Have Your Cake and Eat It Too:

Glucose Effects on Attention and Memory

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Abstract

The brain is the most metabolically expensive organ in the body. Tasks that recruit areas of the brain regulating cognitive control reduce blood glucose levels at higher rates than other mental tasks (Gailliot & Baumeister, 2007). In this experiment we tested the effects of glucose on memory and attention. Participants completed tasks to assess baseline levels of performance, followed by a fatiguing task to deplete glucose in the central executive. Participants then consumed either a glucose or placebo drink followed by re-administration of the original tasks. The glucose drink significantly increased performance on Backwards Digit Span, and also tended to increase performance on a delayed recall task. However, participants receiving the glucose drink failed to show selective improvements on the Attention Network Task.

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Although it constitutes only 2% of the body's weight, the brain uses approximately 75% of the glucose in the blood, making it the by far the most metabolically expensive organ in the human body (Dunbar, 1998; Kahn, 2005). Glucose (the main type of sugar in the blood) is the primary source of energy for the brain and for the rest of the body. When glucose levels are high, excess glucose is converted and stored as glycogen, which can later be metabolically converted back to glucose and used for energy.

The energy cost is especially high for mental tasks that recruit the "central executive," or the areas of the brain that regulate cognitive and emotional control. These tasks reduce blood glucose levels at higher rates than other mental tasks which do not recruit the executive (Gailliot & Baumeister, 2007). In addition, many tasks which would seem to require self-regulation and executive function suffer when glucose is depleted, and can show improved performance if glucose levels are restored. Such tasks include avoiding prejudiced or stereotype-driven behaviors (Gailliot et al., 2009), being willing to help strangers (DeWall, Baumeister, Gailliot, & Maner, 2008), attention-tracking performance in a dual-task situation (Scholey, Sunram-Lea, Greer, Elliot, & Kennedy, 2009) memory (Meikle, Riby, & Stollery, 2004), complex decision-making (Masicampo & Baumeister, 2008), and persistence in difficult tasks (see Gailliot, 2008 for a review).

Most previous studies have used social-cognition procedures that intuitively seem to require executive processing, but that do not have a direct, controlled comparison between executive and nonexecutive-demanding conditions. Therefore, it is not clear whether glucose has its primary effects on executive function per se, or whether it affects cognition and

performance more globally. For example, long-term low-carbohydrate diets appear to have their major effects on the speed of performance rather than specifically on the executive components of performance (D'Anci, Watts, Kanarek, & Taylor, 2009). On the other hand, short-term increases in executive demands (e.g., Stroop tasks with all incongruent trials) result in greater decreases in blood glucose levels than do speeded tasks without those executive requirements (Stroop with only congruent trials; Fairclough & Houston, 2004). Benton, Owens, & Parker (1994) found that individuals' intrinsic changes in blood glucose were specifically related to their performance on incongruent-Stroop trials, but an experimental administration to increase glucose did not significantly improve performance. However, they note that the failure to see these effects may have occurred because they did not fatigue their participants' executive functions before the glucose administration.

Another subset of previous work in glucose enhancement of cognitive functioning studied the impact of glucose on episodic and working memory. It has been demonstrated that subjects receiving a glucose drink instead of a placebo show a significant benefit in performance in terms of numbers of words recalled 20 minutes after encoding (Sunram-Lea, Foster, Durlach, & Perez, 2002). It was also found that a glucose drink improved the memory of a word list in those with poor glucose regulation (Messier, Desrochers, & Gagnon, 1999). Additionally, Scholey, Harper, and Kennedy (2001) found a significant effect of a glucose drink on the Serial Sevens task, a measure of working memory.

Current Study

In the present study, we compared the effects of a drink sweetened with glucose to a drink sweetened with a non-caloric artificial sweetener (Splenda) on memory and attention tasks administered after a task chosen to fatigue the central executive. Before the fatiguing task,

baseline performance was assessed on delayed free recall of a 29-word list, a backwards digit span test, and the Attention Network Task (ANT; Fan, McCandliss, Sommer, Raz, & Posner, 2002). The long-term memory task was chosen because recall of a word list has been shown to be sensitive to glucose effects (Benton, et al., 1994; Foster, Lidder, & Sunram, 1998; Sunram-Lea, et al., 2002). In the present study, we employ the Backwards Digit Span, another commonly used measure of working memory (Wechsler, 1997). The ANT allows assessment of several aspects of attention (alerting, orienting, and central-executive function) within a single procedure, and also allowed us to examine whether there were differences in glucose-sensitivity for measures of accuracy versus measures of reaction time. Following the baseline assessments, participants completed a Stop-Signal task for an extended period of time (45 minutes). The Stop-Signal task was chosen as the fatiguing task because it has high executive demands that are continually adjusted in response to the subject's performance (Verbruggen & Logan, 2008; other citations in their literature review). Participants then consumed the drink (with either glucose or placebo), filled out questionnaires for 15 minutes to allow for glucose absorption, and completed the second round of the criterion memory and attention tasks.

The primary hypothesis was that participants consuming the glucose drink would show greater improvement in these memory and attention tasks following the drink administration. We also examined data relevant to several secondary questions: Are memory or attention measures more sensitive to the glucose effects? Would the executive component of the ANT measures be especially sensitive to fatigue and glucose effects? Are there differential effects for accuracy and reaction time?

Method

Participants

Sixty-one University of Michigan students (28 female, 33 male, mean age: 18.9 years) participated in this experiment for course credit and a performance-dependent monetary reward. Participants were screened for hypoglycemia and diabetes, and excluded for psychological conditions expected to impact performance, as well as medications used to treat those conditions. Irregular performance on neuropsychological screening exams was also used as a measure for exclusion. 30 additional subjects were excluded because they did not fit the criteria for this study (e.g., failed to comply with pre-task fasting instructions or failed screening). Demographic information for the 61 included subjects can be found in Table 1.

Materials

Glucose/placebo drink and questionnaire. Procedures for the glucose manipulation closely followed those of Gailliot and Baumeister (2007). Subjects consumed a lemonade drink sweetened with either 42 grams of sugar (glucose) or 10.5 grams of Splenda (placebo), a non-caloric artificial sweetener, to achieve an equivalent level of sweetness. Both the experimenter and the subject were blind to the drink being administered (drinks were prepared and labeled by another member of the lab), and subjects were unaware of the glucose manipulation. Consistent with Gailliot and Baumeister (2007), participants were given 14 ounces of the lemonade drink, and 15 minutes were allowed after ingestion to ensure digestion of the glucose. During this 15-minute waiting period, participants completed a filler questionnaire and completed the neuropsychological screening assessments described below. The filler questionnaire asked participants to rank factors such as sweetness and temperature according to their personal preferences. (See Appendix A).

Delayed Recall Encoding (A or B). Participants were asked to encode a word list consisting of 29 words (Wickens, Dalezman, & Eggemeier 1976). The words were presented

one at a time, for two seconds each, in the center of the computer screen (Dell PC, 17" monitor) in black font (Courier New, 18pt font), on a white background. Subjects were told that they would later be asked to remember as many words as possible. The word lists of Wickens, et al. were combined to make two different lists (A and B), each consisting of 29 words (see Appendix B). Each list consisted of different nouns drawn from three different categories. Categories were not re-used across lists, and 9-10 nouns were shown per category on each list. Each subject received both lists (one prior to the glucose/placebo drink, and one following the drink). List administration was counterbalanced to ensure that half of the subjects in each condition would receive word list A first, and half would receive word list B first.

Attention Network Task. This is a computerized attention task which assesses different components of attention: orienting, alerting, and executive control (ANT; Fan, et al., 2002). The primary task is to respond to a center arrow, which is flanked by two other arrows. The center arrow is flanked by a) other arrows pointing in the same (congruent) direction, b) other arrows pointing in the opposite (incongruent) direction, or c) a neutral condition in which the center arrow is flanked by a line on either side. A black fixation cross remains in the center of the screen throughout the duration of the task. Subjects were seated 60 cm away from a 17" Dell PC monitor, so a single arrow or line consisted of 1.1° of visual angle, and a full line of stimuli (center arrow flanked by two arrows or lines on either side), consisted of 6.3° of visual angle.

Changing visual cues signal the subject to expect the presentation of arrows. Warning cues (asterisks) signal the subject to expect the arrows either above the fixation cross ("up"), below the fixation cross ("down"), above and below ("double"), or in the center ("center"). Arrows may also be presented without a cue first ("no"). Each trial consisted of 1) a random variable fixation period, between 400-1600 ms; 2) a warning cue, presented for 100 ms; 3) a

fixation period of 400 ms; 4) stimulus (target arrow and flankers) presentation until subject responded, but not exceeding 1700 ms; 5) variable fixation period, (not exceeding 3500 ms) based on the duration of the first fixation period and performance on the first trial (Fan, et al., 2002). On trials where there was no warning cue, trials consisted of an additional 100 ms of fixation presentation. See Figure 1.

Subjects received verbal and on-screen written instructions to respond via key press (index fingers on "z" and "/" keys on a standard keyboard) to the direction of the center arrow when stimuli were presented. Subjects first completed a practice block of 24 trials, and received reaction time and accuracy feedback after each individual response. Following this practice block, subjects completed the test session, comprised of two blocks, both of which consisted of 96 trials without feedback. Between the first and second test block, participants took a self-paced break, and self-initiated the start of the second test block.

Delayed Recall Test. Participants were asked to recall as many words as possible from the list of 30 words previously encoded. Subjects were given lined paper with enough space for all of the words, and asked to write as many as they could remember from the most recent list presented. Subjects were asked to inform the experimenter when they could not recall any more words.

Backwards Digit Span. The Backwards Digit Span is a commonly-used measure of working memory (Wechsler, 1997). It makes demands on both short-term memory and executive function. On each trial, the experimenter reads a list of single-digit numbers at a rate of one digit per second. The participant's task is to recite the list back to the experimenter in reverse order. Two trials are given at each list size, beginning with a list size of two digits and increasing until the participant cannot complete both trials correctly or reaches the maximum list

size of eight digits. The subject must correctly complete at least one trial at the current list size to be tested on the next list size. The standard scoring system awards one point for each correctly recited list of numbers, for a maximum score of 14 points. The Backwards Digit Span administered following the drink differed only in the single-digit numbers presented to the subject in order to prevent any recall effects. The order in which the different forms were administered was counterbalanced across subjects within each glucose/placebo condition.

Stop-Signal Task. The Stop-Signal task, a computerized response inhibition test, was performed following the first Backwards Digit Span, prior to the glucose/placebo drink. The Stop-Signal program used here was obtained from Verbruggen, Logan, and Stevens (2008). Participants are cued to respond by the appearance of white shapes (a circle or a square) on a black background that appear in the center of the screen. Subjects are asked to respond via key press on a keyboard to which shape is shown (circle = "/", square = "z"). The stimulus remains on the screen until subjects respond or for a maximum of 1250 ms. Between trials, a white fixation cross is present in the center of the screen for 2000 ms. On 25% of the trials, an auditory cue, or a "stop signal" (750 Hz, 75 ms), signals the subject to refrain from responding to the visual cue.

The timing of this stop signal presentation is dependent upon subject performance. Stop signal delay (SSD), the time between the visual stimulus and the auditory stop signal, is originally set to be 250 ms, and changes in response to subject performance. Successful inhibitions increase SSD by 50 ms, while unsuccessful inhibitions decrease SSD by 50 ms. If the subject is successful in stopping his/her response, the stimulus remains onscreen for the full 1250 ms duration. One practice block (32 trials) and 15 experimental blocks (64 trials each) were presented to each subject, and a monetary award was given based on task performance on each

run in order to maximize subject effort. Payment on each run was calculated according to an equation that compared current performance to performance on past test blocks, or, for the first block, the practice session. Improvements in reaction time and accuracy on no-signal trials, increases in the total number of correctly suppressed responses, and decreases in missed responses on no-signal trials were incorporated into this equation (see Appendix C), for a maximum of reward of 50 cents per block. This reaction time and accuracy information is shown on the screen following each block of experimental trials for 10 seconds (Verbruggen, Logan, & Stevens, 2008; Verbruggen & Logan, 2008).

Mini-Mental State Exam (MMSE). The data presented in this paper were collected as part of a pilot study in preparation for a potential larger study that would include healthy, nondemented older adults. We therefore collected two standard dementia screening measures, the Mini Mental State Exam (MMSE; Folstein, Folstein, & McHugh, 1975) and the Short Blessed Test (Katzman, Brown, Fuld, Peck, Schechter, & Schimmel, 1983; described below). Previous experiments in our laboratory have also found that some young adult participants score below the traditional cutoff scores on these tasks. Although it is unlikely that these young adults are demented, they are excluded as it is likely that they are either unmotivated or unable to understand the experimental tasks. The MMSE is a standardized task including orientation questions, simple arithmetic, motor skills, immediate and delayed recall, and language use used to screen for dementia. Scores from 24-30 are considered “normal.” Subjects receiving less than 24 were excluded.

Short Blessed Test (SBT). The SBT is a standardized task including orientation questions, simple arithmetic and delayed recall (SBT; Katzman, et al., 1983). The SBT is also

used in screening for dementia and other cognitive impairments. An error score below 4 is considered "normal." Subjects receiving a 4 or above on the SBT were excluded.

Extended Range Vocabulary Test (ERVT). A paper-pencil task that requires the subject to indicate which of five options is a synonym of a listed word (ERVT, Version 3, Educational Testing Service, 1976). Forty-eight words total are listed. One point is awarded for a correct answer, and one quarter of a point is subtracted for an incorrect answer. Questions can be left blank without penalty. Subjects receiving less than a 9 on the ERVT were excluded.

Procedure

All subjects were asked to fast for the 3 hours prior to the start of the experiment (water was allowed). Participants first completed a written consent form, followed by a health and demographics questionnaire. After verification that all requirements for participation were met (i.e., compliance with fasting instructions and no exclusionary conditions), subjects completed baseline assessments for the criterion tasks (Delayed Recall, Attention Network Test and Backwards Digit Span), then performed the fatiguing task (Stop-Signal) for 45 minutes. They next ingested the glucose or placebo drink, followed by a wait period of 15 minutes to allow for absorption, and then completed the second assessment for the criterion tasks. An outline of the procedure with approximate task durations can be found in Table 2.

Baseline assessment. Encoding of the word list for the baseline Delayed Recall Test occurred immediately after the health & demographics questionnaire. Participants then completed the ANT (approximately 20 minutes). They then attempted to recall the words encoded before the ANT, after which they were tested on the Backwards Digit Span.

Fatigue induction. Participants performed the Stop-Signal task for an extended period (approximately 45 minutes) to induce cognitive fatigue. The experimenter explained the rules of

the Stop-Signal task, in addition to the details of the reward. Subjects were told that their monetary reward would be based on accuracy and reaction time, so they should try to respond as quickly and accurately as possible. In total, the Stop-Signal task took approximately 45 minutes to administer.

Glucose/placebo administration. Immediately following the Stop-Signal task, subjects were given the 14-ounce lemonade drink. During the required 15-minute wait period after ingestion of the lemonade drink, a filler questionnaire and 3 standardized neuropsychological screening tests were administered to the subject. These neuropsychological tests included two dementia screenings, the Mini Mental State Exam (MMSE) and the Short Blessed Test (SBT), in addition to the Extended Range Vocabulary Test (ERVT). Duration of these tests rarely exceeded the 15 minute wait period, and post-test assessment was initiated no sooner than 15 minutes after ingestion of the drink, and no later than 20 minutes.

Post-test assessment. After ensuring that 15 minutes had passed since the subject finished the glucose/placebo drink, the experimenter administered the word list for the second Delayed Recall Test. Following the studying of this second word list, subjects again completed the ANT, which did not differ in any way from its first administration. Subjects were then asked to recall as many words as possible from the most recent word list provided to them. Following the final word list recall, the second Backwards Digit Span was administered to the subject. All subjects were then debriefed and received the reward payment earned during the Stop-Signal task.

Data Analysis

Backwards Digit Span. Two different methods were used for scoring the Backwards Digit Span. To assess the total score received, one point was given for each correctly recalled

list of digits for a maximum total score of 14. The maximum digit span (the highest set size at which participants correctly recalled at least one of the two trials) was also recorded for each session, for a maximum score of 8.

Delayed Recall of word list. One point was given for each correct word written down by the subject.

Attention Network Task. Following the analysis procedure of Fan et al. (2002), mean reaction time and accuracy scores for the different trial types were used in assessing three different attentional networks (orienting, alerting, and executive control). The alerting component was evaluated by comparing performance (accuracy and reaction time) on "no" warning trials to "double" warning trials. The double cue provides information that the stimulus is imminent without cueing its location, so the calculated difference between the double-cue and no-cue condition shows the effect of the alerting alone. The orienting component of attention was evaluated by comparing the difference in performance on "center" cues and spatial (the average of "up" and "down") cues, as spatial cues both cued the subject to the exact location of the next stimulus, while the center cue alerts participants to the stimulus's arrival but does not indicate its location. The executive control aspect of attention was measured by comparing performance on congruent and incongruent trials, as incongruent trials require ignoring or overcoming contradictory information from the flankers (opposite direction of arrows) whereas in congruent trials, the flankers elicit the same response as the target.

Results

For both groups, performance generally remained stable or slightly improved due to practice effects. At the time of this writing, the Group (glucose, placebo) X Administration (pre-test, post-test) interaction was not statistically significant for many of the outcome measures. As

noted earlier, this is a partial report of an ongoing study and data collection is ongoing. It is important to note that the sample sizes for the current study at this timepoint are smaller than many used in previous studies that have found effects of a glucose drink on cognition in healthy young adults (e.g., Benton & Owens, 1993; Scholey, et al., 2009).

For analysis at this preliminary stage, I report the results for the within-subjects t-tests for each group. These analyses are reported for descriptive purposes only. Final conclusions will rely on tests of the Group X Administration interaction when data collection is completed.

As described below, the general pattern is that improvements from pre- to post-test are statistically significant for the glucose group, especially on memory and accuracy measures, but smaller and not statistically significant for the placebo group. This pattern is consistent with the primary conceptual hypothesis that glucose administration would result in greater post-test improvements.

Backwards Digit Span

The Backwards Digit Span was the outcome measure most sensitive to glucose effects. Figure 2 illustrates the improvements from pre- to post-test for each group on total Backwards Digit Span score. The increase in Backwards Digit Span score from pre- to post-test was statistically significant for the glucose group, $t(30) = 3.55$, $p = .002$, but not for the placebo group, $t(29) = 1.43$, $p = .16$. Averages in Backwards Digit Span score by group and session can be found in Table 3.

We also examined the maximum digit span, as this measure might be more sensitive to individual differences. For this measure, the Group (glucose, placebo) X Administration (pre, post) interaction was statistically significant, $F(1,59) = 5.61$, $p = .02$. As seen in Figure 3, maximum digit span increased significantly for the glucose group, $t(30) = 3.93$, $p < .001$, but not

the placebo group, $t < 1$. Averages for the maximum digit span recalled in a single trial can be found in Table 3.

Delayed Recall

Figure 4 shows the improvements (post-test – pre-test) for the Delayed Recall test. Consistent with our hypothesis, the glucose group significantly increased the number of items recalled from pre- to post-test, $t(30) = 2.47$, $p = .02$, but the placebo group did not, $t(29) = 1.26$, $p = .22$. Averages in Delayed Recall score by group and session can be found in Table 3.

Attention Network Task

As described earlier, the ANT is an attentional task, measuring orienting, alerting, and executive control components of attention. Differences in both reaction time, accuracy, and all three measures of attention pre- to post-test for the sugar and placebo group did not approach significance, $F>1$. For reaction time and accuracy data, see Table 4 and Table 5, respectively.

Discussion

In this experiment, we tested the effects of a glucose or placebo drink on cognitive function after an executively demanding fatigue task. Previous work has shown that higher executive processes are supplied by limited resources, which can be depleted by a cognitively fatiguing task. Effects of a fatiguing task can show negative "transfer effects" of practicing a task, with subjects showing worse performance after practicing, as a result of the fatigue (Persson, Welsh, Jonides, & Reuter-Lorenz, 2007). This previous work shows that when specific areas of the central executive are intensely fatigued, performance in other tasks which rely on the same areas and resource supply will suffer (Persson, et al., 2007). It has been shown, however, that glucose administration following a cognitively fatiguing task can replenish the energy

supply to the central executive, resulting in improved behavioral performance on various tasks relying on executive control (Gailliot, et al., 2007).

In the present experiment, the working memory measure showed the greatest sensitivity to glucose effects, followed by the long-term memory task. Attention measures showed little or no sensitivity. In the literature, findings regarding working memory measures' sensitivity to glucose effects have been mixed. Several studies have found benefits of glucose administration on working memory tasks including Digit Span (Backwards and Forwards) and Serial Sevens (Scholey et al., 2001; Stephens and Tunney, 2004;) but others have not (Foster et al., 1998, Sunram-Lea, Foster, Durlac, & Perez, 2001). One factor that may have contributed to the sensitivity of the working measure in the current study is the use of a within-subjects pre-test/post-test comparison. Both Scholey et al. and Stephens & Tunney used within-subjects glucose manipulations; Foster et al., and Sunram-Lea et al. used between-subjects designs with a very small (n = 10) number of subjects per group. Notably, numerical trends in both of these studies were consistent with a beneficial effect of glucose, though as noted earlier it did not reach standard levels for statistical significance. Overall, the results seem consistent with the hypothesis of a beneficial effect of glucose on working memory, but suggest that it is important to control for baseline individual differences in working memory to allow those effects to be detected statistically.

Beneficial effects of glucose on long-term memory are more consistent in the literature (e.g., Foster et al., 1998; Sunram-Lea et al., 2002; see reviews by Galliot, 2008; Hoyland, Lawton, & Dye, 2008) and were reproduced here. It has been suggested that the hippocampus may be especially sensitive to glucose effects because of a high concentration of insulin receptors (see discussion by Scholey, Sunram-Lea, Greer, Elliot, & Kennedy, 2008). Significant

results are found more often with recall tests than with recognition tests (Hoyland et al., 2008), suggesting that the requirements for self-initiated processing and organization in recall tests may also play a role.

Contrary to the original hypothesis, there were no significant effects of glucose administration on either accuracy or reaction time measures of attention. One possible factor is that the ANT was not a sensitive performance measure for this sample overall; accuracy measures were near ceiling, and neither accuracy nor reaction time changed for either group over the course of the session. It was especially surprising to not see fatiguing effects from the Stop-Signal task onto the executive component of the ANT. Although both Stop-Signal and the ANT executive component are thought to require the central executive and application of the restraint function of inhibition, it is possible that they tap different aspects of these functions and require different brain regions. It is possible that stronger fatiguing effects would be found by choosing tasks known to deplete resources mediated by the same brain regions (c.f., Persson et al., 2007).

Several other factors, not mutually exclusive, may have influenced our findings of significant glucose effects on memory measures but not on the attention measures. First, it is feasible that the glucose administration had an effect on the memory measures that was independent of the fatiguing task. Although glucose effects on attention measures may only occur in the presence of fatigue (Benton et al., 1993; Galliot et al., 2007), several of the studies finding a significant benefit of glucose on long-term memory measures did not use a fatiguing task (see review by Hoyland, 2008).

A related possibility is that attentional performance may be somehow “privileged” and given higher priority than the memory tasks. This theory is supported by the findings of Scholey, et al. (2009), who co-administered an attention test (tracking task) and a memory task

(encoding of a word list). This co-administration showed that performance on the memory tests, as compared to the attention task, were significantly impaired (Scholey, et al., 2009). This is evidence that in times of high demand, the central executive may favor attention tasks over memory. In many of the glucose-cognition studies reviewed by Galliot (2008), effects were seen in terms of attentional performance's effects on glucose levels, rather than vice versa. Thus, one possibility is that although attention tasks do tax the cognitive system and glucose levels, their performance is preserved at the potential expense of other tasks. Attention tasks may also be more sensitive to participants' initial glucose levels and glucose tolerance (Benton & Owens, 1993; Benton, Owens, & Parker, 1994). Further analyses (e.g., changes in Stop-Signal performance over the fatiguing period and their potential correlations with the attention and memory outcome measures) are planned to better explore these possibilities, and additional experimentation may be required.

The intention is to use the results of the current study as proof of concept, and to later apply these methods to older adults. Our results show that, overall, both groups of young-adult subjects showed practice effects on memory tasks, but the group receiving glucose improved significantly more than the placebo group. However, past research has shown that older adults may not have the same practice benefits in performance as compared to young adults. For example, Rowe, Hasher, and Turcotte (2009) found that the behavioral performance of young adults on a task is heavily influenced by practice effects, whereas the performance of older adults is more heavily influenced by interference. Increased interference effects may prove to make an older population of subjects more sensitive to the fatigue manipulation employed in the current study. If it is true that older adults are more sensitive to the Stop-Signal fatigue, the outcome

measures employed may show larger glucose effects in the older adult population than were observed in the young-adult population.

While the present study did not show a significant effect of glucose administration on the ANT in young adults, the ANT may be more sensitive to both fatigue effects and to the glucose administration in older adults. Past research has shown that older adults show significantly less alerting than young adults on the ANT (Jennings, Dagenbach, Engle, & Funke, 2007). If older adults are more sensitive to the Stop-Signal fatigue, and have more difficulty with the ANT than younger adults, the ANT may prove to be a sensitive outcome measure in an older adult population. Also, older adults have been shown to be more sensitive than young adults to the effects of glucose on some nonmemory aspects of cognition (Allen, Gross, Aloia, & Billingsley, 1996), which may translate to significant differences between groups in the ANT that were not observed in young adults.

In short, the present study generally replicated previous findings of glucose benefits to performance on tests of working and long-term memory. Somewhat surprisingly, attention measures did not show significant effects of either fatigue or glucose. Future studies are planned using older adult participants, who may show greater sensitivity due to both greater vulnerability to cognitive fatigue effects and to greater physiological sensitivity to glucose. An important addition to these studies may be the addition of blood-glucose monitoring, to allow assessment of both glucose's effects on cognition and the reverse. A question of particular interest for these future studies will be whether attention measures may have a privileged performance status despite changing levels in glucose, and the degree to which overlap in specific cognitive processes is critical for both fatigue and glucose effects.

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Table 1

Demographic Information

	Group			
	Sugar		Placebo	
Measures	Amount	Mean (*SD*)	Amount	Mean (*SD*)
N	31	-	30	-
Male	17	-	16	-
Years of education	-	13.6 (1.2)	-	12.9 (0.9)
Age	-	19.1 (1.7)	-	18.7 (0.9)
MMSE	-	28.8 (1.1)	-	29.1 (1.0)
SBT	-	0.7 (1.1)	-	0.3 (0.7)
ERVT	-	19.3 (5.6)	-	18.2 (7.1)

Table 2

Experiment Design

Task	Approximate Time (minutes)
Delayed Recall encoding 1	2
Attention Network Task 1	20
Delayed Recall test 1	2
Backwards Digit Span 1	3
Stop-Signal task	45
Drink administration and wait time	20
Dealyed Recall encoding 2	2
Attention Network Task 2	20
Delayed Recall test 2	2
Backwards Digit Span 2	3

Note. Approximate task duration: 120 minutes (2 hours).

Table 3

Digit Span and Delayed Recall Results by Group and Session.

	Group			
	Sugar		Placebo	
	Session 1	Session 2	Session 1	Session 2
Measure	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)	Mean (*SD*)
BDS score	8.3 (2.6)	9.4 (2.2)	7.7 (2.5)	8.3 (2.3)
BDS maximum span	5.6 (1.4)	6.3 (1.1)	5.7 (1.2)	5.7 (1.3)
DR score	9.1 (3.2)	10.2 (2.8)	11.2 (3.9)	11.8 (4.3)

Note. BDS = Backwards Digit Span. DR = Delayed Recall. "Longest span" reflects the longest total digit span recalled in a single trial.

Table 4

Attention Network Task Reaction Time (ms) by Group and Session

	Group			
	Sugar		Placebo	
	Session 1 Mean (*SD*)	Session 2 Mean (*SD*)	Session 1 Mean (*SD*)	Session 2 Mean (*SD*)
Flanker Type				
Congruent	518 (43)	522 (65)	530 (54)	535 (56)
Incongruent	620 (56)	617 (65)	636 (57)	634 (70)
Neutral	517 (45)	519 (49)	527 (52)	525 (53)
Warning Type				
Center	563 (49)	552 (60)	572 (56)	569 (61)
Double	548 (44)	550 (62)	569 (61)	560 (62)
Spatial	505 (48)	509 (54)	519 (51)	515 (59)
No	585 (56)	594 (63)	601 (54)	609 (66)
Attentional Measures				
Executive	101 (30)	95 (36)	106 (25)	99 (31)
Alerting	38 (24)	43 (30)	41 (25)	50 (22)
Orienting	58 (27)	43 (27)	53 (26)	54 (33)

Note. Spatial warning is the average of "up" and "down" cue types. Executive = incongruent – congruent trials. Alerting = "no" – "double" warning types. Orienting = "center" – "spatial" warning types.

Table 5

Attention Network Task Accuracy by Group and Session

	Group			
	Sugar		Placebo	
	Session 1 Mean (*SD*)	Session 2 Mean (*SD*)	Session 1 Mean (*SD*)	Session 2 Mean (*SD*)
Flanker Type				
Congruent	.99 (.01)	.99 (.01)	.99 (.01)	.99 (.03)
Incongruent	.94 (.06)	.92 (.09)	.93 (.07)	.93 (.09)
Neutral	.99 (.02)	.99 (.02)	.99 (.02)	.98 (.06)
Warning Type				
Center	.97 (.04)	.96 (.06)	.97 (.05)	.97 (.05)
Double	.98 (.04)	.96 (.04)	.97 (.04)	.96 (.07)
Spatial	.98 (.03)	.98 (.03)	.98 (.03)	.98 (.05)
No	.98 (.04)	.98 (.03)	.97 (.04)	.96 (.08)
Attentional Measures				
Executive	-.05 (.06)	-.07 (.09)	-.06 (.07)	-.06 (.07)
Alerting	.00 (.03)	.01 (.04)	.00 (.05)	.01 (.03)
Orienting	-.01 (.03)	-.02 (.04)	-.01 (.03)	-.01 (.03)

Note. Spatial warning is the average of "up" and "down" cue types. Executive = incongruent – congruent trials. Alerting = "no" – "double" warning types. Orienting = "center" – "spatial" warning types.

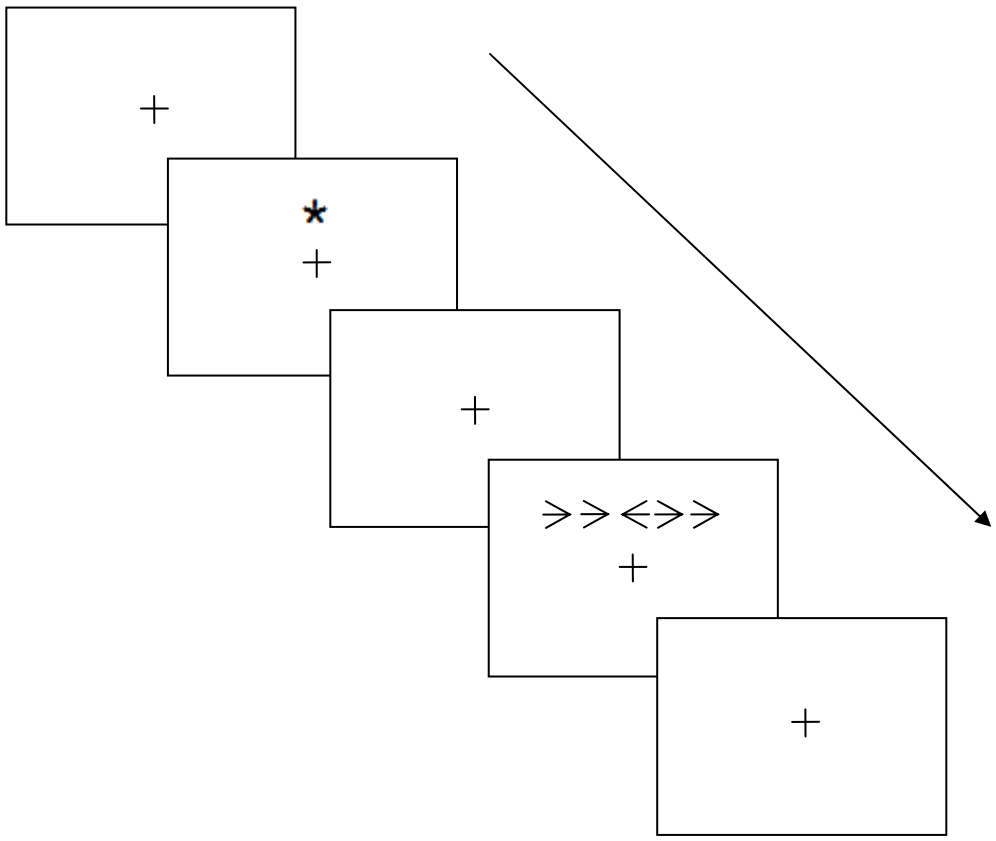

Figure 1. Attention Network Task (ANT) diagram. 1) Initial fixation period; duration varies randomly between 400-1600 ms; 2) warning event (100 ms); 3) second, brief fixation period (400 ms); 4) target presentation, lasting until a response is made (up to a maximum of 1700 ms; 5) post-trial fixation period. Duration varies depending on the durations of pre-trial fixation and target presentation, to bring total trial duration up to 4000 ms.

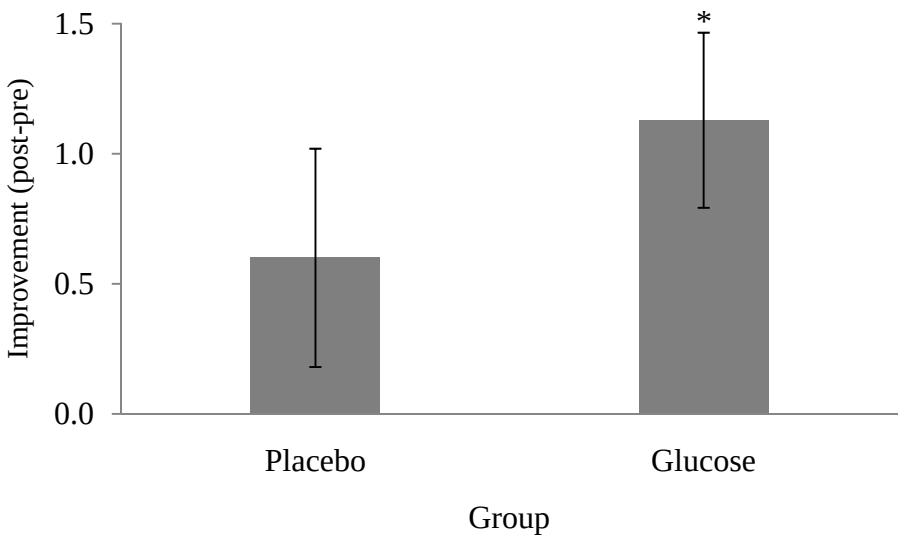

Figure 2. Backwards Digit Span score improvements (post-test – pre-test) by group. Error bars indicate the standard error of the mean difference. Asterisk (*) indicates statistically significant improvement in Backwards Digit Span score for the sugar group from pre- to post-test, $t(30) = 3.55$, $p = .002$.

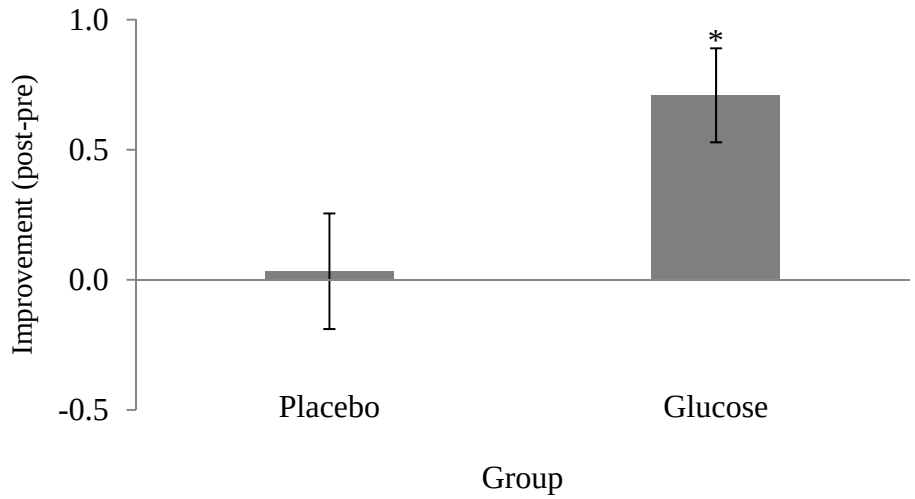

Figure 3. Backwards Digit Span, maximum digit span recalled in a single trial, improvements (post-test – pre-test) by group. Error bars indicate the standard error of the mean difference. Asterisk (*) indicates statistically significant improvement in Backwards Digit Span, highest span recalled, for the sugar group from pre- to post-test, $t(30) = 3.93$, $p < .001$.

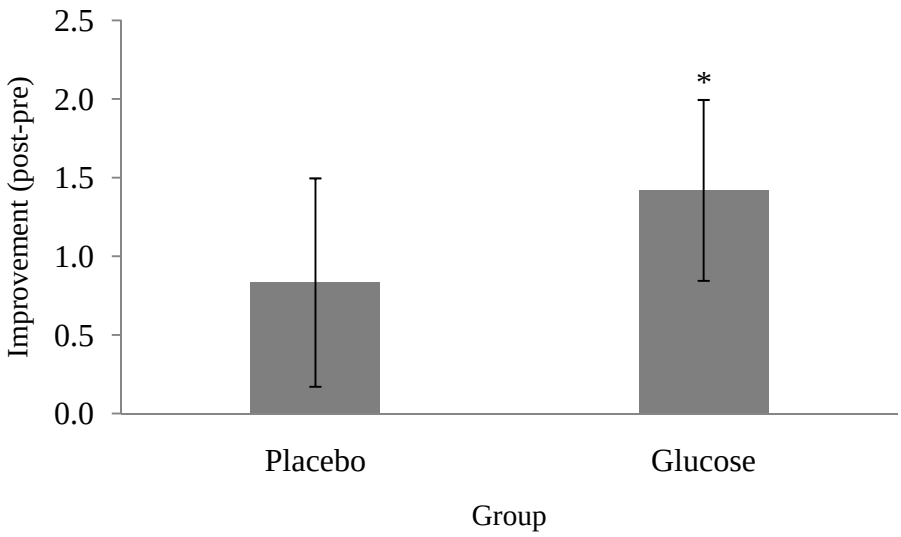

Figure 4. Delayed Recall improvements (post-test – pre-test) by group. Error bars indicate the standard error of the mean difference. Asterisk (*) represents statistically significant improvement for total words recalled for the sugar group from pre-test to post-test, $t(30) = 2.47$, $p = .02$.

Appendix A

Drink Evaluation

How much did you like the taste of the drink?

Did not like at all						Liked very much
1	2	3	4	5	6	7

How sour did you consider the drink?

Not sour at all						Very sour
1	2	3	4	5	6	7

How sweet did you consider the drink?

Not sweet at all						Very sweet
1	2	3	4	5	6	7

How cold did you consider the drink?

Very warm						Very cold
1	2	3	4	5	6	7

What did you think about the size of drink?

Too small						Too large
1	2	3	4	5	6	7

How many calories do you think that the drink contained? **Note: a can of soda contains about 150 calories.*

Please let us know if you have any additional comments about the drink.

Appendix B
Delayed Recall Word Lists

Word List A:	Word List B:
apple	acid
apricot	ammonia
banana	antifreeze
cherry	asparagus
cider	bean
clover	bleach
cocoa	bourbon
cream	brandy
daisies	broccoli
grape	carrot
honeysuckle	cauliflower
juice	celery
Kool-Aid	champagne
lemonade	daiquiri
lilac	gasoline
milkshake	gin
orchids	ink
pansy	kerosene
peach	martini
pear	mercury
Pepsi	paint
pineapple	perfume
plum	onion
poinsettia	potato
poppy	radish
soda	rum
tea	scotch
tulip	spinach
violet	vodka

Appendix C

Stop-Signal Payment Calculation

(Suppression Base – Error Penalty + RT bonus>1,1,Suppression Base – Error Penalty + RT bonus)/2

Note. Suppression Base = percent of trials correctly suppressed. Error Penalty = ((No-signal errors + No-signal trials without response) x .05). RT bonus = (((average RT of no-signal trials on previous block – average RT no-signal trials of current block)/RT of no-signal trials on previous block) x 5). Therefore, subjects who improved their reaction time (no-signal trials) and correctly suppressed responses were rewarded (maximum reward = 50 cents per block).