cause a depletion of self-control relative to the low GI All-Bran condition.

It should be noted that implementing glucose and placebo drinks would result in a more pronounced contrast of blood glucose levels between participants in comparison to the contrast observed between two cereals because both cereals would increase blood glucose levels to some degree. The use of glucose and placebo drinks could then perhaps magnify a depletion of self-control; however, few studies have found effects even under these conditions. The observed difficulty in replicating the results of experiments that did find an effect of glucose on self-control further suggests that if such an effect exists, it is likely very small.

One of the goals of the present study was to obtain a sample size larger than those used in the previous research on glucose and self-control to account for the small sample size criticism garnered by skeptics in the field. Experiments that have found metabolic effects of glucose manipulations on self-control have frequently used sample sizes smaller than 30. For example, in five of the nine experiments conducted by Gailliot and colleagues (2007), the sample size of participants was less than 20. Interestingly, many of the studies that indeed used larger sample sizes found either no effect or a questionable effect of a glucose manipulation on measures of self-control (e.g. Job et al., 2013; Kelly et al., 2015; Lurquin et al., 2016). Job and colleagues (2013) performed three experiments with sample sizes ranging from 62 to 154; Kelly and colleagues (2015) used 67 participants, and Lurquin and colleagues (2016) recruited a respectable total of 200 participants. In the present study, the failure to find an effect of glucose manipulations on self-control after including 59 participants may provide further criticism for the hypothesis that self-control can be mediated by fluctuations in blood glucose levels.

It should be acknowledged that although reaching a minimum sample size of 30 participants per condition is often used as a yardstick for obtaining representative results, in some cases, even this value is not large enough to detect a psychological effect. Thus, even though the sample size of the present study was larger than those of many previous studies in this area, it remains possible that the study was underpowered and still too small to identify an effect of GI and GL on self-control. In future designs, it will be imperative to garner a sample size well above the typical benchmark of 30 participants.

Since the results of prior studies that found metabolic effects of glucose on self-control are quite difficult to explain, if such an effect exists, it is probably small at best. A possible alternative explanation is that glucose may impact self-control through non-metabolic means. A large number of studies have observed that simply swishing glucose in one's mouth can immediately prevent self-control depletion relative to swishing an artificially-sweetened placebo (e.g. Molden et al., 2012; Sanders, Shirk, Burgin, & Martin, 2012; Hagger & Chatzisarantis, 2013; Carter & McCullough, 2013). Instead of underlying self-control processes, glucose could act as a motivator because the neural sensation of glucose rinses has been shown to activate the striatum — an area in the brain responsible for processing reward (Molden et al., 2012).

Although the present study was not designed to examine the motivation model of glucose, if glucose indeed replenishes self-control in a motivational fashion as opposed to a metabolic fashion, the results obtained by the present study may not be surprising. Firstly, the self-control of participants in the present study was tested roughly two hours after eating breakfast, whereas participants who swished glucose or placebo rinses were tested either 10 minutes after swishing (e.g. Carter & McCullough, 2013), immediately after swishing (e.g. Molden et al., 2012; Hagger & Chatzisarantis, 2013) or while swishing (e.g. Sanders et al., 2012). In the context of the present study, this substantial time difference may have allowed for the glucose-induced activation of the striatum to subside during the two-hour fast and while participants completed the Stroop task in the present study. Furthermore, because both groups consumed breakfast at the same time, it is unlikely that a motivational component of glucose would have been made salient between both conditions.

The finding that participants who consumed Corn Flakes experienced higher levels of positive affect and fairly equivalent levels of negative affect appears surprising. It was predicted that those who consumed All-Bran would experience lower levels of negative affect, as many pieces of past research indicate that long-term low GI and GL diets correlate with greater levels of positive affect than high GI and GL diets (e.g. Cheatham et al., 2009; Gangwisch et al., 2015; Breymeyer et al., 2016). While this evidence should certainly be taken into consideration when interpreting the results of the current study, it is worth pointing out that some short-term breakfast manipulations have not reached the same conclusions. For example, while Pasman and colleagues (2003) identified that participants who consumed a higher GL breakfast experienced greater levels of fatigue than those who consumed a lower GL breakfast, there were no differences in other forms of negative affect, such as depression, anger, or tension between the two conditions. Furthermore, Lloyd and colleagues (1996) identified that those who consumed a LFHC breakfast (higher in GL) reported lower levels of fatigue and dysphoria than those who consumed a MFMC or HFLC breakfast (lower in GL).

The lack of agreement between long-term and several short-term studies warrant future examination of low and high GL diets in varying spans of time. The observed discrepancies between these studies potentially allude to the allowance of high GI or GL foods in moderation sans the consequences of certain forms of negative affect; however, affect-related responses to certain foods could certainly vary between individuals. Additional research regarding the quantity of high GL food necessary in a diet to result in a change in subjective well-being is merited.

It is particularly interesting that the current study observed an increase in positive affect in the Corn Flakes condition and not simply levels of positive affect equivalent to the All-Bran group. This observation is similar to the results found in the study done by Lloyd and colleagues (1996). These researchers' interpretation was that negative affect occurred as a result of a deviation from eating a breakfast of similar macronutrient composition to one's typical breakfast; therefore, positive affect was more pronounced in those who consumed a LFHC breakfast (higher in GL) because this is the type of breakfast they habitually consumed in the morning. Although the current study did not question participants about their typical breakfast habits, it is possible that the current study's participants typically eat breakfasts similar to the Corn Flakes that were provided to them and that those who ate All-Bran were not as pleased because of an inconsistency to their typical breakfast routine.

Although the research done by Lloyd and colleagues (1996) suggests a familiar breakfast may promote greater levels of positive affect in individuals, they do acknowledge all experimental breakfasts provided in the study were approximately 600kcal, whereas the typical caloric intake of the participants at breakfast was around 250kcal. If the authors' interpretation of their results is true, the levels of positive affect described by the participants may have already been lower than it normally would be if they had eaten a breakfast that was around 250kcal in size, regardless of whether or not the breakfast was similar in macronutrient composition to their typical breakfast. Indeed, the size of a breakfast and its influence on mood may pose a similar issue to the size of a breakfast and its influence on memory. Pasman and colleagues (2003) explain that the breakfast provided in their study was based on a typical Dutch breakfast for men; however, the authors did not specify whether the size of the breakfast was typical. In the study conducted by Smith and colleagues (2001), evidence that the consumption of cereals with a higher GL led to increased fatigue and emotional distress was found; yet, the serving size of these cereals was larger than the recommended serving size.

There appears to be very limited research within the literature about the effects of breakfasts of different sizes on one's subjective well-being. Currently in the literature, it appears as though one study (Michaud et al., 1991) examined the effect of manipulated breakfast sizes on mood. Michaud and colleagues (1991) report that a higher caloric breakfast did not have an impact on participants' reported mood; however, this study may have had several methodological errors that hinder the conclusions that can be drawn from its results. For example, the breakfast size manipulations in this study were put into effect by telling participants to eat more as opposed to standardizing the amount of food that constitutes as "more". This may be problematic due to the subjectivity involved in allowing a participant to determine what is "more". Thus, when attempting to relate the results of studies that increase portion sizes to the average person eating an average breakfast, it remains difficult to form a conclusion of ecological value. The results of the current study may, therefore, serve as pioneering research to suggest that consuming a high GI breakfast of typical size may result in higher levels of positive affect than consuming a low GI breakfast of typical size.

Certain semester effects on Stroop task reaction time seem logical. Those who participated during the end of the fall semester likely experienced higher levels of stress associated with upcoming exams and essays, whereas those who participated at the beginning of the spring semester likely felt more rested. Thus, it would appear reasonable that those who participated during the end of the fall semester would have slower reaction times to both congruent and incongruent stimuli because their self-control reserves may have been compromised by stress and studying. Indeed, participants who consumed All-Bran during the spring semester demonstrated faster reaction times to both congruent and incongruent stimuli as opposed to those who consumed All-Bran during the fall on the eve of final exams; however, it is unclear as to why those who consumed Corn Flakes did not also demonstrate faster reaction times during the spring semester compared to those who ate Corn Flakes in the fall. While this disparity between Corn Flakes and All-Bran eaters is certainly interesting, it can perhaps be explained by biases within the small sample sizes that compose each breakfast condition within each semester.

The small sample sizes of Corn Flakes and All-Bran participants between each semester may also explain why participants who consumed All-Bran had significantly slower reaction times to both congruent and incongruent Stroop stimuli than those who consumed Corn Flakes during the fall semester. Since there are natural variations in individuals' reaction times to stimuli, it is possible that the small group of participants who consumed All-Bran in the fall had naturally slower reaction times than the small group of participants who consumed Corn Flakes in the fall.

The observed semester effects on positive affect are also worth mentioning. It is legitimate that some participants would experience higher levels of positive affect in the spring semester as opposed to the fall for the same reason that there were effects of semester on Stroop task reaction time: participants in the fall presumptively felt less contented because they experienced looming final exams and projects, whereas participants in the spring generally had fewer class-related stressors. This being said, it is intriguing that only participants who consumed Corn Flakes displayed a significant increase in positive affect from the fall to the spring; those who consumed All-Bran maintained a relatively stable average positive affect from semester to semester. A plausible explanation for this curious data could again reflect the nature of the small sample sizes in each breakfast condition within the two semesters.

The present study encountered a few limitations that may have affected the observed results. Firstly, given the limited amount of resources available to the experimenter, the sample size was of the present study is smaller than optimal which may have led to underpowered results. If a replication of this study were to be conducted, it would be important to gather as large a sample as possible. Secondly, the sample of participants obtained was not a random sample. Due to difficulty in the recruiting process, the experimenter relied on networking and social media to gather participants. The majority of the participants in this study were acquaintances of the experimenter; therefore, it is possible that the results may have been biased in a way that could not have been anticipated. Future replications of the present study would do well to advertise on a larger, more public domain to encourage a sample that could be more representative of the general population.

Future study designs focused towards conducting research in this area could consider implementing a breakfast that is both high in GI and GL along with a breakfast that is low in GI and GL. Examining the effects on cognition of two different breakfasts that are more contradictory than the ones selected for the present study may bring to light differences in cognition that were not detected in the current data. Moreover, another imperative avenue to explore would be to examine the impact of breakfasts of different sizes. Since there appears to be a gap in the literature regarding the influence of breakfast size on cognition, it may be fruitful to compare cognitive performance and affect among breakfasts that are in smaller than, larger than, and in accordance with serving size recommendations. The implementation of these ideas in future research designs could provide valuable contributions to the current understanding of the influence of GL and GI on cognition.

The goal of this research was to identify connections between breakfasts varying in GI and GL and one's cognitive performance and affect. Although no link between breakfast type and memory performance and a limited link related to self-control was established, a noteworthy result remains the positive influence of a high GI/medium GL breakfast of Corn Flakes on mood. The implications of these results are compelling because they may change the way in which future studies are structured and alter the way in which foods high in GI are viewed. For example, when studying the typical, everyday effects of GI breakfasts, future studies may structure their designs to adopt a focus on maintaining recommended serving sizes. This practice could help to support a goal of increasing the practical application of the findings to the general population. With respect to the association between long-term high GI diets and several physiological and psychological consequences, the present study cannot conclude that a high GI breakfast is a better option than a low GI breakfast, despite the higher levels of positive affect observed in those who consumed a high GI breakfast. However, in a short-term context, the present findings appear to suggest that consuming one serving of a high GI cereal for breakfast does not have negative effects on memory, self-control, or mood. The practical application of the present research could influence perceptions of high GI foods from solely negative toward one of acceptance when serving size recommendations are adhered to and within the context of a diet generally relying on low GI foods.

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