2016

The Role of Chronic Sugar Consumption as a Moderating Variable on Acute Sugar Consumption and Aspects of Executive Function

Caroline M. Joyce
Scripps College

The Role of Chronic Sugar Consumption as a Moderating Variable on Acute Sugar Consumption and Aspects of Executive Function

Caroline Joyce

Scripps College

Abstract

This study explores the relationship between acute sugar consumption and its effect on executive function (EF). Specifically, this study examines the effect of both acute and chronic sugar consumption on EF. An epidemiological survey was given on an online work distribution platform, where participants finished cognitive tasks of EF after completing questionnaires assessing sugar consumption both in the last year and last 24 hours ($n = 273$). It was hypothesized that acute and chronic sugar intake would significantly predict scores on measures of aspects of EF. Additionally, it was hypothesized that chronic sugar intake would significantly moderate the relationship between acute sugar intake and EF. Neither acute nor chronic sugar consumption predicted EF. This effect was not changed by including chronic sugar consumption as a moderating variable upon acute sugar consumption and EF. This research provides greater evidence about what effect sugar consumption has on EF.

History of Sugar Consumption as a Moderating Variable on Sugar and Aspects of Executive Function

To investigate the role that acute sugar consumption plays in measures of executive function this research executed an epidemiological survey. It was a study of the population at large, with the hope of establishing the effect of lifetime sugar consumption on measures of aspects of executive function (EF) (Akintola et al., 2014). This goal of this study is to provide preliminary results that a significant relationship does exist between acute sugar consumption, chronic sugar consumption, and scores on measures of EF. Specifically, that increased chronic sugar consumption will lead to decreased scores of EF, while higher acute sugar consumption leads to higher scores on measures of EF. The role of EF has been chosen, as will be shown, to highlight one area that it is suspected to be influenced by chronic and acute sugar consumption. The results of this study aimed to bring greater understanding of the interaction of acute and chronic sugar consumptions effect on EF. Narrowing in on EF will provide concrete examples in the ways that sugar can have a detrimental effect on cognition, and open the door for further investigation on cognitive effects in general.

Executive Function

According to the Banich model of integrated executive function (2009) different abilities, such as planning, self-control, and mental flexibility, are controlled by this system. These include planning, self-control, and mental flexibility. In particular, working memory (WM) and the processes related to it are housed in this system (Salthouse & Davis, 2005). While WM is often a broad term, in this case it is referring to the “temporary storage and manipulation of information in the service of performing complex cognitive activities” (Baddeley et al., 2011). Due to previous research done on rat populations, it is expected that acute sugar consumption will have a significant effect on aspects associated with EF.[1] Many different processes fall under the umbrella that is EF, however, for this study subcomponents examining WM and processes related to it will be examined. As will be seen, these aspects of EF are most supported in the literature.

Sugar

When the term sugar is used, it can refer to glucose, sucrose, or fructose. All three are carbohydrates that can exist on their own (monosaccharide), or linked together (disaccharide). Sucrose, a derivative from sugar cane and the most common type of sugar, is comprised of two molecules linked together: glucose and fructose (Figure 2).

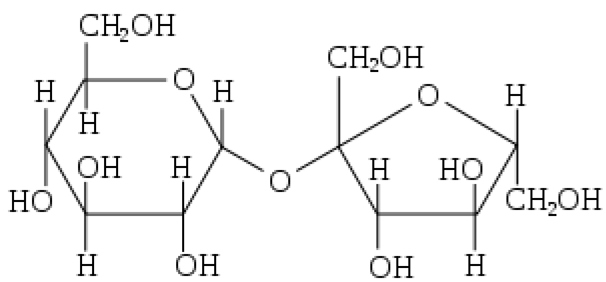

Figure 1. Sucrose: a connection of glucose (left) and fructose (right).

Table sugar, or anything used in cooking or baking is always sucrose. However, in some studies, glucose is isolated and administered in its monosaccharide form (Ullrich et al., 2015). In others, sucrose is given in its disaccharide form (Hill et al., 2014). When examining these effects, it is important that whenever sucrose—or colloquially sugar—is described, glucose is also implicated. Due to the lack of uniformity between pure sucrose and pure glucose administration in the literature, the terms will be used somewhat interchangeably in this study. Additionally,

[1] See Dalm et al. (2009); Kendig et al. (2013); Reichelt et al. (2015).

when using self-report measures of sugar consumption, no distinction will be made between monosaccharide or disaccharide versions of sugar. While some processed foods will use glucose over sucrose, it is assumed that the average person would not note this, or be able to report this difference. While van der Zwaluw et al. (2014) investigate a difference in the effects of these two sugars, previous literature has not. Therefore, while it will be important in the future to examine whether these sugars lead to different effects, the current study will use the terms interchangeably.

Acute Effects of Sugar

Positive effect

Short-term, beneficial effects of sugar on measures of EF have been demonstrated. In order to solely examine the effect glucose and sucrose have on cognition it is possible to isolate them. This is because it has been shown that, in rats, the brain uses more glucose when completing demanding cognitive tasks (McNay, Fries & Gold, as cited in van der Zwaluw et al., 2014). Sucrose, which is half glucose and half fructose, has not been investigated. It is known that fructose will only slightly raise blood glucose levels due to its inability to cross the blood-brain barrier (Messier & White, 1987, as cited in van der Zwaluw et al., 2014). This interaction of glucose and sucrose is also pertinent to be studied in an adult population. In a study by van der Zwaluw et al. (2014), 43 adults aged 70 and older drank a beverage of glucose or sucrose and then immediately completed cognitive measures. It was found that the sucrose drink significantly benefited attentional performance—a process that is part of EF. Interestingly, no effect of glucose or sucrose was seen on scores of episodic memory. It is possible that this is due to the ordering of tasks, as the memory task was the first one performed and there might not have been enough time for the glucose to be absorbed by the body. Glucose levels may not have risen enough at this point for an effect to be seen. It is also feasible that different levels of glucose are needed for significantly improved performance on a variety of tasks. By having only one dose of glucose and one of sucrose the researchers did not have enough of a manipulation to see if a small effect could be seen on scores of cognition. Had various doses of sucrose and glucose been used, the researchers might have noticed a difference in cognition. Research should be limited to multiple doses of one type of sugar, either glucose or sucrose, to see their effects on a variety of tasks.

Further research has noted the beneficial role that an acute sugar dose can have, specifically within a population of young women. Donohoe & Benton (2000) examined the blood glucose levels of undergraduate women using a blood glucose tolerance test (GTT), a highly reliable measure of current levels of sugar in the blood. These occurred after ten hours of fasting so that the most accurate read of blood glucose could be obtained. Without fasting, the blood glucose level could show a much higher or lower read, depending on what the participants had eaten recently. By having these GTT values, researchers were able to make assumptions about the general glucose tolerance of each participant, and it could be inferred that these were steady levels that would not change suddenly over the lifespan. Using undergraduates (mean age 22 years), it is possible to examine the effect of sugar on an even younger population than seen the literature—although no conclusions can be made about whether it would be possible to change the glucose levels, and by extension, any scores on cognitive testing. It was found that lower blood glucose levels were associated with poorer performance on measures of cognition, including EF. Interestingly, this effect was seen across all measures of WM, indicating that higher blood glucose levels are necessary for basic cognitive functioning. The researchers point out that this is noteworthy because it was GTT values that were not hypoglycemic, but solely on the lower end of the spectrum of blood glucose levels. This finding exhibits how susceptible aspects of EF can be to sugar fluctuation—even in a quite young cohort of healthy adults. It is not only people who have disorders of blood glucose levels—such as diabetics—that can have cognitive processes affected. It is possible to be within the normal healthy range of blood glucose levels and still see significant differences on cognitive measures. These results points to the role that baseline glucose levels play in all aspects of EF. Researchers did not manipulate the levels of glucose in the participant' bodies, and therefore it is unknown whether someone with a baseline lower GTT level would show greater improvement on the administered tasks when given a sugar supplement as compared with someone who had higher levels. Further research should examine whether participants with differing baseline levels of glucose react in significantly different ways to sugar supplementation.

By examining specific object-location binding it is possible to verify the role that glucose plays in WM. A study by Stollery & Christian (2015) examined the effect of acute glucose administration on remembering object location. It was found that the consumption of a glucose drink by the participants significantly increased their ability to remember the location of objects and to bind the objects to their location. This significant relationship indicates that the visual-spatial sketchpad of Baddeley's model is in fact impacted by glucose administration. Additionally, by indicating the exact way in which WM is effected this research indicates that other parts of WM might be as well, and there is room for more investigation. Researchers in this study did not account for chronic sugar consumption in their analyses, they instead just had participants come in after fasting all night. While this assumes a blank slate of sugar consumption, it does not leave room for the effect chronic sugar consumption has on this significant relationship. By including information on whether the participants are high, medium, and low chronic sugar consumers, the researchers would be able to show whether this relationship holds true for all people. Additionally, the glucose dose in this study was kept static and not varied across groups of participants. The glucose dose given was relatively small (30 g) indicating that this effect on WM can be seen at even low levels of acute sugar consumption. It is possible that the effect seen varies depending on the level of acute glucose administration given. The next steps, which the current study aims to do, will be to take into account chronic sugar consumption.

Examining the difference in effect of glucose doses on aspects of EF indicates the role that differing levels of acute sugar consumption can have. Most studies reviewed do not make a distinction between sugar dosages, and therefore it is noteworthy when researchers indicate that varying sugar levels can have differing effects. A study by Mohanty & Flint (2001) examined the role of acute glucose administration upon performance on emotional or neutral WM tasks. The researchers varied dosages of glucose between 100 mg per kg (weight of the participant), and 50 grams, noting that previous literature on humans standardizes glucose 50 grams, whereas animal research consistently uses an approach of 100mg/kg. It was found that varying the dosage had a significant effect, with enhanced performance on the neutral stimuli task of WM when using the dose of 100 mg/kg that was not observed in those who received the 50 grams dose. This research indicates that the difference in effect due to glucose dose should be investigated, as they can play different roles. Participants in this study were not asked to fast before coming into the lab, indicating that their current blood glucose levels could have affected their response to the glucose drink that was given. Additionally, researchers did not account for chronic sugar consumption, which could have played a role in the participant’s response to the acute glucose administration. By showing that differing the doses of glucose affects measures of WM the researchers indicated that there is room in the literature for a more thorough investigation on the role of varying doses of acute glucose administration on aspects of EF.

Null effect

Additional research has found conflicting results to the previous literature, showing that sugar might not provide the same effect as seen by others. A study by Ullrich et al. (2015) tested whether cognitive performance could be influenced by caffeine or glucose ingestion, when compared to a placebo. Seventeen men, spanning from young adult to middle age (19-40) served as the participant pool. Although the researchers hypothesized that the consumption of glucose would enhance EF, it was found that performance was unaffected by glucose consumption. Researchers did not take GTT levels, nor did they gather a history of sugar consumption, therefore it cannot be said whether either of these played a role on the day that the experiment was carried out. Interestingly, no effect was seen with caffeine either—though it has previously been exhibited in other studies (Jones et al., 2012, as cited in Ullrich et al., 2015). While these effects seem to indicate that glucose supplementation does not play a role in EF, it is also possible that outside factors were not considered. Had lifetime history of sugar consumption been used, it is possible that a greater pattern could be seen. Specifically, as exhibited by Donohoe & Benton (2000), lower blood sugar levels do lead to decreased cognition, and therefore it is possible that the variability of blood sugar levels within the participants canceled out the effect seen. The majority might have had high GTT levels when given the study, removing any statistically significant effect seen by those who had lower blood glucose levels. This study provides valuable information about the need for a larger sample size, and indicates that different ages might require different levels of sugar consumption to see an effect. If ages had been separated and GTT levels, or self-reported sugar consumption, recorded, it is possible that an effect would be seen. Further research should aim to do this, as by controlling for other variables, the true effect of glucose consumption on measures of cognition may be seen.

Verifying sugar's acute effect

If sugar has been seen to have a positive effect on EF, it is important to verify that it is not solely a placebo response to the ingestion of a sweet beverage. Hill et al. (2014) compared the decision-making processes of those who consumed a sugar-sweetened drink (Sprite) to an artificially sweetened one (Sprite Zero). If it was solely a placebo response participants should have displayed the same behavior after ingestion of a sugar, or non-calorically sweetened (NCS), beverage. This is because the structural differences of sugar compared to NCS make them be absorbed in different ways by the body. If the sugar effect was in fact not a placebo it can be assumed that their resulting effect on EF would be different. It was found that consumption of the NCS beverage led to significantly different effects on decision making. Specifically, those who consumed a NCS beverage were significantly more likely to choose a high-calorie food item as a treat (M&M chocolate candies) than those who had consumed the sugar beverage (more likely to choose sparkling water or gum). These results indicate that sugar and NCS influence separate systems. Therefore, it can be assumed that the sugar-dose effect is not a placebo, and participants will not exhibit the same behavior when given a fake sugar supplement. Researchers of this study did not give other tasks of EF, so no conclusions can be made about the exact effect differences NCS and sugar beverages will have on WM or processes related to it. It is encouraging to note that sugar plays a real, and different, role in processes of EF, and therefore should continue to be investigated.

Chronic Effects of Sugar

Positive effect

As positive effects of sugar have been previously found within an acute consumption level, it is interesting to note that a similar result has been noted in chronic consumption studies. The effect that was found by Best, Kemps, & Bryan (2010) in adults aged 45 to 60 is noteworthy. In this study, participants were instructed to take a saccharide (sugar) supplement twice a day for 84 days. This extended period of time that was studied stands out in the literature, while it does not mirror lifetime consumption it is more than can be considered acute. It can be inferred that there was a constant level of saccharide in the blood due to this continuous consumption. Adults in this sample were generally healthy, anyone with a long-term illness that would compromise the ingestion and absorption of saccharides was excluded. The supplementation consisted of many different types of sugar, all put together to form quite a strong dose. Measures of WM were given before the consumption began and after it ended. Saccharide supplementation had a significant effect on memory performance, specifically on immediate recall, potentially because saccharides enhance the cellular activity in the hippocampus required for memory formation (Matties, H. et al., 1999, as cited in Best, Kemps, & Bryan, 2010). A strong effect was seen here, however, it is tempered by the amount and type of saccharide being administered. This effect may not be seen in nature, as the powder supplement of the different sugars was ingested twice a day, for 84 days, for this effect to be seen. While the researchers collected food diaries from the participants no significant correlations could be drawn to increased cognitive power. No other types of sugar ingestion were controlled for in this study. A small effect was seen on speed processing tasks, suggesting that if saccharide supplementation had been continued, a stronger correlation could have been made. Overall, the saccharide supplementation had an extremely positive effect on the EF processes of middle-aged adults. Because these were specially formulated sugar supplements it is unknown whether a basic sugar supplement would have the same effect. Although the time period was long, it did not result in the declining cognitive processes that are normally associated with long-term sugar ingestion. The fact that a positive effect is seen in middle aged adults suggests the change that sugar can have in cognitive processes—even in healthy, younger, people.

The dichotomous effect of sugar, with both beneficial and detrimental effects shown, has been noted previously, and can similarly be seen through a chronic consumption lens. Hope et al. (2013) examined this within a school context—as they noted that when schools ban sugar, there are increases in exam and reading scores (Park, 2008; Radnedge, 2009; as cited in Hope et al., 2013). However, it has also been shown that higher blood glucose levels also result in better performance on cognitive tasks (Riby, 2004; Feldman and Barshi, 2007; as cited in Hope et al., 2013). This interesting relationship is not fully understood, so the researchers hypothesized that examining the effect of the Flanker task could provide more information about whether sugar's effect was beneficial, or detrimental. The Flanker task is optimal for this because of its ability to separate out and assess stimulus-response time. This would provide greater information about how much of an effect sugar had on participants' cognition. By being able to compare stimulus-response time both pre and post consumption of glucose drinks the researchers were able to control for any other effects that might influence this relationship. The researchers found that there was glucose-induced slowing effects on both parts of the Flanker task (congruent and incongruent) indicating that there is a negative effect of sugar on EF. While previous research has in fact shown the opposite, this study posited that this interesting effect was due to differential effects of glucose on brain function and EF. When examining tasks that consist of different processes, different parts of the brain would be utilized, and a positive affect would be seen. While this is indeed likely, one thing the researchers did not examine was lifetime sugar use by the participants. Participants had to fast all night, which the researchers assumed was a blank slate of glucose. This however, seems unlikely, as the research has already proved that long-term sugar use proves detrimental to cognition (Seetharaman et al., 2015)—and it would not be possible to erase that solely through an over-night fasting process. Had the researchers examined lifetime sugar use a different effect might have been seen.

Negative effect

Examining the effect that sugar plays within the body shows the ways in which it can lead to significant differences in behavior. In a study based in Oslo, 5547 10th-grade students in self-reported how often they normally consumed soft drinks with sugar (Lien et al., 2006). There was a direct relationship between scores of hyperactivity and the number of soft drinks consumed in a week. Participants who consumed soft drinks at a high level had the highest scores on measures of conduct problems and total difficulties. The researchers did not measure other sugar-substances consumed by the participants, indicating that those in the highest consumption of sugar group (>4 glasses/day) could still be consuming additional sugar in other food products. The researchers note that the effect of sugar consumption on behavior might be mediated through other nutritional factors, and showed the need for more research to be done in this area. Sugar consumption showed a significant detrimental effect on mental health status, indicating that the health consequences of sugar—both physical and mental—need to be investigated further, as international efforts to understand more about sugar are brought underway. Many of the behavioral issues noted in this study are related to issues with attentional control, related to EF. By putting issues with EF in a broader framework of mental health and behavioral issues, it is possible to see the important role EF plays. Control of functions related to EF is very necessary, as there can be reverberations to other aspects of cognition and behavior.

Another avenue of research of sugar research involves neuroimaging studies, so that more information can be gained about the exact effect sugar has on neural mechanisms. A study by Akintola et al. (2015) had adults (mean age 66.2 years) undergo an oral glucose tolerance test, have an MRI scan, and take three cognitive tests, that included the evaluation of EF. From the MRI scans it was observed that as insulin action increased—in part due to the glucose taken—there was a decrease in the function of the brain's microstructures. No causal inference can be deduced, and therefore it is unknown whether microstructural integrity of the brain lead to an increased activation of peripheral insulin action, or vice versa. However, this effect shows the strong correlation that nutrition—specifically sugar—has on EF. Participants were gathered from a longitudinal study of adults in the Netherlands (Leiden Longevity Study), which identifies genetic factors and biomarkers that lead to familial longevity. It is possible that had a more diverse sample been investigated, results would be different. The population was the offspring of Caucasian nonagenarians whose siblings were also still alive at an older age. Since their parents had lived to such old age, these study participants might have had genetic factors that make them also predisposed to live longer, and it is possible that this influences the way they take in and absorb glucose. Nonetheless, this study indicates that sugar does have a significant effect on brain structure, and that more work must be done to investigate the role it plays aspects related to EF.

One way to look at the interaction of sugar and cognition is by examining diabetics, as diabetes is a disorder of the way the body processes insulin—one of the components of sugar. Examining the cognitive processes of someone who is known to have different processing of sugar than a control sample can show the way they are related. Bangen et al. (2015) examined a large sample of adults from the Washington Heights—Inwood Columbia Aging Project.

Participants came from a diverse sample (White 36.4%, Non-Hispanic black 31.4%, Hispanic 31.0%), providing a nice contrast to studies such as those done by Akintola et al. (2015). Those with diabetes had worse baseline performance on all cognitive measures when compared with a healthy control. This is expected as it has been shown in middle-aged adults that cognitive decline begins in the prediabetic stages and continues to progress downwards (Rejimer, YD et al., 2010, as cited in Bangen et al., 2015). This change seen hints at the importance of working sugar processing system when it comes to cognitive function. When there is a disrupted mechanism, the risk for cognitive decline significantly increases, putting all those with prediabetes and diabetes—about 50% of adults aged 65 and older in the U.S. (National Diabetes Fact Sheet, as cited in Bangen et al., 2015)—at even further risk for cognitive decline. The association between sugar and cognitive function must be investigated due to this large at risk population. It is known that sugar can have a detrimental effect on EF, and this should be investigated in conjunction with the diabetes research to see whether it can be changed.

Current Study

The current study seeks to further investigate what role sugar plays in human cognition—specifically looking at different aspects of EF. As has been seen, there can be both positive and negative effects on cognition due to the ingestion of sugar. This study aims to re-conceptualize that question within a broader framework, specifically, whether the sugar that people have consumed within the past 24-hours influences whether there is a positive or negative effect on their scores on measures of EF, and whether this effect is influenced by sugar consumption in the past year. Ideally, this will provide more information about the various effects that sugar can have on an otherwise healthy adult sample. Previous research has indicated that sugar consumption can have a positive effect on tasks involving working memory, a facet of executive function. This study will employ tasks measuring different aspects of EF see what specific effect sugar consumption has upon them.

Prior research is clear about two things: sugar can have both negative and positive effects. However, the research that finds this does not examine the glucose effect within a framework of lifetime sugar consumption. This study aims to examine this possible interaction, and to provide more information about the ways in which sugar can influence people across a span of sugar consumption patterns. This study posits that the effect of acute sugar consumption upon EF must be examined within the larger framework of lifetime sugar consumption.

Cognitive research has shown mixed results on the effect of sugar on measures of executive function. The strongest results—in both human and animal models—have been when examining measures of aspects of EF (van der Zwaluw et al., 2014; Donohoe & Benton, 2015; Stollery & Christian, 2015; Mohanty & Flint, 2001). The current study will be examining this relationship.

Hypotheses

It is hypothesized that acute sugar consumption will significantly predict scores on measures of aspects of EF, with higher acute sugar consumption leading to significantly better scores on cognitive measures. It is hypothesized that the opposite effect will be seen with chronic sugar consumption, with lower chronic sugar consumption significantly predicting better scores on cognitive measures. It is thought that chronic sugar consumption will significantly moderate the relationship between high acute sugar consumption and scores on cognitive measures.

Method

Participants

Participants were recruited using an online work distribution site from Amazon. 79.64% of participants (n = 1,024) identified as white. 93.66% of participants were between 18 and 59 years old, 6.34% were 60 or older, with 31.32% between the ages of 30 and 39, and 30.82% between 21-29. 35.59% of participants had completed a Bachelor's degree, and 54.38% were currently employed and working full-time.13.32% of participants were currently part of the supplemental nutrition assistance program (SNAP), colloquially known as receiving food stamps. BMI of participants ranged from 12.91 to 70.847. For their time, Amazon participants were paid between $0.75 and $1.00. IP addresses were restricted to the United States, but were not collected in order to ensure the anonymity of the participants. Participants verified that they were at least 18 years old on the consent form. Age, race, height and weight were self-reported. Of the 1,024 participants who completed the survey part of the study 428 completed the Corsi Block Tapping Task, 348 completed the N-Back 2-Back, 339 completed the N-Back 3-Back and 274 the Arrow Flanker Task.

Materials

Estimated Daily Intake for Sugar Scale (EDIS-S). A survey created by Privitera & Wallace, (2011) to measure sugar intake that is composed of 11 seven-point Likert-type scale responses. Statements are about typical sugar consumption (i.e. "I tend to eat cereals that have sugar in them") and participants rate how well they feel that fact applies to them. Reliability was found to be $\alpha = 0.897$ by examining corrected item-total correlation. Validity of the measure related to general liking for sugars was found to be $r = 0.411$ (Privitera & Wallace, 2011). Participants filled out the scale twice, the first time to assess sugar intake within the past day, and then for lifetime consumption.

Self-Rated Diet Quality Questionnaire (SRDQM). A one-question survey (Loftfield, Immerwahr, & Eisenhower, 2015) that asks people to self-rate on a five-point Likert-type scale how healthy the feel their diet is: *In general, how healthy is your overall diet? Would you say (1) excellent, (2) very good, (3) good, (4) fair, (5) poor*. Participants filled out one for the last 24-hours of their diet, and one for lifetime sugar intake. According to a construct validity test carried out by Loftfield et al. (2014), of 2,305 participants surveyed sugar-sweetened beverage consumption significantly increased as ratings worsened ($p < .001$).

Energy Balance Related Questionnaire (EBRBQ). Created by Singh et al. (2009) this questionnaire assesses energy expended (in modes such as biking and walking to school/work) and energy taken in (consumption of soft drinks and juices, and sweet snacks) within a given week. Answers are given on a six-point scale *none* to *everyday*. The scale adopted validated questionnaires on dietary intake (van Assema, et al., 2002; van Assema, et al, 2001), television viewing (Robinson, 2001), and physical activity (Booth, et al., (2002)). These measures were validated by correlating their questionnaires to larger, in depth, surveys of diet, television viewing, and physical activity, respectively. The previously found validity of these previous scales followed through to the current one. The scale was given twice, for lifetime and recent consumption, with the second administration amended to have participants fill it out for the last 24-hours.

Arrow Flanker Task. Created by Stoffels & van der Model (1988) the flanker task measures a participant’s attention and ability to deal with interference. A focusing cross appeared first for 1000 milliseconds to show the participant where the stimulus would appear. Five arrows served as the stimuli, pointing to the right or to the left. The stimulus would appear on the screen for 1750 milliseconds. When the task was congruent all five arrows would point in the same direction. When the task was incongruent the central arrow would point in the opposite direction of its flanking arrows. Participants were instructed to press the “p” key on the keyboard as quickly as possible if the central arrow pointed to the right and the “q” key if the central arrow pointed to the left. Halfway through the task these keys switched, and participants were told to press the “q” if the central arrow pointed to the right, and the “p” key if the central arrow pointed to the right. Twenty practice trials were given, followed by two experimental blocks of 100 trials each. The dependent measure was the mean reaction time for congruent trials subtracted from the mean reaction time for incongruent trials, which resulted in the congruency effect.

N-Back Task. Created by Jaeggi et al., (2010) this task was used as part of a study on WM. This task measures WM capability, by presenting participants with a stream of visual stimuli, and having them mark when the current image is the same as what was presented two, or three images ago. Eight visual stimuli (abstract shapes) were shown to participants for 500 milliseconds each, after which there would be a 2500 millisecond break. Participants pressed the “A” key to indicate when the target stimulus was presented. When doing the 2-back task, participants had to press “A” whenever the stimulus on the screen was the same as the one presented two previously. When doing the 3-back task participants had to press “A” whenever the stimulus was the same as the what was shown three images ago. Each level (2-back and 3-back) was presented for 3 blocks, resulting in 6 blocks total. Each block had 20+ trials, with six targets and 14+ non-targets. Because this task requires both the encoding of the image, and processing of the previous one, it is a gold-standard test of WM. According to Jaeggi et al. (2010) this task has a significant construct validity, of $p < .001$, which was found by correlating three different versions of the task. Reliability ranged from .54 to .80, depending on the stimulus presented, this was found by correlating with two other working memory measures (Ravens

Advanced Progressive Matrices and Operation Span Task) (Kane, M.J., et al., 2007). The dependent measures from this task were the 2-back percent correct mean and 3-back percent correct mean.

Corsi's Block Tapping Task. Created by Corsi (1972), this task is used to measure short-term memory. Nine boxes are presented on screen, and a sequence of blocks lighting up is demonstrated. Participants are asked to repeat the sequence that was shown to them by clicking the boxes on the screen in the correct order. The sequence length starts at two boxes, and can go up to nine. Participants get two chances at each sequence length; if they fail both the task ends. While this is a widely used test, no real reliability or validity information is available (Berch et al., 1998). The dependent measure from this task is total blockspan attained.

Procedure

Participants from Amazon's online work distribution site, mTurk, were directed to a SurveyMonkey link where the first page was the informed consent for this study. All research questions were disclosed, and workers were made aware of their ability to make a contribution to the project. They were also told what types of questionnaires they would be filling out, and were instructed that if they felt at all uncomfortable with the questions they could quit the task at any time. The first thing participants did on SurveyMonkey was create a unique four digit code as their worker ID, this was also the code they entered into mTurk to signify completion of the task and receive payment. Participants then completed demographic sugar consumption questionnaires. While previous research looked at sugar consumption in a controlled time frame, the current study evaluated acute sugar consumption by having participants think of their diet in the last 24-hours to approximate a contained time period. At the end of the survey they were given the link to the cognitive tasks on the Millisecond software platform. Participants had to download the software in order to complete the tasks. At the end of the cognitive tasks Millisecond automatically redirected participants to the debriefing page, also hosted by SurveyMonkey. Participants were instructed to return to Amazon's worker distribution page and submit their 4-digit unique code. In the case that participants decided to quit out of the cognitive tasks and go back to the SurveyMonkey page the survey also ended with the debriefing and payment instructions.

Analysis

T-tests were executed to see if there was a significant difference between chronic and acute sugar consumption. To view the relationship between the different sugar questionnaires correlations were computed. Linear regression was used to investigate whether acute sugar consumption was a predictor of scores on the tasks of spatial working memory. All sugar intake measures were summed to create a total intake variable for each of the three measures, this was done for both chronic and acute sugar intake. An interaction effect of chronic sugar consumption and acute sugar consumption was created to investigate whether this would serve as a moderating variable upon the relationship between acute sugar consumption and each task of spatial working memory. Principal components analysis was used to examine both sugar intake questionnaires and cognitive measures. Linear regression was run using each task of EF as the dependent variable, with acute sugar intake (EDIS_Day_Sum, EBRBQ_Day_Sum, & SRDQM_Day_Sum) and the interaction effect of acute and chronic sugar intake (EDIS_DayXEDIS_Year, EBRBQ_DayXEBRBQ_Year, SRDQM_DayXSRDQM_Year). Analysis was first run looking solely at acute sugar intake, and then the interaction variable of chronic and acute sugar intake was added in.

Ethics

The study investigated whether factors related to diet can change scores on measures of aspects of EF. While the study might have been a bit boring for participants, it was hoped that this would provide information about the relationship between sugar consumption and aspects of executive function. Hopefully, society at large will benefit from the knowledge gained about what role sugar consumption can play in influencing cognition.

The study itself was deemed to be minimal risk. The procedure did not call for tasks that participants would not undertake in their own daily lives. The one risk that was anticipated was mild boredom during the cognitive testing. Participation in this study was entirely voluntary. During the introduction of the study all participants were told they were free to stop participation at any point, and that it would not impact the payment that they received. The participants (all adults on mTurk over 18 years old) were not part of a protected population.

The only part of the study that involved sensitive information was the demographic information given, specifically height and weight. This information was necessary to collect it could be examined whether BMI predicted scores on cognitive measures. It was important to receive this information to better understand the health risks that currently affect the population. All data was anonymized, and the researchers never knew which participants gave what answers. All participants were assigned a study number. All data was put into a spreadsheet that only the researcher had access to. Finally, the study did not include any deception. All information regarding the study was presented upfront, and then reiterated during debriefing.

Results

Data were organized and cleaned separately before being linked. Once the data were merged Q-Q plots were constructed and examined for normalcy. 100 outliers were removed, and log transformations were executed to make the data as normal as possible.

Sugar Scales

Overall chronic and acute sugar consumption was examined. Items on both the EDIS and EBRBQ were totaled to create a composite score for each measure. The SRDQM has only item so a composite score was not necessary. This was done for both chronic and and acute versions of the measures. The mean and standard deviation of each measure was calculated (Table 1) A paired sample t-test was executed to see if average scores between chronic and acute consumption were significantly different. Chronic sugar intake as measured by the EDIS was significantly higher than acute consumption, $t(974) = 18.856$, $p < 0.001$. However, there was no significant difference between average chronic sugar consumption and average acute sugar consumption as measured by the SRDQM, $t(937) = -0.122$, $p = 0.903$. The average chronic sugar consumption as measured by the EBRBQ could not be compared to acute sugar consumption of the EBRBQ due to the different number of items the scale contained.

Table 1. Mean scores of both chronic and acute sugar consumption

Scale	**Chronic Mean**	**Chronic SD**	**Acute Mean**	**Acute SD**
EDIS**	41.262	11.487	35.494	12.347
SRDQM	3.142	0.935	3.151	1.072
EBRBQ	18.636	4.196	2.867	0.379

Pearson correlation values were calculated to see how well correlated the sugar intake questionnaires were to each other. For acute sugar intake, the EDIS was significantly correlated to the SRDQM, with $r = 0.265$, $p < .001$. The EBRBQ was not significantly correlated to the EDIS with $r = -0.059$, $p = 0.071$. Additionally, the EBRBQ was not significantly correlated to the SRDQM with $r = 0.063$, $p = 0.055$. In summary, assessments of acute sugar intake were not significantly correlated, and therefore appeared to be tapping into different aspects of acute sugar consumption. However, when examining chronic sugar consumption all measures were significantly correlated. The EDIS was significantly correlated to the SRDQM with $r = 0.348$, $p < 0.001$, and to the EBRBQ with $r = 0.419$, $p < 0.001$. The SRDQM was significantly correlated to the EBRBQ with $r = 0.316$, $p < 0.001$. These findings that assessments of chronic sugar consumption measured similar aspects of chronic sugar consumption behavior.

A principal components analysis was executed using the six measures of sugar consumption. Five of the six measures had correlations of at least 0.3 with at least three other measures. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.641. Bartlett's test of sphericity was significant with $\chi 2$ (15) = 1582.252, $p < 0.001$. Examination of the eigenvalues showed that the first two factors explained 42.71% and 20.27% of the variance respectively. Factors three, four, five, and six had eigenvalues less than one and cumulatively accounted for 37.02% of the variance. Given this information, a principal components analysis was deemed acceptable and executed. Due to the given variance, and the scree plot (Figure 3), the two factor model was preferred.

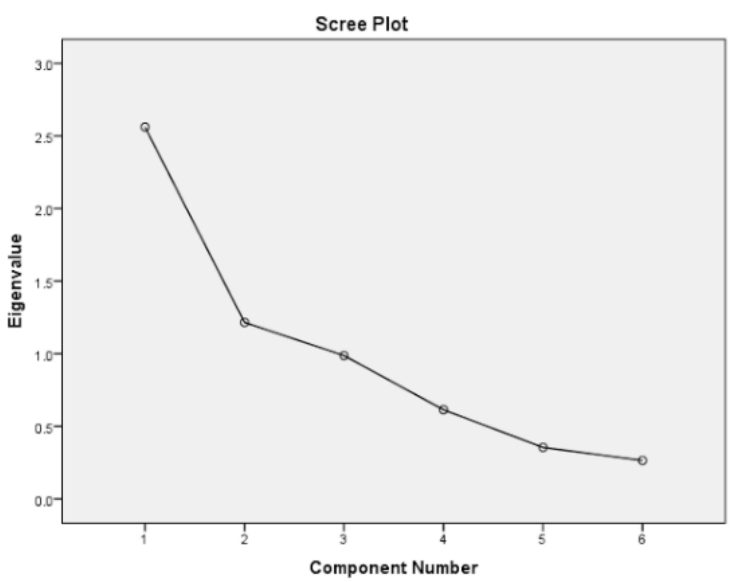

Figure 2. Scree Plot of the Principal Components Analysis of Sugar Consumption

There was no significant difference between varimax and and oblimin rotations, therefore, a varimax rotation was used. The individual items of each measure (see Appendix A) were examined, and labels were fit to the extracted factors (Table 2). In summary, there appears to be a strong rationale to consider two factors, Health of Diet and Health of Lifestyle from the six questionnaires administered.

Table 2. Rotated Component Matrix. Components less than 0.3 are suppressed.

	Health of Diet	**Health of Lifestyle**
EDIS _YEAR	0.792	
SRDQM_DAY	0.321	0.811
SRDQM_YEAR		0.832
EDIS_DAY	0.798	-0.421
EBRBQ_YEAR	0.687	
EBRBQ_DAY	-.420	0.495

Cognitive Tasks

The mean scores of each cognitive task were calculated, along with their standard deviation (Table 3) A paired samples t-test was run to verify that participants took significantly longer to complete the incongruent part of the arrow flanker task compared to the congruent part. The t-test was significant, with $t(273) = -7.188$, $p < 0.001$. A similar test was run to verify that participants did significantly worse on the 3-back version of the n-back task, compared to the 2-back. This t-test was also significant with $t(338) = 11.894$, $p < 0.001$. All expected effects of the cognitive tasks were found to hold true in this study.

Table 3. Average and standard deviation of scores on cognitive tasks

Scale	**Mean Score**	**SD**

Corsi Block Span	5.736	1.688
Flanker Task Congruent Reaction Time	517.772 milliseconds	142.079 milliseconds
Flanker Task Incongruent Reaction Time	537.784 milliseconds	126.286 milliseconds
2-back percent correct mean	0.768	0.102
3-back percent correct mean	0.71	0.099

Pearson correlation values were calculated to see how well correlated the measures of EF were with each other measure. The only significant correlation was between the N-back 2-back correct mean, and N-back 3-back correct mean, with r (339) = 0.614, p < 0.001. The N-back 2-back correct mean was not significantly correlated to the Corsi block tapping task, with r (348) = 0.73, p = 0.174, nor was it significantly correlated to the arrow flanker task, with r (274) = -0.004, p = 0.941. The N-back 3-back correct mean was not significantly correlated to the Corsi block tapping task, with r (339) = 0.006, p = 0.918; nor was it significantly correlated to the arrow flanker task, with r (266) = -0.113, p = 0.065. Finally, the arrow flanker task was not significantly correlated to the Corsi block tapping task, with r (274) = -0.033, p = 0.587.

Since the cognitive measures were not correlated to each other a principal components analysis was executed to examine what components they were each measuring. The Kaiser-Meyer-Olkin measure of sampling adequacy was 0.498. Bartlett's test of sphericity was significant with $\chi2$ (10) = 377.464, p < 0.001. Examination of the eigenvalues showed that the first three factors explained 38.265% and 29.703%, and 19.993% of the variance respectively. Factors four and five had eigenvalues less than one and cumulatively accounted for 12.1% of the variance. Given this information, a principal components analysis was deemed acceptable and executed. Due to the given variance, and the scree plot (Figure 4), the three factor model was preferred (Table 4). These three factors are tapping into different aspects of EF, specifically susceptibility to interference, nonverbal working memory, and short-term memory.

Figure 4. Scree Plot of the Principal Components Analysis of Aspects of Cognition

Table 4. Rotated Component Matrix of Cognitive Measures. Components less than 0.3 are suppressed.

	Susceptibility to Interference	Nonverbal Working Memory	Short-Term Memory
Corsi Blockspan			.999
N-back 2-back Correct Mean		.890	
N-back 3-back Correct Mean		.902	
Flanker Task Mean Reaction Time for Congruent Stimuli	.944		
Flanker Task Mean Reaction Time for Incongruent Stimuli	.936		

Arrow Flanker Task

A linear regression was executed examining the predictive power of acute sugar consumption in determining scores on the arrow flanker task. Acute sugar consumption was not a significant predictor of the arrow flanker task, $F(3, 243) = .283$, $p = .837$, $r^2 = 0.003$. Adding in the moderating interaction variable of chronic and acute sugar consumption did not affect the relationship, with $F(6, 238) = .283$, $p = .944$, $r^2 = 0.007$. On its own, chronic sugar consumption was not a significant predictor of scores on the arrow flanker task, with $F\ (3, 245) = 0.489$, $p = 0.691$, $r^2 = 0.006$.

N-Back Task

A linear regression was run to see if acute sugar consumption significantly predicted scores of the n-back task. Acute sugar consumption was not a significant predictor of 2-back correct mean, with $F(3, 339) = .182$, $p = .909$, $r^2 = .002$. The moderating interaction variable of chronic and acute sugar consumption did not add significantly to the relationship, $F(6, 334) = .617$, $p = .717$, $r^2 = .007$. Chronic sugar consumption was not a significant predictor, with $F(3, 342) = .746$, $p = .525$, $r^2 = .002$. A similar test was executed to examine the predictive power of acute sugar consumption upon the 3-back correct mean, it was non-significant $F(3, 330) = 1.03$, $p = .381$, $r^2 = 0.009$. The interaction variables of chronic and acute sugar consumption did not change the relationship; a linear regression showed that it was still not significant with $F(6, 325) = 0.824$, $p = 0.552$, $r^2 = 0.015$. The same non-significance was seen when examining chronic sugar consumption as a predictor, it was found that $F\ (3, 333) = 0.713$, $p = 0.545$, $r^2 = 0.003$

Corsi Block Tapping Task

A linear regression was executed to examine whether acute sugar consumption was a significant predictor of scores on the Corsi block tapping task. No significance was found, with

$F(3, 419) = .393$, $p = .758$, $r^2 = 0.003$. The regression was repeated and included the interacting variable of chronic and acute sugar consumption did not moderate this effect, $F(6, 413) = .260$, $p = .955$, $r^2 = 0.004$. Chronic sugar consumption was not found to be a significant predictor, $F(3, 421) = .296$, $p = .828$, $r^2 = .005$

BMI

A linear regression was run to examine whether BMI was a significant predictor of performance on the cognitive tasks. BMI was not a significant predictor of the Corsi block tapping task, $F(1, 413) = 0.879$, $p = 0.349$, $r^2 = 0.002$, arrow flanker task $F(1, 247) = 1.209$, $p = 0.273$, $r^2 = 0.005$, the 2-back, $F(1, 343) = 0.497$, $p = 0.481$, $r^2 = 0.001$; or 3-back task, $F(1, 334) = 0.112$, $p = 0.738$, $r^2 < 0.001$.

Age

A linear regression was run to see if age was a significant predictor of any of the tasks of EF. Regression showed that it was not a significant predictor: for 2-back $F(1, 345) = 1.647$, $p = 0.200$, $r^2 = 0.005$, for the 3-back $F(1, 336) = 0.101$, $p = 0.751$, $r^2 < 0.001$, on arrow flanker task $F(1, 248) = 1.034$, $p = .310$, $r^2 < 0.001$, and on Corsi Block Tapping $F(1, 425) = 0.110$, $p = 0.740$ $r^2 < 0.001$.

Discussion

This study examined the relationship between aspects of EF and consumption of sugar. Previous literature has not examined this interaction within a framework of both lifetime and recent sugar consumption. This research aimed to rectify that, as the competing knowledge that sugar is both bad—and good—for cognition is confusing to parse and understand. If recommendations are going to be made about sugar intake to the general public, more information must be gained. By gathering information about sugar consumption over the past year, and last the 24-hours, it was hypothesized that acute sugar consumption would serve as a significant predictor of scores on measures of EF, and this relationship would be moderated by chronic sugar consumption. However, this effect was not seen. In line with work done by Ullrich et al. (2015), neither chronic nor acute sugar consumption proved to be significant predictors of scores on measures of EF.

The measures of sugar consumption that were used for this study were picked to cover a broad range of sugar intake. Correlations revealed that the EDIS and SRDQM were significantly correlated for measuring acute sugar consumption. The EBRBQ was not correlated to either the EDIS or SRDQM, indicating that it was not internally valid. It is possible that the removal of certain items from the EBRBQ significantly changed its correlation to both the EDIS and SRDQM. A principal components analysis was executed to examine what main components were being measured from the sugar questionnaires. From looking at the items on the individual measures it was determined that the EDIS and SRDQM were mostly measuring health of overall diet, while the EBRBQ measured health of overall lifestyle. The EDIS and SRDQM were able to measure similar types of acute sugar consumption, while the EBRBQ was also looking at variables related to sugar consumption, such as screen use and exercise. For chronic consumption, all three measures were significantly correlated. The significant correlation of all chronic sugar intake questionnaires indicates that they all measured the same constructs of sugar consumption, specifically in food choices made. Overall, the questionnaires used were mostly examining one thing—sugar consumption. If there was an effect of sugar consumption upon the measures of executive function a significant relationship would have been viewed. The EDIS, in particular, is the one most likely to have shown this effect. The lack of significant relationship indicates that sugar consumption may not have an effect upon aspects of executive function as assessed in this study.

Participants reported significantly higher chronic sugar consumption than acute sugar consumption on the EDIS. All sugar consumption scales were based on self-report, which is a report measure with inherent flaws. Both under and over reporting are common in these measures due to the limits of human memory. From a social desirability standpoint participants might have underreported their sugar consumption to make themselves more socially desirable. Therefore, while this difference is significant it is possibly due to confounds in the self-reporting. There was a lack of a significant difference between scores on chronic and acute sugar consumption as measured by the SRDQM, participants did not perceive their diet in the last day as different from their diet in the last year. However, this measure had only one item, and therefore it is possible that it insensitive. Because the EBRBQ had to be amended for acute consumption it could not be compared to its measurement of chronic consumption. Therefore, it cannot be used to come to overall conclusions about significant differences between chronic and acute sugar consumption. Additionally, there is a general lack of awareness about the types of foods that have added sugar to them. Any item asking about frequency of eating sugary foods is entirely dependent on what the participant perceives as a food with added sugar. The impression that someone has of their sugar consumption could be completely unrelated to their actual sugar consumption. These issues show that external validity is likely quite low for the sugar consumption questionnaires. All questionnaires related to sugar consumption relied upon the participant’s memory of their diet both in the last year, and last day. Due to the inherent fallibility of human memory it is surmised that these measures are not entirely reliable. This, on top of the lack of external and internal validity, most likely created additional noise and variability in the data.

Using an online worker population with a simple methodological design means that there are many ways in which this epidemiological study is limited. There was an extremely high attrition rate, over 350%, between the sugar questionnaires and cognitive tasks. While this significantly reduced the sample size, it would have still possibly shown any relationship between sugar and EF. This attrition rate is partly due to technical difficulties, the platform that was being used for the cognitive tests is one that the participants had to load and use themselves. Many participants reported issues with the cognitive task software working on their computer, for some, it quit halfway through the tasks. It is possible that people who are high sugar consumers decided to not finish the study after seeing the questionnaires. According to the principal components analysis all cognitive measures fall into different components, indicating that they all managed to measure different aspects of EF. However, due to the survey being taken online additional noise was most likely introduced into the data, which could possibly be obscuring any given effect. Results from this study contradict what was found by Hope et al. (2009), and this is possibly due to the additional noise introduced.

While a fair amount of noise was most likely introduced into the data, there were still a relatively powerful sample attained, indicating that if there was a significant relationship the data would have shown a significant effect. Previous studies, with smaller sample sizes, were able to show a significant relationship between sugar consumption and measures of cognition (van der Zwaluw, et al., 2014; Stollery & Christian, 2015). This lack of significant relationship runs contrary to previous literature—such as Hope et al. (2009)—indicating that the specific measures of EF used in this study are not actually effected by sugar consumption. Previous studies may have found significant relationships due to both more accurate measures of sugar consumption, and by narrowing in on one specific aspect of EF to assess. Work done by Donohoe & Benton (2000) found a significant relationship between sugar consumption and spatial working memory, however they measured sugar levels using blood glucose levels. Participants had to fast for ten hours before coming into the lab to ensure accurate measurements. This is a much more reliable measure of sugar consumption than human memory. Additionally, Mohanty & Flint (2001) gave participants sugar supplements based on their weight, to ensure an accurate and titrated dose. While this does not control for baseline sugar consumption, it does introduce greater external validity as researchers were able to tell exactly how much sugar had been consumed by participants. Donohoe & Benton (2000) examined spatial working memory using a variety of measures to make sure to hit at all different parts of it.

The current study used different measures to evaluate various aspects of EF. However, no previous study has evaluated the effect of both chronic and acute sugar consumption upon EF. This more in depth investigation into parsing out types of sugar consumption hints that there is no real effect between dietary sugar and aspects of EF. It is possible that the opposite effects of chronic and acute sugar consumption upon EF canceled each other out. However, due to the large sample size, it is likely that there would have still been participants with low chronic sugar consumption and high acute sugar consumption—and vice versa—which would have shown the predicted effect. Additionally, the separate regressions that were run examining chronic and acute sugar consumptions effect upon aspects of EF might still have been significant, even though the interaction effects would not be.

Further research should examine this effect within a lab based setting. One way to gain more control over the procedure would be to have participants record a food diary over a sustained period of time so that their sugar intake could be evaluated by the researchers themselves. Additionally, using a simple blood glucose test sample would greatly increase validity of personal sugar levels. Having participants come in monthly would allow researchers to compare both chronic and acute glucose levels. By requiring participants to come in to measure blood glucose levels and complete the cognitive tasks much more control could be had over the study. Future research should continue to examine the interaction of short and long-term sugar use on processes related to all cognitive systems—the null effect it was found to play upon EF might not hold true for other processes. It is only when looked at within this broader framework can a true understanding of the role that sugar plays on cognition be had. Should it prove possible, similar studies should be carried out with an added element of neuroimaging. More information about the way that sugar affects neural structures be gained through fMRI or PET scans. While a null effect was found in this study, it does not preclude significant results being found on the effect of sugar upon the brain's other processes. Due to significant results found in the past, the field is still open to this investigation, though further research should take this study's findings into account. The effect of nutrition upon cognitive processes continues to be parsed out, and the results presented from this study aim to aid in this discovery.

Broadly, the general population's current perception of sugar is not good. It is avoided and substituted by many due to a general lack of understanding and fear. This study indicates that there is neither a positive nor negative effect between sugar consumption and some aspects of EF. Specifically, the data gathered from this study hoped to provide a greater understanding about the way sugar affects people within a broader framework of diet and nutrition. Research from this study indicates that when looking solely at varying aspects of EF there is no reason to either encourage, or discourage, its consumption. The general fear and anxiety surrounding sugar is not supported by this study. This investigation aimed to be a first step in providing concrete reasons why sugar should, or should not, be consumed by the general population. Due to the lack of significant relationship found by this study, sugar intake—both chronic and acute—does not appear to influence scores on measures of aspects of EF. Any role it plays in other cognitive processes should continue to be investigated, however, this study indicates that there is not a concrete relationship between dietary sugar consumption and processes related to EF.

References

Akintola, A. a., van den Berg, A., van Buchem, M. a., Jansen, S. W., Slagboom, E. P., Westendorp, R. G., van der Grond, J., van Heemst, D. (2015). Associations between insulin action and integrity of brain microstructure differ with familial longevity and with age. *Frontiers in Aging Neuroscience*, *7*(May).

Baddeley, A. D., Allen, R. J., & Hitch, G. J. (2011). Binding in visual working memory: The role of the episodic buffer. *Neuropsychologia*, *49*(6), 1393-1400.

Banich, M. T. (2009). Executive function the search for an integrated account. *Current Directions in Psychological Science*, *18*(2), 89-94.

Beilharz, J. E., Maniam, J., & Morris, M. J. (2014). Short exposure to a diet rich in both fat and sugar or sugar alone impairs place, but not object recognition memory in rats. *Brain, behavior, and immunity*, *37*, 134-141.

Best, T., Kemps, E., & Bryan, J. (2010). Saccharide effects on cognition and well-being in middle-aged adults: a randomized controlled trial. *Developmental Neuropsychology*, *35*(1), 66–80.

Coley, N., Vaurs, C., Andrieu, S. (2015). Nutrition and Cognition in Aging Adults. *Clinical Geriatric Medicine, 31,* 453-465.

Dalm, S., Schachinger, H., Oitzl, M.S. (2009). Post-training self administration of sugar facilitates cognitive performance of male C57BL/6J mice in two spatial learning tasks. *Behavioral Brain Research, 198*. 98-104.

Donohoe, R. T. & Benton, D. (2000). Glucose tolerance predicts performance on tests of memory and cognition. *Physiology & Behavior ,71,* 395-401.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & psychophysics*, *16*(1), 143-149.

Franics, H., Stevenson, R. (2013). The longer-term impacts of Western diet on human cognition and the brain. *Appetite, 63*, 119-128.

Hill, S. E., Prokosch, M.L., Morin, A., Rodeheffer, C.D. (2014). The effect of non-caloric sweeteners on cognition, choice, and post-consumption satisfaction. *Appetite, 83,* 82-88.

Hope, C., Seiss, E., Dean, P.J.A., Williams, K.E.M., Sterr, A. (2013). Consumption of glucose drinks slows sensorimotor processing: double-blind placebo-controlled studies with the Eriksen flanker task. *Frontiers in Human Neuroscience, 7,* 1-10.

Kendig, M.D., Boakes, R.A., Rooney, K.B., Corbit, L.H. (2013). Chronic restricted access to 10% sucrose solution in adolescent and young adult rats impairs spatial memory and alters sensitivity to outcome devaluation. *Physiology & Behavior, 120*, 164-172.

Lamport, D.J., Hoyle, E., Lawton, C.L., Mansfield, M.W., Dye, L. (2011). Evidence for a second meal cognitive effect: glycemic responses to high and low glycemic index evening meals are associated with cognition the following morning. *Nutritional Neuroscience, 14(2),* 66-71.

Lien, M., Lien, N., Heyerdah, S., Thoresen, M., Bjertness, E. (2006). Consmuption of soft drinks and hyperactivity, mental distress, and conduct problems among adolescents in Oslo, Norway. *American Journal of Public Health, 96(10),* 1815-1820.

Luchsinger, J.A., Cabral, R., Eimicke, J.P., Manly, J.J,, Teresi, J. (2015). Glycemia, Diabetes Status, and Cognition in Hispanic Adults aged 55-64 Years. *Psychosomatic Medicine, 77,* 653-663.

Milich R., Wolraich, M., Lindgren, S. (1986). Sugar and hyperactivity: A critical review of empirical findings. *Clinical Psychology Review, 6,* 493-513.

Mohanty, A., & Flint, R. W. (2001). Differential effects of glucose on modulation of emotional and nonemotional spatial memory tasks. *Cognitive, Affective, & Behavioral Neuroscience, 1*(1), 90-95.

Morris, N., Sarll, P., (2001). Drinking glucose improves listening span in students who miss breakfast, *Educational Research, 43(2),* 201-207.

Morris, M.J., Beilharz, J.E., Maniam, J., Reichelt, A.C., Westbrook, R.F. (2014). Why is obesity such a problem in the 21st century? The intersection of palatable food, cues, and reward pathways, stress, and cognition, *Neuroscience and Biobehavioral Reviews.*

Reichelt, A.C., Maniam, J., Westbrook, R.F. (2015). Dietary-induced obesity disrupts trace fear conditioning and decreases hippocampal reelin expression. *Brain, Behavior, and Immunity, 43,* 68-75.

Reichelt, A. C., Killcross, S., Hambly, L.D., Morris, M.J., Westbrook, R.F. (2015). Impact of adolescent sucrose access on cognitive control, recognition memory, and parvalbumin immunoreactivity. *Learning and Memory, 22,* 215-224

Salthouse, T. A., & Davis, H. P. (2006). Organization of cognitive abilities and neuropsychological variables across the lifespan. *Developmental Review*, *26*(1), 31-54.

Stangor, C. (2015). *Research methods for the behavioral sciences* (5th ed). Belmont, CA: Wadsworth, Inc.

Stollery, B., & Christian, L. (2015). Glucose improves object-location binding in visual-spatial working memory. *Psychopharmacology*, 1-19.

Stranahan, A.M., Norman, E.D., Lee, K., Cutler, R.G., Tellijohann, R.S., Egan, J.M., Mattson, M.P (2008). Diet-induced insulin resistance impairs hippocampal synaptic plasticity and cognition in middle-aged rats. *Hippocampus, 18,* 1085-1088.

Seetharaman, S., Andel, R., McEvoy, C., Aslan, A.K.D., Finkel, D., Pederson, N.L. (2015). Blood glucose, diet-based glycemic load and cognitive aging among dementia-free older adults. *Journal of Gerontology, 70(4),* 471-479.

Ullrich, S., de Vries, Y.C., Kühn, S., Repantis, D., Dresler, M., Ohla, K. (2015). Feeling smart: Effects of caffeine and glucose on cognition, mood and self-judgement. *Physiology & Behavior, 151*, 629-637.

Wild, S., Roglic, G., Green, A., Sicree, R., & King, H. (2004). Global prevalence of diabetes: estimates for the year 2000 and projections for 2030. *Diabetes Care, 27*(5), 1047-1053.

Yaffe, K., Barnes, D., Nevitt, M., Lui, L.-Y. Y., & Covinsky, K. (2001). A prospective study of physical activity and cognitive decline in elderly women: women who walk. *Archives of Internal Medicine*, *161*(14), 1703–1708.

van der Zwaluw, N. L., van de Rest, O., Kessels, R. P. C., & de Groot, L. C. P. G. M. (2014). Short-term effects of glucose and sucrose on cognitive performance and mood in elderly people. *Journal of Clinical and Experimental Neuropsychology*, *36*(5), 517–527.

Appendix A

Chronic Sugar Measures

Estimated Daily Intake Scale for Sugar

11. Please rate how well the following statements apply to your eating habits over the LAST YEAR

	Completely Disagree						Completely Agree
I tend to eat cereals that have sugar in them.							
I tend to put a lot of syrup on my pancakes or waffles.							
I often eat candy to snack on when I am hungry.							
I tend to crave foods that are high in sugar.							
I tend to snack on healthier food options.							
I tend to consume a low sugar diet.							
I often snack on sugary foods when I am hungry.							
When I crave a snack, I typically seek out sweet-tasting foods.							
I tend to eat foods that are most convenient, even if they contain a lot of sugar.							
I like consuming sweet-tasting foods and drinks each day							
I tend to avoid consuming a high sugar diet							

Self-Rated Diet Quality Measure

12. Please rate how well the following statement applies to your perception of your overall diet over the LAST YEAR

	Excellent	Very good	Good	Fair	Poor
In general, how healthy is your overall diet?					

Energy Balance Related Behavior Questionnaire

13. Please answer the following questions about an AVERAGE WEEK in the PAST YEAR

	None	1	2	3	4	5	6	Every day
How many days a week do you watch television / use the computer?	○	○	○	○	○	○	○	○

14. How long on average did you watch television/use the computer on a usual day. Think about a usual school/work day when answering the question.

Please answer in hours and minutes / day

15. Please think about an average week in the last year

	None	1	2	3	4	5
How many days did you go to school or work by bicycle/on foot in an average week?	○	○	○	○	○	○

16. How many minutes does it usually take for you to bike/walk to school/work in an average week?

Please answer in hours and minutes

17. Please think about a typical week in the past year

	None	1	2	3	4	5	6	Every day
How many days did you drink soft drinks/fruit juices in an average week?	○	○	○	○	○	○	○	○
How many days did you eat savory snacks/sweets in an average week?	○	○	○	○	○	○	○	○

18. On days that you drank soft drinks/fruit juices, how many glasses/bottles/cans did you drink?

Please answer in glasses/day, bottles/day, or cans/day

19. When you ate savory snacks/sweets, how many portions did you usually eat?

Please answer in portions/day

Acute Sugar Measures

Estimated Daily Sugar Intake Scale

20. Please rate how well the following statements apply to your eating habits over the PAST 24 HOURS

	Completely Disagree						Completely Agree
I ate cereals that have sugar in them.							
I put a lot of syrup on my pancakes or waffles.							
I ate candy to snack on while I was hungry.							
I craved foods that are high in sugar.							
I snacked on healthier food options.							
I consumed a low sugar diet.							
I snacked on sugary foods when I was hungry.							
When I craved a snack, I typically sought out sweet-tasting foods.							
I ate foods that were most convenient, even if they contain a lot of sugar.							
I enjoyed consuming sweet-tasting foods and drinks							
I avoided consuming a high sugar diet							

Self-Rated Diet Quality Measure

21. Please rate how well the following statement applies to your perception of your overall diet over the PAST 24 HOURS

	Excellent	Very good	Good	Fair	Poor
In general, how healthy is your overall diet?					

Energy Balance Related Behavior Questionnaire

22. Did you watch television/use the computer in the last day?

- ◯ Yes
- ◯ No

23. How long did you watch television/use the computer in the last day?

Please answer in hours and minutes / day

24. Did you go to school / work on bicycle or foot in the last day?

- ◯ Yes
- ◯ No

25. How many minutes did it take you to bike/walk to school or work?

Please answer in hours and minutes

26. How many glasses/bottles/cans of soft drinks/fruit juices did you drink in the last day?

Please answer in glasses/day, bottles/day, or cans/day

27. How many portions of savory snacks/sweets did you eat in the past day?

Please answer in portions/day