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Effect of Sugars in Solutions on Immediate and Delayed Word List Recall in Normal Weight Boys

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Background: Dietary glucose improves memory performance in several adult populations; however, there are no comparative studies of commonly consumed sugars on memory performance in children.
Objectives: The objective was to compare the effect of glucose, sucrose and high-fructose corn syrup-55 (HFCS) solutions on immediate and delayed word list recall in 9 to 14 year-old normal weight boys.
Patients and Methods: In a repeated measures design, 15 normal weight boys received, in random order, preloads (200 kcal/250 mL) of glucose, sucrose, HFCS, or non-caloric sucralose control. The boys were presented with a 15 item word list to memorize 15 minutes after ingestion of the preloads and asked to recall the words immediately after, and at 30, 45, 60 and 90 minutes.
Results: There were no significant differences among the glucose, sucrose and HFCS preloads on word list recall compared with the non-caloric sucralose control at any of the time points. However, word list recall was highest at 15 minutes, and decreased over time to 90 minutes after all preloads ($P < 0.0001$).
Conclusions: Sugars in solutions do not differ in their effects on word list memory recall compared with a non-caloric sucralose control in 9 to 14 year-old normal weight boys.

*Keywords:*Children; Memory; Glucose; Sucrose; High-Fructose Corn Syrup

1. Background

Memory performance is improved following ingestion of dietary glucose in healthy young and aged adults (1), but the effect is less consistent in older adults with either memory deficits or poor glucose control (2). This benefit of dietary glucose is referred to as the glucose enhancement effect, which posits that a moderate increase in blood glucose improves cognitive performance by enhancing glucose metabolism in the brain (3). In healthy older adults, a dose response study of a fruit drink sweetened with 10, 25 and 50 g of glucose, compared with a saccharin sweetened control drink, enhanced logical memory in an inverted U-shaped manner, with the greatest enhancements observed after the 25 g dose (4). However, older adults with type 2 diabetes experienced further declines beyond the deficit associated with poor glucose control in word and paragraph recall 30 minutes after consuming a high glycemic index (GI) breakfast (5).

While there is a positive association between regular breakfast consumption and cognitive performance in children, especially among those with poor nutrition status (6), little is known about the role of macronutrient composition on memory performance. In elementary school children, instant oatmeal and ready-to-eat cereal enhanced spatial memory and auditory attention in older and younger children, respectively (7). In addition, both younger and older girls, but not boys, had better short-term memory after oatmeal compared with the ready-to-eat breakfast cereal. Girls who consumed a low- or high- glycemic load breakfast recalled significantly more words than boys and following a high glycemic load compared with the very high glycemic load breakfast (8). The foregoing observations may be due to the greater utilization of oxygen and glucose in the brains of children compared with adults, which may be modified depending on the source of carbohydrates in the diet.

2. Objectives

The objective of this study was to determine the effect of glucose, sucrose and HFCS solutions on immediate and delayed memory performance in normal weight, 9 to 14 year-old boys. We hypothesized that the glucose solution enhances memory performance to a greater extent than sucrose and HFCS due to its effect on increasing blood glucose and insulin concentrations.

3. Patients and Methods

3.1. Participants

Participants were recruited through advertisements posted throughout the Halifax Regional Municipality and printed in the local newspaper, as well as by word-of-mouth. Fifteen, 9 to 14 year-old normal weight boys, between the 5th and 85th BMI percentile for age and sex (9) participated in the study. To be included in the study, boys had to be born at full-term and normal weight at birth (10). Those dieting, taking medications affecting brain physiology, breakfast skippers, or with learning, behavioral, or emotional difficulties were excluded from the study. Participant characteristics are described in greater detail in our previous publication (11). The study was approved by the Research Ethics Board, Mount Saint Vincent University.

3.2. Treatments

Preloads included isovolumetric (250 mL) and isocaloric solutions (200 kcal) of glucose (54.6 g; Grain Process Enterprises Ltd., Scarborough, ON), sucrose (53.3 g; Redpath Sugar Ltd., Toronto, ON), HFCS-55 (64.9 g; donated by Casco Inc., Etobicoke, ON) or a non-caloric sucralose control (250 mg of SPLENDA, donated by Tate and Lyle, Decatur, IL). The preloads were matched for sweetness with the addition of 1.1 g of aspartame-sweetened, orange-flavored crystals (Sugar Free Kool-Aid, Kraft Canada Inc., Don Mills, ON) and 70, 50, 20 mg of sucralose added to the glucose, sucrose and HFCS solutions, respectively.

3.3. Protocol

This randomized, repeated measures study examined the effect of sugars in solutions on subjective appetite, food intake, and immediate and delayed memory recall. The subjective appetite and food intake data were previously reported (11). Following a telephone screening interview with the parent, an in-person interview was scheduled where informed written consent and assent were obtained from the parent and child, respectively. Anthropometric measurements including height (m), weight (kg) and skinfold measurements (mm) at four points (triceps, biceps, supra-ilial, and subscapular) were taken as previously reported (11).

The study took place on four separate mornings following a 10 to 12 hours overnight fast, at least one week apart and two hours after consuming a standardized breakfast at home consisting of fat-free skim milk (250 mL, 90 kcal; Baxter, Saint John, NB, Canada), Honey Nut Cheerios® (26 g, 90 kcal; General Mills, Mississauga, ON, Canada), and Tropicana Orange Juice® (236 mL, 110 kcal; Tropicana Products Inc, Bradenton, FL, USA). Boys arrived at the Department of Applied Human Nutrition at Mount Saint Vincent University at a consistent time across all test sessions between 10:00 am and 12:00 pm.

Upon arrival, the boys were asked about their adherence to the pre-test study protocol. Participants then consumed one of the chilled preloads followed by 100 mL of water to minimize aftertaste, within five minutes. The boys were presented with one of the six word lists to remember 15 minutes later. Lists were composed of 15 words of common objects that came from different categories (e.g. toys, animals, vegetables). The majority of the words were one syllable, and four words in each list were two syllables long. Participants were given a different list of words to remember at each session. They were asked to repeat each word as it was read out loud by the researcher and then asked to write down as many words as they could remember at 15 minutes (immediate recall), and 30, 45, and 60 minutes, as well as after the pizza lunch at 90 minutes (delayed recall). Two varieties of pepperoni or three-cheese pizza (McCain Foods: "Deep and Delicious 5" Pizza) were served at the test meal. The composition of the lunch was previously described (11).

3.4. Statistical Analysis

All statistical analyses were conducted using SAS version 9.2 (SAS Institute Inc. Cary, NC). The effect of preloads on immediate and delayed word-list recall was determined by a two-factor repeated measures analysis of variance (ANOVA) using the Proc Mixed procedure with preload (control, glucose, sucrose, and HFCS) and time (15, 30, 45, 60 and 90 minutes) as main factors. Data are presented as means ± standard error of the mean (SEM). Significance was considered at $P < 0.05$.

4. Results

4.1. Participant Characteristics

As previously reported (11), 15 normal weight boys with a mean age of 12.2 ± 0.4 years, body weight of 45.4 ± 2.4 kg, BMI percentile of 47.7 ± 6.7, fat mass of 8.4 ± 0.9 kg and fat-free mass of 37.0 ± 2.1 kg participated in the study.

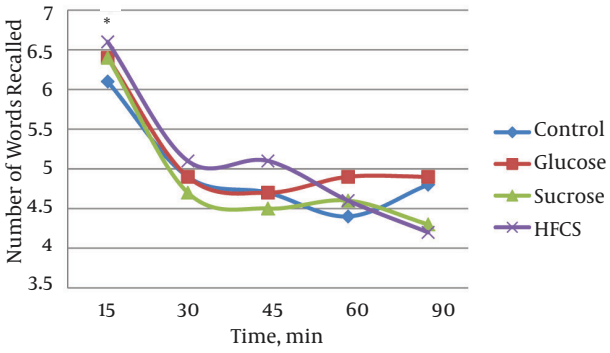
4.2. Memory Scores

There was a main effect of time ($P < 0.0001$), but there was no preload or time by preload interaction. Participants recalled significantly more words at 15 minutes compared to the other measurement periods (Figure 1).

5. Discussion

The results did not support the hypothesis that glucose ingestion, compared with sucrose and HFCS, or the non-caloric sucralose control, enhances immediate or delayed memory performance in adolescent boys. However, boys recalled approximately 1.5 more words at 15 minutes compared with the other time points.

Figure 1. Mean (± SEM) Words Recalled in 15 Normal Weight Boys After Ingestion of Sugars in Solutions



Significantly different at 15 minutes compared to 30, 45, 60 and 90 minutes (Two-way ANOVA, Proc Mixed, $P < 0.0001$).

This study was the first to compare the effect of sugars in solutions on memory performance in children. Prior studies have examined the effect of sugars on memory performance as part of mixed meals, or included in beverages with other components. Thus, it is difficult to attribute the effects to any individual component in isolation. In 10 to 12 year-old children, the effect of isocaloric beverages of glucose, milk, or a mixture of milk and glucose on word list recall was examined over three hours (8). Girls, but not boys, recalled more words after consuming the milk-containing beverages, suggesting that both sex and macronutrient composition interact to affect memory performance. In healthy older adults (12), despite difference in the glycemic response, both dietary protein and fat improved memory performance similar to carbohydrate. Thus, multiple mechanisms other than an increase in blood glucose contribute to improvements in memory performance. One potential mechanism is suggested from the observation that receptors for gastrointestinal hormones are expressed in brain regions that are important for memory and learning (13). Therefore, the gut-brain axis and in particular, the profile of macronutrient-specific gastrointestinal hormone secretion may offer additional insight into the role of macronutrient composition on memory performance. In addition, it is important to examine both the combined and individual effects of food components on memory performance. For example, a beverage containing glucose (37.5 g), caffeine (75 mg), ginseng and Ginkgo biloba enhanced secondary memory and attention performance compared with the control, while the components given in isolation did not (14). This suggests a synergistic effect of dietary glucose and bioactive components.

The failure of glucose to enhance memory performance more than sucrose and HFCS was unexpected, but it may be related, in part, to the dose of sugar. In healthy older adults, a dose response study of a fruit drink sweetened with glucose, compared with a saccharin sweetened control drink, enhanced logical memory in an inverted U-shaped manner, with the greatest enhancements observed after the 25 g dose (4). Thus, a dose-response study in children is merited to confirm the potential for an optimal carbohydrate dose on memory performance. Another possible explanation for the lack of effect of sugars in solutions is that several brain regions (15) are involved in the control of declarative memory that may not be predicted by changes in blood glucose or insulin concentrations. It has been suggested that glucose and other carbohydrates are more strongly associated with long-term declarative memory, which is mediated by the medial temporal lobe (2, 16), rather than on short-term verbal memory, which occurs primarily in the prefrontal cortex (17). Therefore, future comparative studies should include a comprehensive battery of memory tests to more clearly delineate the role of macronutrient composition on memory performance.

There are several limitations worth noting. First, the word list recall test was measured for only 90 minutes after preload consumption, but a longer measurement interval may be required to detect differences in memory performance between low- and high- GI meals (18). Second, although the effect of sugars was examined only in boys in this study, memory performance in girls is more strongly modulated by changes in macronutrient composition (8), which may be related, in part, to the effects of estrogen (19). Finally, the effect of the caloric sugars in solutions may have been masked by the relatively larger breakfast two hours earlier, as breakfast intake alone is strongly associated with improved memory performance in children (20).

In conclusion, sugars in solutions do not differ in their effects on word list memory recall compared with the non-caloric sucralose control in 9 to 14 year-old normal weight boys.

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Authors' contributions

Tina Akhavan performed all statistical analyses and drafted the manuscript. Michelle Eskritt contributed to the study design and helped draft the manuscript. Marissa Van Engelen coordinated the study, assisted with participant recruitment and data acquisition. Nick Bellissimo designed the study, supervised Tina Akhavan and Marissa Van Engelen, and directed drafting of the manuscript. All authors read and approved the final manuscript.

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