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The Effect of Glucose and Emotional Arousal on Memory in College Students

Wpływ glukozy i pobudzenia emocjonalnego na pamięć studentów

Keywords:
memory, emotional arousal, glucose, sex-related differences, males, females, IAPS pictures, recall, recognition

Summary: This study investigated the effect of glucose administration and emotional arousal on memory. Participants were undergraduate college students randomly assigned to glucose (50 g glucose) and placebo groups (50.6 mg saccharine) and further divided into high and low emotional arousal groups. High and low emotional arousal groups were shown a slide show whose content was either emotionally arousing

or emotionally neutral, respectively. Blood glucose measurements were taken, and memory recall and recognition tests were given at various intervals throughout the experiment. Glucose improved memory for immediate recall in females only, while emotional arousal resulted in enhanced immediate and delayed recall for all subjects. Furthermore, emotional arousal enhanced recognition memory for males only. While the present findings confirm the facilitatory effects of glucose and emotional arousal on memory, they simultaneously stimulate more questions on the differences in the effect of these two factors on memory in males versus females.

Słowa kluczowe:
pamięć, pobudzenie emocjonalne, glukoza, różnice związane z płcią, mężczyźni, kobiety, zdjęcia IAPS, odwołanie, uznanie

Streszczenie: Celem badania było sprawdzenie wpływu podania glukozy oraz pobudzenia emocjonalnego na pamięć. Uczestnikami byli studenci przydzieleni losowo do grup glukozy (50 g glukozy) i grup placebo (50,6 mg sacharyny), a następnie podzieleni na grupy o wysokim i niskim poziomie podniecenia emocjonalnego. Grupom o wysokim i niskim poziomie podniecenia emocjonalnego pokazano zestaw slajdów, których treść była odpowiednio pobudzająca emocjonalnie lub neutralna emocjonalnie. Wykonano pomiary glukozy we krwi, a testy pamięci i rozpoznawania były przeprowadzane w różnych odstępach czasu w trakcie eksperymentu. Glukoza poprawiła pamięć natychmiastową tylko u kobiet, podczas gdy pobudzenie emocjonalne poprawiło zarówno pamięć natychmiastową, jak i przywoływanie wspomnień u wszystkich badanych. Pobudzenie emocjonalne poprawiło pamięć rozpoznawczą tylko u mężczyzn. Chociaż przedstawione w artykule odkrycia potwierdzają usprawniające działanie glukozy i pobudzenia emocjonalnego na pamięć, jednocześnie prowokują więcej pytań na temat różnic we wpływie tych dwóch czynników na pamięć u mężczyzn i kobiet.

Introduction

Glucose is the basic fuel for the brain (Sieber & Traystman, 1992). Years of research have confirmed that glucose facilitates memory both in animals and humans (for a review see Messier, 2004). Glucose is known to exert its effect mainly on declarative long-term memory (LTM) associated with hippocampal functioning, namely the verbal episodic (Craft, Murphy & Wemstrom, 1994; Manning, Hall & Gold, 1990; Messier, 2004; Messier & Gagnon, 1996; Sünram-Lea, Dewhurst & Foster, 2008; Sünram-Lea, Foster, Durlach & Perez, 2001, 2002a, 2002b). However, glucose has also been shown to facilitate other cognitive processes such as working memory (Martin & Benton, 1999; Sünram-Lea et al., 2001, 2002a, 2002b), non-declarative kinesthetic memory (Scholey & Fowles, 2002), reaction times (Owens & Benton, 1994) and attention (Messier, Gagnon & Knott, 1997). Glucose also seems to facilitate memory for tasks of recall more than recognition (Sünram-Lea et al., 2008).

There are various factors that modulate the glucose memory-facilitation effect, namely age (Craft et al., 1994; Messier, 2004; Messier, Tsiakas, Gagnon, Desrochers & Awad, 2003), task difficulty (Kennedy & Scholey, 2000; Meikle, Riby & Stollery, 2004; Scholey, Harper & Kennedy, 2001; Sünram-Lea et al. 2002b) and management of blood glucose level following a glucose load termed blood glucoregulation (Awad, Desrochers, Tsiakas & Messier, 2002; Craft et al., 1994; Knott, Messier, Mahoney & Gagnon, 2001; Messier, Desrochers & Gagnon 1999; Messier, Gagnon & Knott, 1997; Messier et al., 2003). Even though the results of these studies are not in complete agreement, the consensus seems to be that glucose exerts its effect on memory particularly in conditions where the cognitive resources have been challenged, such as in older subjects (Macpherson et al., 2015) or when completing difficult tasks that require high cognitive load (Hall et al., 1989; Meikle et al., 2004; Messier 2004; Scholey et al., 2001). However, it is important to keep in mind that glucose has repeatedly been shown to enhance memory in healthy young adults using a variety of memory tasks that vary widely in their level of difficulty (Metzger, 2000; Morris, 2008; Sünram-Lea et al., 2001; 2002a; 2002b; 2008).

Besides age, task difficulty and blood glucoregulation, emotional arousal also seems to modulate the effect of glucose on memory. Studies researching the effects of emotional arousal and glucose on memory have varied in their methodology on factors such as glucose dosage. Some administered 25 g to

all subjects independent of sex or weight (Brandt, Sünram-Lea & Qualtrough, 2006; Ford, Scholey, Ayre & Wesnes, 2002), some administered 50 g to all subjects (Mohanty & Flint, 2001; Parent, Varnhagen & Gold, 1999) and some gave dosages adjustable to body weight (Mohanty & Flint, 2001). Studies also varied in methodology on factors such as valence of emotionally arousing stimuli (Blake, Varnhagen & Parent, 2001; Brandt et al., 2006; Ford et al., 2002; Gore 2002; Gore, Krebs & Parent, 2006; Parent et al., 1999) and types of stimuli used (words [Messier, Desrochers & Gagnon, 1999; Messier, Pierre, Desrochers & Gravel, 1998; Parent et al., 1999] vs. pictures [Blake et al., 2001; Bradley, Greenwald & Petry, 1992; Gore, 2002; Gore et al., 2006]). However, the most striking methodological variability among the studies pertains to glucose administration. As discussed below, some studies did not administer glucose to subjects but rather measured their blood glucose levels under various emotional arousal conditions. Other studies, however, did administer glucose in conjunction with manipulation of emotional arousal.

In those studies where there was no administration of glucose, researchers assessed blood glucose level and its relationship to emotional arousal (Blake et al., 2001; Gore, 2002; Gore et al., 2006; Scholey et al., 2006). In a study where male participants viewed emotionally arousing or neutral pictures, it was shown that circulating blood glucose levels increased in those participants who viewed the emotionally arousing pictures, whereas those who viewed the neutral pictures did not show such a change. Furthermore, the increase in blood glucose levels seemed to be related to better recall for the emotionally arousing versus the neutral stimuli (Blake et al., 2001). In contrast, a study on young and older adults found that highly emotionally arousing pictures did not affect blood glucose levels, regardless of self-report of arousal. This study did, however, corroborate previous findings in that both the young and older participants who were exposed to the high arousal stimuli were able to recall more pictures than the neutral group (Gore et al., 2006). Results from a similar study indicated that while recall was impaired for older adults compared to young adults, both groups experienced an enhancement of recall based on self-reported arousal. Glucose levels were also not affected by arousal in this experiment (Gore, 2002). One study which used words instead of pictures obtained entirely different results. In this experiment, participants were placed into one of four groups based on combinations of level of arousal and level of mental effort. It was shown that there was an increase in blood glucose level for the high arousal condition compared to the neutral condition; however,

emotional arousal did not affect recall of the words (Scholey, Laing & Kennedy, 2006). Clearly, there is a controversy in this area of research, with some studies showing a relationship between elevated blood glucose levels, arousal and memory and some not showing such relationships.

Studies in which researchers investigated the effect of glucose on memory did not show a consistent memory facilitating effect of glucose (Beaver et al., 2017; Stollery & Christian, 2015). The first study to look at the combined effects of emotional arousal and glucose on memory was conducted by Parent et al. (1999). Participants in this study were given either a saccharin placebo or 50 g glucose drink and then exposed to a slide show accompanied by either a neutral or emotionally arousing narrative. Emotional arousal resulted in an increase in circulating blood glucose levels. Glucose administration, however, prevented the memory-enhancing effect of emotional arousal. Another study also using glucose and placebo groups showed that emotional words were both recognized and recalled better than neutral words, but there was no direct effect of a 25 g dose of glucose on memory for either type of word (Ford et al., 2002). Mohanty & Flint (2001) took Parent et al.'s study a step further and tested the effects of different dosages of glucose and emotional arousal on memory. They found that doses of 100 mg/kg and 50 g of glucose lead to impaired performances in spatial memory tasks for emotionally arousing pictures. However, their research also showed that a 100 mg/kg dose of glucose enhanced memory for neutral stimuli, while there was no effect following the 50 g dose. In addition, Brandt et al. (2006) examined the effect of glucose and emotional arousal on memory and conducted two experiments that differentiated between neutral, negative and positive emotional words (Brandt et al., 2006). In their first experiment, they found that negative words were remembered better than both neutral and positive words in a task of recognition. In the second experiment, the researchers divided participants into groups receiving either a placebo or 25 g of glucose and conducted the same experiment as before. It was shown that the glucose did not affect memory performance compared to the placebo group; both groups remembered negative words more than both neutral and positive ones. In conclusion, the few studies that did examine the effect of glucose administration in conjunction with emotional arousal vary in their methodology (pictures vs. words, dosage of glucose, and type of memory tests used). This variation in the methodologies could account for the disagreement in their findings regarding the effect of glucose on memory in the presence of emotional arousal.

The present research aims at shedding light on the contradictory results of the studies mentioned above by investigating the combined effect of glucose and emotional arousal on free recall and recognition memory. We hypothesize that glucose will enhance memory for immediate and delayed free recall tests that are known to be hippocampus dependent. Also, we hypothesize that emotional arousal will enhance memory on all free recall and recognition tests.

Methods

All procedures used for this study were approved by the Cedarville University Institutional Review Board and were deemed safe and appropriate.

Participants

One hundred sixty-two undergraduate students (120 females and 42 males) from a comprehensive liberal arts university participated in the present study in order to fulfill a course requirement. Each participant willing to participate signed a consent form. Exclusion criteria pertained to glycemic disorders such as diabetes mellitus, hypoglycemia, hyperglycemia and thyroid dysfunctions.

Design/Treatment

This study is a 2 × 2 between-groups design where subjects were randomly assigned to a glucose or placebo group. The glucose and placebo groups were each further divided into low emotional arousal and high emotional arousal groups. Subjects belonging to the glucose group received 240 ml of a lemon-flavored drink containing 50 g of glucose, 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. The low emotional arousal and high emotional arousal groups were shown a slide show consisting of 51 colored pictures whose content was either emotionally neutral or emotionally arousing, respectively. The two sets of pictures were graciously provided to us by Dr. Marise Parent. They were obtained from the IAPS database (Lang, Bradley & Cuthbert, 1997) and were used in a previous study (Blake et al., 2001). However, in the present study, nine images were eliminated from the high arousal set due to sexually explicit content. In order to make both sets of power point presentations equivalent in number of slides, nine

images were also removed at random from the original low arousal slide show. The original two sets of slide shows obtained from Dr. Parent with 60 pictures each were specifically designed in the Blake et al. study to vary in arousal level but to be similar in valence level, so arousal is the only variable between the two presentations. Those two low and high arousal original sets of pictures had in males mean normative emotional arousal ratings of 2.65 and 6.46, respectively, and mean normative valence ratings of 5.17 and 5.37, respectively (Blake et al., 2001). Due to the elimination of nine pictures from each of the original sets of pictures and the fact that both males and females were used in this study, normative ratings of arousal and valence were re-measured in the present study on our campus using a sample of 40 subjects for each set of pictures. Those 80 subjects were male and female also undergraduate college students who constituted a separate group from the 162 subjects used for the main part of this study. The 9-likert point self-assessment manikin (SAM) rating scale (Lang, 1980) was used for both arousal and valence. The arousal and valence values obtained in this study echoed those found in Blake et al. The mean normative emotional arousal rating for the low arousal set was 3.17 and the rating for the high arousal set was 5.47. The mean valence ratings for the low and high sets were, however, very similar at 4.85 and 4.15, respectively.

Procedure

All participants were asked to abstain from food and drink, with the exception of water, beginning at midnight the night before the experiment. The sessions were held from 8:30 a.m. through 10:00 a.m. Testing started with a fasting baseline blood glucose level followed immediately by ingestion of the glucose or saccharine placebo drink. Blood glucose measurements were also taken at 30 minutes, 45 minutes and 60 minutes following drink administration. Blood glucose measurements were carried out using Ultra Touch glucometer devices. Ten minutes following the drink administration, subjects viewed either the low emotional arousal or the high emotional arousal slide show. The slide show pictures were 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 slide show, and in each test, subjects were instructed to describe as many of the pictures as they could remember in any order using a word or a sentence. A recognition memory test including the original target pictures and 22 other distracter pictures was administered 60 minutes following

the viewing of the slide show. Subjects were asked to identify the pictures they had seen in the slide show. For the recognition test, pictures were projected onto a screen at a rate of 5 seconds per picture.

Results

Analysis of variance using SPSS software was carried out on the data with an alpha level of 0.05. Figure 1 shows blood glucose levels of the glucose and placebo groups relative to the amount of time before and after drink consumption. No significant difference was found in the glucose and placebo groups for the baseline fasting glucose measurement [$F(1.161) = 2.84$, $p > 0.05$]. However, group differences were found in the last three measurements following drink ingestion: 30 minute post drink [$F(1.161) = 334.16$, $p < 0.05$], 45 minute post drink [$F(1.152) = 234.62$, $p < 0.05$], and 60 minute post drink [$F(1.152) = 102.21$, $p < 0.05$]. The results indicate that blood glucose levels increased significantly in subjects who ingested the glucose drink relative to the placebo group.

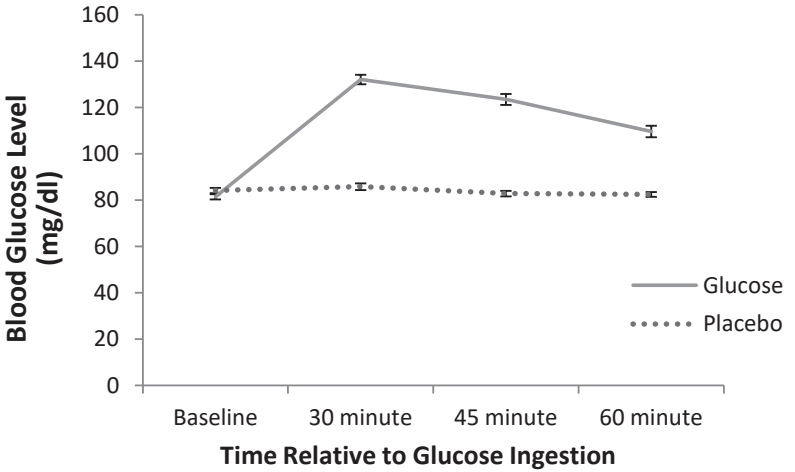

Figure 1.
Average blood glucose levels at baseline (following 8 hrs. of fasting) and at various intervals following drink ingestion. Mean ± SE; *p < 0.05.
Source: own research.

The results of this study show that there was no effect of emotional arousal on blood glucose level for all the subjects for the 30 minute post drink [$F(1.161) = 0.84$, $p > 0.05$], 45 minute post drink [$F(1.152) = 0.007$, $p > 0.05$], or 60 minute post drink [$F(1.152) = 0.18$, $p > 0.05$] blood glucose measurements. This lack of effect was also seen when comparing low emotional arousal to high emotional arousal in the placebo group only: 30 minute post drink [$F(1.77) = 0.36$, $p > 0.05$], 45 minute post drink [$F(1. 75) = 0.75$, $p > 0.05$], and 60 minute post drink [$F(1.75) = 0.58$, $p > 0.05$].

As shown in Figure 2, relative to placebo, glucose ingestion resulted in a marginally significant enhancement of memory in the immediate free recall test only, in all subjects [$F(1.142) = 2.93$, $p = 0.089$]. When females were analyzed separately from males, glucose administration improved memory also selectively for immediate recall [$F(1.102) = 3.98$, $p < 0.05$], but no such effect was found in males [$F(1.35) = 0.01$, $p > 0.05$].

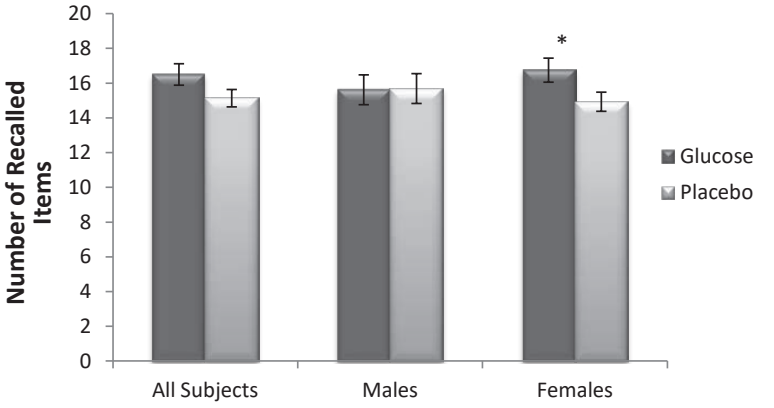

Figure 2.
Effect of glucose on number of items recalled by all subjects, males alone and females alone, immediately following presentation of images. Mean ± SE; *p < 0.05.
Source: own research.

High emotional arousal resulted in enhanced free recall immediately following viewing of the pictures and also at various delays following viewing of the pictures, as shown in Figure 3: immediate [$F(1.142) = 13.36$, $p < 0.05$], 20-minute delayed [$F(1.154) = 9.01$, $p < 0.05$], and 40-minute delayed [$F(1.146) = 15.12$, $p < 0.05$].

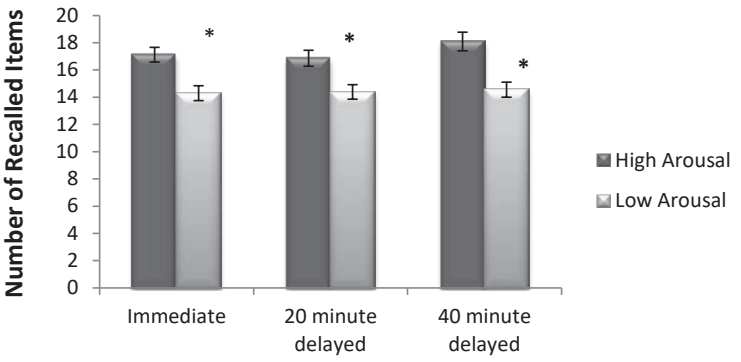

Figure 3.
Effect of emotional arousal on number of items recalled by all subjects immediately, 20 min and 40 min following presentation of images. Mean ± SE; *p < 0.05.
Source: own research.

When males alone are considered, emotional arousal enhanced free recall immediately following viewing of the pictures [$F(1.35) = 4.95$, $p < 0.05$], at a 20-minute delay [$F(1.35) = 6.20$, $p < 0.05$], and at a 40-minute delay [$F(1.34) = 6.67$, $p < 0.05$], as shown in Figure 4.

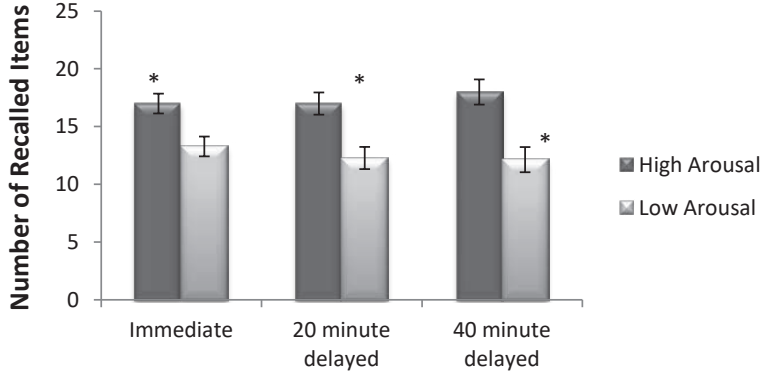

Figure 4.
Effect of emotional arousal on number of items recalled by males immediately, 20 min and 40 min following presentation of images. Mean ± SE; *p < 0.05.
Source: own research.

When females alone are considered, emotional arousal also enhanced free recall immediately following viewing of the pictures [$F(1.102) = 8.27$, $p < 0.05$], at a 20-minute delay [$F(1.114) = 3.88$, $p = 0.05$], and at a 40-minute delay [$F(1.107) = 8.30$, $p < 0.05$], as shown in Figure 5. For the recognition test, Figure 6 shows that emotional arousal enhanced recognition memory for males [$F(1.34) = 4.63$, $p < 0.05$] but not for females [$F(1.99) = 0.77$, $p > 0.05$].

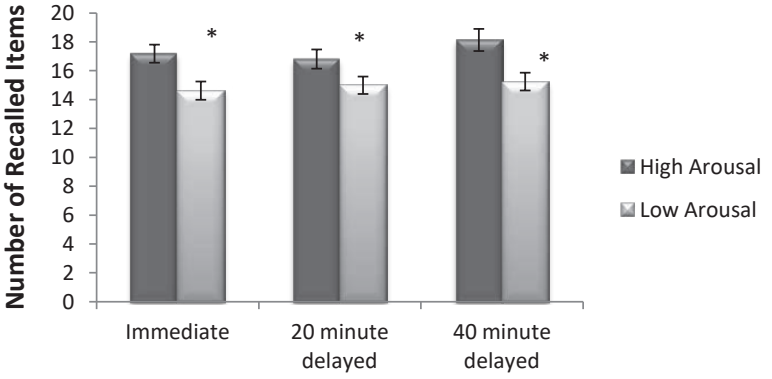

Figure 5.
Effect of emotional arousal on number of items recalled by females immediately, 20 min and 40 min following presentation of images. Mean ± SE; *p < 0.05.
Source: own research.

No interaction was found between type of drink, levels of emotional arousal and sex of subjects for any of the immediate [$F(1.119) = 0.14$, $p > 0.05$], 20-minute delayed [$F(1.119) = 0.00$, $p > 0.05$], or 40-minute delayed [$F(1.119) = 0.55$, $p > 0.05$] free recall tests. However, an interaction was found between emotional arousal and sex of subjects for the recognition test [$F(1.119) = 5.11$, $p < 0.05$]. As shown in Figure 6, males performed better than females in recognition [$F(1.137) = 8.10$, $p < 0.05$] and this sex-related difference was only true for highly emotional material.

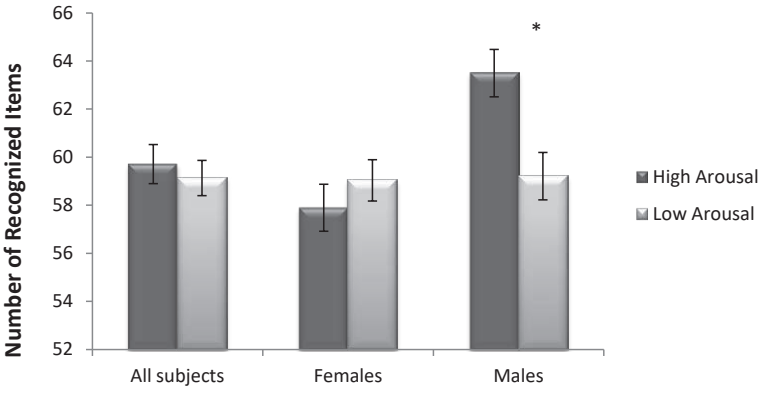

Figure 6.
Effect of emotional arousal on number of items recognized by all subjects, females alone and males alone. Mean ± SE; *p < 0.05.
Source: own research.

Discussion

Our hypotheses were only partly confirmed when all subjects were considered. Glucose had a marginally significant memory-enhancing effect on the free recall test immediately following the viewing of the pictures. However, contrary to our hypothesis, glucose did not affect the delayed free recall tests. Emotional arousal enhanced memory for all free recall tests but not for the recognition test, also contrary to our hypothesis.

When analyzing our findings from the perspective of the entire group (males and females combined), glucose improved memory of immediate free recall but only at a marginally significant level. However, when males are analyzed separately from females, the results indicated that glucose enhanced immediate recall for female subjects but not for male subjects. Craft et al. (1994) similarly reported that male and female participants were affected differently by glucose administration, suggesting sex-differences in glucose regulation processes. Specific sex-related factors that Craft et al. offer involve differences in glucose-related processing mechanisms. These elements include the oxidation process of glucose, which is higher in males than in females, and the relatively higher rates that males have for glucose utilization at similar plasma levels. These differences in glucose-related processing mechanisms could have accounted for

the sex-related differences in the effect of glucose on memory that was found in the present study. Research findings on sex-differences in glucose regulation, however, remain equivocal (Foster, Lidder & Sünram-Lea, 1998). In the present sample, we administered the same quantity of glucose to all participants, regardless of their sex and weight. While this procedure constitutes standard administration protocol for the majority of research in this area, the effects of administering uniform dosages may have, in fact, become a moderating variable that influenced the study's outcomes. Specifically, because our sample consisted of males and females, the same dosage of glucose may have affected males in quantitatively different capacities than how the same dosages affect females, considering that females have, on average, a relatively lower body weight. Further research is needed in this area to better clarify the facilitative effects of glucose on memory in order to determine whether males or females are more responsive to the effects of glucose and to discover the mechanisms behind the apparent differences in glucose-facilitating processes.

Glucose had no effect on memory in the male subjects and no effect on the delayed recalls as well as the recognition test. Although the effect of glucose on memory was assessed separately in males and females, the purpose of this analysis is not to compare males to females but rather to dissect the effect of glucose on memory in light of the sex of the subjects. Comparing males to females in this study would not be valid because there was a great discrepancy in the number of males and females participating in it. In agreement with our results, other previous studies also found no facilitatory relationship between glucose and memory (Azari, 1991; Brandt et al., 2006; Ford et al., 2002; Scholey, Sünram-Lea, Greer, Elliot & Kennedy, 2009). Scholey et al. examined males and females and reported that, while tracking memory was facilitated through the presence of glucose, recognition memory was not. These findings suggest that glucose administration does not enhance memory performance in all conditions. Accordingly, one study proposes that reliable effects of glucose on memory may be limited to populations that already possess pre-existing memory deficits (Azari, 1991).

Researchers have linked the effects of glucose on memory with the effects of emotional arousal on memory through findings that indicate emotional arousal both enhances memory and may sometimes result in relatively elevated blood glucose levels (Blake et al., 2001; Ford et al., 2002). Blake et al. specifically offer that the memory-enhancing effects of emotional arousal likely result from the release of peripheral epinephrine which, in turn, enhances

memory through increasing subjects' circulating blood glucose levels. While our research affirmed previous research findings that arousal tends to enhance memory (Blake et al., 2001; Bradley et al., 1992; Knight & Mather, 2009; Mather & Nesmith, 2008), the subjects in our study did not experience an increase in glucose levels from emotional arousal. As mentioned previously, though a few previous studies have demonstrated a pattern of elevated glucose levels in the presence of arousal, other studies have been in accordance with our present findings and did not find such an effect (Gore, 2002; Gore et al., 2006). The latter studies suggested that changes in blood glucose levels are not necessary for arousal to enhance memory. Specifically, results indicated that emotional arousal did enhance memory, but arousal had no effect on subjects' glucose or salivary cortisol levels. In conjunction with the above studies, findings from our present research seemingly support the conclusion that the facilitative effects of arousal on memory are not necessarily dependent on a rise in blood glucose level.

The present study assessed the combined effects of glucose and emotional arousal on memory. Prior research has shown that glucose ingestion did not affect memory performance for participants on material that already possessed other memory advantages, such as high arousal (Brandt et al., 2006; Ford et al., 2002), or prevented the emotional arousal-induced memory enhancement (Mohanty & Flint, 2001; Parent et al., 1999). Brandt et al. specifically reported that high blood glucose levels may, in fact, hinder memory performance for emotionally arousing items, while improving memory for neutral items. Their research findings further indicate potential connections between emotional arousal, the activation of the amygdala, and glucose – specifically, the role glucose might play in the potential amygdala-hippocampal interaction generated by beta-adrenergic-dependent activation. Our results agree with previous studies (Brandt et al., 2006; Ford et al., 2002) in finding no additive effect of glucose and emotional arousal on memory. No interaction between type of drink and level of arousal was found for recall or recognition.

The results of our present study, however, reveal an interaction between the effects of sex and emotional arousal on recognition memory. Emotional arousal enhanced free recall in all subjects but enhanced recognition memory only in the male subjects. Furthermore, male subjects performed higher on recognition tests than did females, and this sex-related difference was only true under the condition of high emotional arousal. While the amygdala is the brain's center for processing emotion-related information, sex-related

differences may involve lateralization in the involvement of the amygdala in emotional arousal (Cahill, Dray & Coderre, 1998). Cahill et al. suggested that in males, emotional arousal activates the right amygdala and in females, such arousal triggers the left amygdala. For males, when the right amygdala is triggered, better recall of central information is experienced. Females, in contrast, generally excel in the recall of peripheral (or detail-related) information in relation to activation of the left amygdala (Cahill, Prins, Weber & McGaugh, 1994). Our study concentrated entirely on central information processing in both recall and recognition, especially the latter. Since males are better at recall of central information of emotional stimuli, it might explain why males did better than females on recognition under the high emotional arousal condition and why emotional arousal enhanced recognition in males only. As mentioned earlier, one main weakness of this study is the discrepancy in the number of male and female subjects. Therefore, dissecting the effect of emotional arousal on memory in relation to sex of the subjects has to be interpreted carefully.

Future research is warranted in this area in order to further investigate the facilitative effects of glucose as well as the mechanisms that underlie these relationships between glucose, arousal, and memory. While the present findings confirm the facilitatory effects of glucose and emotional arousal on memory, they simultaneously stimulate more questions on the differences in the effect of these two factors on memory in males versus females.

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