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The Effect of Sucrose and Stress on Male Participants' Memory

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ABSTRACT

Glucose has been shown to have a memory facilitating effect. The goal of this study is to test if sucrose, a carbohydrate consumed on a daily basis, would also enhance memory in male college students. Subjects were given either a sucrose (50 g) or a placebo drink (50.6 mg of saccharine). Subjects filled the Stress Indicator Questionnaire that measures five stress indicators: physical, sleep, behavioral, emotional, and personal habits. A slideshow of 52 IAPS pictures were then shown to the subjects followed by immediate and delayed recall tests and a recognition test. Even though we found no direct effect of sucrose on memory, the results showed that high fasting blood glucose level is associated with lower recognition memory. Furthermore, high sleep stress enhanced memory for immediate recall. On the other hand, high behavioral stress was detrimental for delayed recall and recognition. The differential effects of the different indicators of stress on memory is discussed in relation to changes in cortisol levels that may result in modulation of blood glucose levels which in turn can affect memory. The results of this study shed light on the effect of different types of stress and fasting glucose levels on memory.

Carbohydrates, converted into glucose, are the basic fuel for the brain (Sieber and Traystman 1992). Previous research has confirmed that glucose and sucrose facilitate memory in animals and humans (for a review see Messier 2004). Glucose is known to exert its effects mainly on declarative long-term memory, specifically verbal episodic, meaning recollection of past experiences (Craft, Murphy and Wemstrom 1994; Manning, Hall, and Gold 1990; Messier, 2004; Messier and Gagnon 1996; Sünram-Lea, Dewhurst, and Foster 2008; Sünram-Lea, Foster, Durlach, and Perez 2001, 2002a, 2002b). However, glucose has also been shown to facilitate other cognitive processes such as working memory (Martin and Benton 1999; Sünram-Lea. Foster, Durlach, and Perez 2001, 2002a, 2002b), non-declarative kinesthetic memory (Scholey and Fowles 2002), reaction times (Owens and Benton 1994) and attention (Messier, Gagnon, and Knott 1997).

There are various factors that modulate the memory facilitation effect of glucose among which are age, blood glucose regulation, task difficulty and emotional arousal. Glucose has been shown to enhance various aspects of memory in older adults (Craft, Murphy, Wemstrom 1994; Messier 2004; Messier, Tsiakas, Gagnon, Desrochers, and Awad 2003) including recognition memory (Macpherson, Robertson, Sünram-Lea, Stough, Kennedy and Scholey 2015). Older adults benefit from relatively greater glucose-induced cognitive enhancement due to the fact that aging is accompanied by cognitive decline that can be improved by extra glucose supply. Some aspects of this cognitive decline pertain to loss in memory, attention, processing speed, and executive functioning. This age-related memory decline suggests that older adults have more room for cognitive improvement when compared to younger adults (van der 2015). However, keep in mind that older adults have difficulty metabolizing glucose causing them to have a reduced ability to normalize elevated blood glucose levels. They also have a relatively decreased peripheral and central glucose utilization (van der Zwaluw et al. 2015). Moreover, glucose enhances memory in older subjects referred to as 'bad glucoregulators'. That term has been used in the literature to refer to subjects who have difficulty metabolizing glucose at a normal rate (Awad, Desrochers, Tsiakas, and Messier 2002; Craft, Murphy, Wemstrom 1994; Knott, Messier, Mahoney, and Gagnon, 2001; Messier, Desrochers, and Gagnon 1999; Messier, Gagnon and Knott 1997; Messier et al. 2003).

Task difficulty is another factor that plays a role in the memory-facilitation effect of glucose (Kennedy and Scholey, 2000; Meikle, Riby, and Stollery 2004; Scholey, Harper, and Kennedy 2001; Sünram-Lea et al. 2002b). When shown low imagery word pairs, which was rated as a relatively more difficult task, glucose administration enhanced memory. Furthermore, studies showed that glucose had a greater effect on enhancing memory for longer word lists (Meike, Riby, and Stolley 2005).

Emotional arousal seems to also mitigate the memory-facilitating effect of glucose (Parent, Varnhagen, and Gold 1999). However, this relationship is not yet clear. The relationship between the memory facilitating effect of glucose and emotions needs further clarification. Negative emotional arousal using unpleasant stimuli has been shown in some studies to modulate the effect of glucose on memory (Brandt, Sünram-Lea, and Qualtrough, 2006; Ford, Scholey, Ayre, and Wesnes 2002; Mohanty and Flint 2001; Parent, Varnhagen, and Gold 1999). However, to our knowledge only one study has looked at the relationship between anxiety and glucose administration on memory (Smith, Hii, Foster and Van Eekelen 2011). Glucose administration enhanced memory up to a week only in male participants with high trait anxiety. This relationship between anxiety and glucose has been explained through the effect of cortisol. This stress hormone may mediate the memory facilitation of glucose under conditions of high anxiety or negative emotional arousal by increasing the amount of glucose released in the blood (Smith et al. 2011).

In order to fill in the research gap, the goal of our study is to test if sucrose would enhance memory in male college students and if this relationship is mitigated by stress, an emotion very common in college students. Sucrose was chosen instead of glucose for practical reasons because it is the carbohydrate normally ingested on a daily basis. The following stress indicators were measured: physical, sleep, behavioral, emotional, and personal habits. According to Smith et al. 2011, our hypothesis is that sucrose will enhance memory only in male students who portray high stress.

Methods

Sample

Participants consisted of thirty-nine male students at Holy Cross College, ranging in age from18 to 22 years old. Participants who had type 1 or type 2 diabetes were excluded from the study. Subjects were recruited from classrooms and participation was voluntary.

Instruments and Design

This study was pre-approved by the Holy Cross College Institutional Review Board. All participants were asked to abstain from eating and drinking, with the exception of water, from midnight until 8 am before testing began.

Upon arrival, subjects filled out a consent form and a demographic questionnaire. Using a glucometer, baseline blood glucose levels were measured at the beginning of the study before ingestion of the sucrose or placebo drink. Subjects' blood glucose measurements were taken again at intervals of 30, 45, and 60 minutes following drink consumption. Subjects were randomly assigned to a sucrose or placebo group. Subjects belonging to the sucrose group received 240 ml of a lemon-flavored drink containing 50 g of sucrose, whereas the placebo group received 240 ml of a lemon-flavored drink containing 50.6 mg of saccharine (Messier et al 2003). Drink administration was double blind. Upon consumption of the drink, subjects were instructed to do Sudoku puzzles for 5 minutes, which gave enough time for the sucrose to reach the brain. Subjects then filled out the Stress Indicators Questionnaire, created by the Counseling Team International. This questionnaire measured self - reported stress based on five indicators: physical (e.g. My body feels tense all over), sleep (e.g. I have trouble falling asleep), behavioral (e.g. I drink alcohol or use drugs to relax), emotional (e.g. I worry a lot), and personal habits (e.g. I watch television for entertainment more than one hour a day). The questions were rated on a 5-point Likert scale ranging from 1 = Never to 5 = Almost Always. Following the stress questionnaire, subjects were shown a slideshow of 52 neutral images such as a table, bowl or flowers that were procured from the International Affective Picture System (IAPS) (Lang, Bradley, and Cuthbert 1997; Blake, Varnhagen and Parent 2001). The slideshow of pictures was projected onto a screen at a rate of 2 seconds per picture. Free-recall memory tests were given immediately, 20 minutes and 40 minutes following the viewing of the slideshow. In the free-recall memory tests, subjects were instructed to describe as many of the pictures from the slideshow as they could in a word or sentence. A recognition memory test, including the original target pictures and 22 other distracter pictures, was administered 60 minutes following the viewing of the original slide show. For the recognition test, pictures were projected onto a screen at a rate of 5 seconds per picture. Subjects were asked to indicate if they saw the pictures in the original slideshow.

Based on the results of the Stress Indicators Questionnaire, the median was calculated for each of the stress indicators. This median split procedure was used to separate participants into low and high stress groups for each of the indicators. The median split technique was also used to separate subjects into low fasting blood glucose levels group and high fasting blood glucose level group. The median split technique turns a continuous variable such as fasting levels of blood glucose into a categorical variable where values below the calculated median are part of the 'low group' and values equal to or above the calculated median are part of the 'high group'. One Way ANOVA, 2x2 factorial ANOVA and Pearson Correlations with an alpha level of 0.05 were conducted using SPSS.

Results

At baseline or fasting, the sucrose group (M=89.09, SD=9.85) and placebo group (M=84.16, SD=9.43) showed no difference in their blood glucose levels $F(1,37)$=2.52, p=.121. However, the placebo group's blood glucose levels at 30 min (M=86.39, SD=15.57), 45 min (M=81.78, SD=7.56), and 60 min (M=81.43, SD=8.42) were lower than those of the sucrose group at 30 min (M=127.47, SD=23.74), $F(1,37)$=39.31, p=.000, at 45 min (M=119.50, SD=31.65), $F(1,28)$=18.85, p=.000, and at 60 min (M=99.37,SD=27.81), $F(1,28)$=5.37, p=.028 following drink consumption. Blood glucose levels peaked in the sucrose group at the 30-minute interval (see Figure 1).

The 2x2 factorial ANOVAs for each stress indicator (high or low stress groups) and type of drink (sucrose or placebo) showed no main effect of

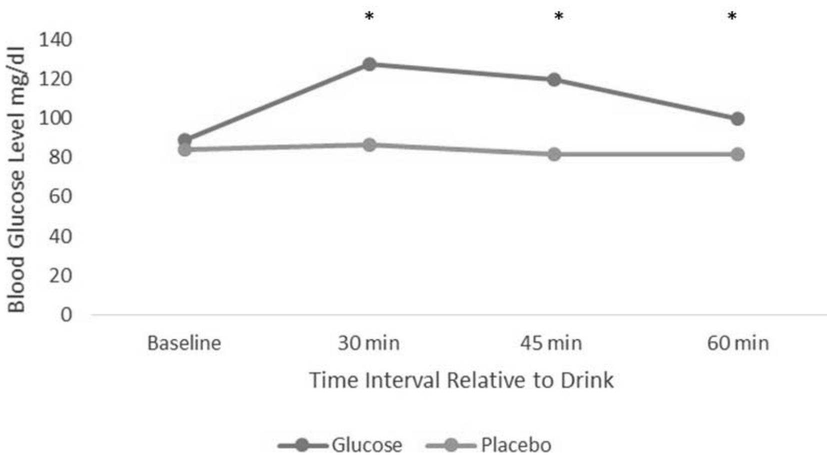

FIGURE 1. Blood glucose level measures at fasting and at 30 min, 45 min, and 60 min post drink in the sucrose and saccharin groups. Glucose peaks 30 min following drink in the sucrose group. Mean values of blood glucose levels (mg/dl) and standard deviations, $*p<0.05$.

sucrose on memory. Sucrose ingestion did not improve memory on any of the free recall tests or the recognition test.

Further ANOVA analysis showed that baseline fasting blood glucose level modulated memory. Specifically for the recognition test, subjects with low fasting glucose ($M_{Low\ glucose}$=61.50, $SD_{Low\ glucose}$=6.55) performed better than those with high fasting glucose ($M_{High\ Glucose}$=54.13, $SD_{High\ Glucose}$ =9.98), $F(1,37)$=6.68, p=.014 . Pearson correlations were then conducted between fasting blood glucose levels and memory testing. Fasting glucose levels correlated negatively with the recognition test (r=-0.39, p=.015).

Even though 2x2 ANOVA showed no effect of sucrose on memory, the analysis revealed a main effect of stress on memory. As mentioned earlier, using the median split technique, subjects were divided into high and low stress groups for each of the indicators of the Stress Indicators Questionnaire. As shown in Figure 2, high sleep stress subjects showed better memory for immediate recall, ($M_{High\ stress}$=17.00, $SD_{High\ stress}$=5.71, $F(1,33)$=4.85, p=.035) than those with low sleep stress, ($M_{Low\ stress}$ =13.47, $SD_{Low\ stress}$=3.69). Figure 3 shows high behavioral stress is detrimental to memory at the 40 minute delayed recall ($M_{Low\ stress}$=14.50, $SD_{Low\ stress}$=3.76, $M_{High\ stress}$=12.17, $SD_{High\ stress}$=3.81, $F(1,37)$=3.61, p=.065). This effect was marginally significant. Figure 4 shows that high behavioral stress subjects also performed relatively poorer on the recognition test ($M_{Low\ stress}$=60.82,

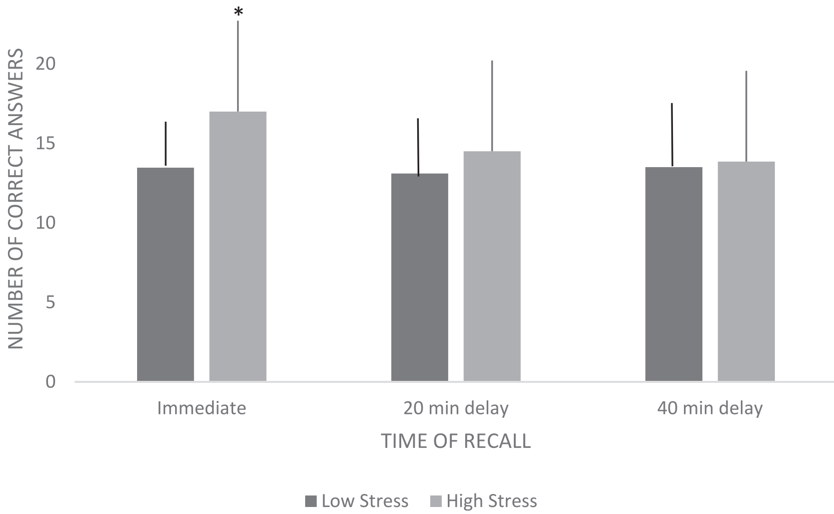

FIGURE 2. High sleep stress facilitates immediate recall memory. Mean values of number of correct answers and standard deviations, *$p<0.05$.

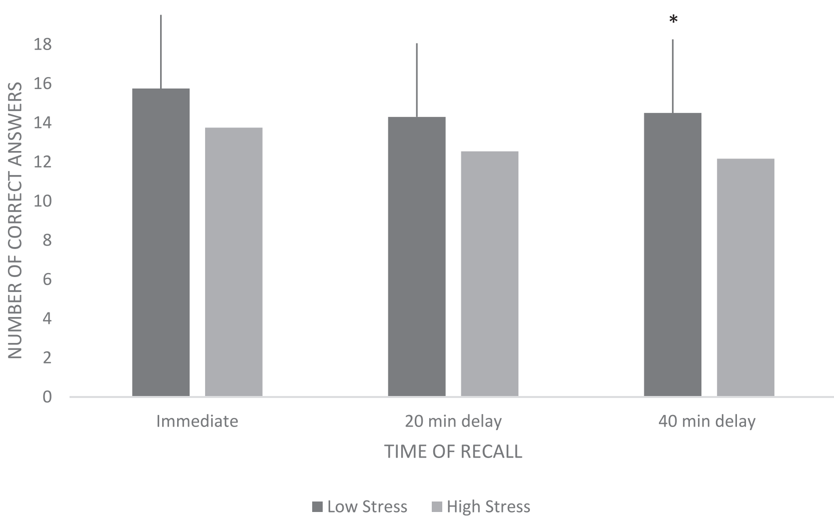

FIGURE 3. High behavioral stress disrupts memory at 40-minute delayed recall. Mean values of number of correct answers and standard deviations, *$p=0.065$.

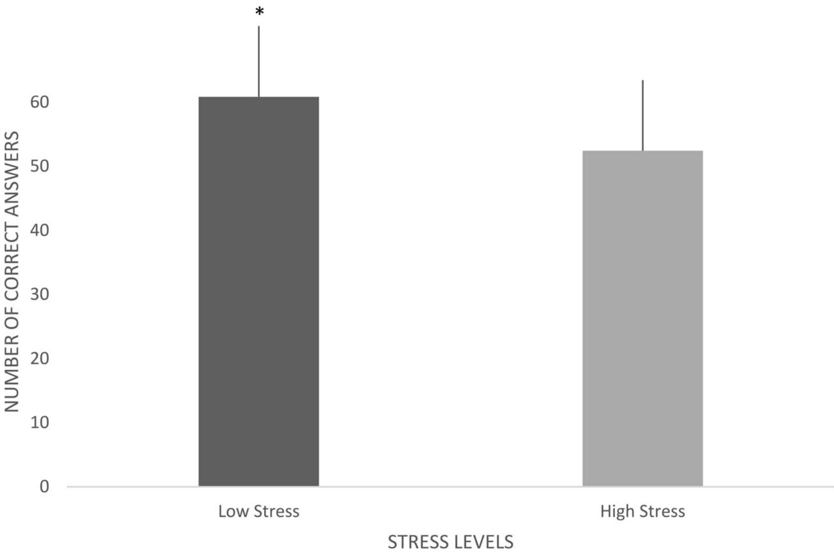

FIGURE 4. High behavioral stress is detrimental for recognition memory. Mean values of number of correct answers and standard deviations, $^*p<0.05$.

$SD_{Low\ stress}$=5.87, $M_{High\ stress}$=52.41, $SD_{High\ stress}$=11.03, $F(1,37)$=9.37, p=.004).

No interaction between sucrose and stress was found. Therefore, sucrose did not improve memory differentially in the high and low stress groups.

Discussion

Contrary to our hypothesis, sucrose administration did not improve memory in any of the stress groups. Instead, fasting blood glucose levels modulated memory. Subjects with high fasting blood glucose levels relatively had relatively lower recognition memory. When taking a look at stress and memory, we found that high sleep stress individuals have a greater immediate recall than those with low sleep stress. On the other hand, participants with high behavioral stress had worse memory than participants with low behavioral stress. This happened at a 40 min delayed recall test and on the recognition test.

Astonishingly, subjects who had a higher fasting glucose level performed worse than those with a lower baseline glucose level. Accordingly, high blood glucose levels were shown to have a detrimental effect on subjects' overall performance, especially in cognitive functions (Seetharaman, Andel, Mcevoy, Aslan, Finkel, and Pedersen 2014). Cognitive functions, including memory, were also impaired under conditions of high blood glucose levels after two years in participants with diabetes (Samaras, Lutgers, Kochan, Crawford, Campbell, Wen, and Sachdev 2014).

Our results show that high sleep stress enhances immediate recall but not delayed recall. This effect could be due to the increase of cortisol levels from stress, which then results in a higher level of glucose in the blood (Smith et al. 2011). This increase in blood glucose level due to stress might result in facilitation of memory recall at a shorter delay following exposure to the material but not at longer delays. Our results also show that contrary to the beneficial effect of sleep stress on immediate recall, behavioral stress seems to be detrimental to long-term memory. When looking at the Stress Indicator Questionnaire, behavioral stress is associated with risky activities that could be detrimental for long-term memory. Long term, problematic drinking has been shown to lead to cognitive impairments including detriments to long-term memory (Kim, Kim, and Park 2016).

The results of this study shed light on the effect of stress on memory showing that not only trait anxiety (Smith et al. 2011) but also specific stress indicators can modulate immediate and delayed memory recall and recognition. Therefore, researchers investigating the relationship between stress and memory may need to pay closer attention to the specific type of stress in relation to memory. Furthermore, the study's results highlight the importance of monitoring morning fasting blood glucose levels as they can affect recognition memory performance. The study's sample size was relatively small. For future research, we would like to further clarify the effect of stress on memory by measuring salivary cortisol levels, blood pressure and heart rate to show physiological evidence of the subjects' stress level.

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