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Effect of an afternoon confectionery snack on cognitive processes critical to learning

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Abstract

Two experiments examined how an afternoon confectionery snack affects a variety of cognitive processes critical to learning. For Experiment 1, thirty-eight male undergraduates completed a dual learning task where the primary task involved learning either a map or stories and the secondary task required monitoring a radio broadcast for a specific word category. Results showed that for map learning, participants who consumed the confectionery snack performed better on the primary task. They correctly placed more country names and left fewer blanks on a map during long-term recall. However, on the secondary attention task, participants who consumed the confectionery snack had a lower hit rate. The confectionary snack did not affect story memory performance. In Experiment 2, 38 boys, aged 9–11 years, participated in a similar, age appropriate task. Results showed that boys who had consumed the confectionery snack correctly placed more names and left fewer blanks on a map in both short-term and long-term recall. In contrast with Experiment 1, performance on the secondary task was better after confectionary consumption. However, when tested on a separate vigilance attention task, children who consumed the placebo performed better. Overall results indicate that a confectionery snack, ingested in the afternoon, generally improves spatial memory, but has a mixed effect on attention performance.

Keywords: Carbohydrate; Cognition; Attention; Snacks

1. Introduction

In recent years, the notion that short-term changes in dietary intake affect cognitive processes, such as learning and memory, has gained considerable recognition [1]. This notion is supported by research showing that modest increases in circulating blood glucose concentration enhance learning and memory [2–4]. Previous research indicates that such positive effects apply across age groups, including children [5], young adults [6,7], and elderly adults [8–11].

The time of day a meal is consumed has also been shown to affect cognitive performance. For example, eating breakfast, compared to skipping it, can improve school-aged children's performance on some cognitive tasks [12,13]. These effects were even more pronounced in malnourished children [14,15]. In addition, the nutritional composition of the breakfast affects some areas of cognitive performance. A high-energy breakfast has been shown to improve short-term memory and concentration compared to a low energy breakfast [16]. The improved performance after high-energy breakfasts may relate to blood glucose levels, as high carbohydrate meals tend to show more pronounced effects on cognition than other types of meals [17]. However the relationship between carbohydrate intake and cognitive performance may not be a direct one, as a breakfast that is moderate to low on the glycemic scale has been shown to improve spatial memory and attention compared to a high glycemic index (GI) breakfast [18]. It is hypothesized that the differences in performance between these two meals may be due to the slower and more sustained release of glucose into the bloodstream following the lower GI breakfast.

In contrast, a mid-day meal can impair reaction time and attention [19,20]. Again, the type of meal consumed qualifies this effect. For example, a high carbohydrate lunch impairs reaction time and vigilance attention compared to a high protein

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lunch [21]. Furthermore, a larger than usual meal impairs performance to a greater extent than a smaller than normal meal [22].

The comparison of cognitive performance following breakfast and a mid-day meal highlights how food consumption at different times of day can differentially affect behavior. Other factors such as meal quality and variations from normal meal size exacerbate these effects. In addition, the interval between the test meal and the last meal consumed must be considered. Performance may be quite different following a meal if participants have been previously fasting then if they have recently consumed another meal. These effects may be due to differences in gastric contents, blood glucose levels, or simply, feelings of satiety.

Food is not just consumed at mealtime. For many individuals, snacking accounts for a substantial amount of energy intake throughout the day. However, the effect of snacking on cognitive performance has received little attention. A recent study which examined the effect of breakfast and a mid-morning snack on word-list memory showed that memory was not influenced by breakfast, but 20 min after a mid-morning snack, memory improved [23]. In addition, a study examining the effect of a confectionery snack consumed in the morning showed better attention following confectionary snack consumption than when no snack was consumed [24]. The mid-afternoon snack is a common time for food consumption, but has received little research attention. The effect of the mid-afternoon snack on cognition may be particularly important to examine particularly since children often snack after school and then begin their homework. Since lunch consumption generally impairs cognitive performance, might a mid-afternoon snack counteract these effects? Alternatively, since an afternoon snack does not follow a fasting period, its affect on cognitive performance may match the effect of lunch. In one of the only studies to date, Kanarek and Swinney (1990) reported that a mid-afternoon high carbohydrate snack improved verbal memory, vigilance attention, and arithmetic performance [25]. The present studies examined how a mid-afternoon confectionary snack affects spatial and verbal memory and attention. Based on the previous work by Kanarek and Swinney (1990) we predicted that an afternoon confectionary snack would enhance performance on measures of memory and attention compared to placebo.

1.1. Experiment 1

Experiment 1 assessed how a mid-afternoon confectionary snack affected memory and attention in adult males. These cognitive processes were chosen for two reasons. First, attention and memory are processes required when students are completing real-world tasks, such as studying for an exam. Second, previous research clearly demonstrates the beneficial effects of glucose consumption on memory [6,8,9,26,27], but its effects on attention are less clear. If Experiments 1 and 2 show that the confectionery snack also positively influences attention, it could be that the positive effects seen with memory tasks are in part due to an increase in attention to the material that is studied. To examine this issue, participants studied either a map or stories while simultaneously monitoring a radio broadcast for target words. Participants were to learn the primary material (map or stories) while noting each time a word of a particular category appeared in the radio broadcast. This task allowed for an examination of both monitoring and vigilance attention and both spatial and verbal memory.

2. Method

2.1. Participants

Thirty-eight Tufts University male undergraduates, between the ages of 18 and 22, participated for $75 (mean BMI 23.02). Participants were recruited through announcements posted on campus and in the campus newspaper.

2.2. Questionnaires

A screening questionnaire addressed current dietary patterns as well as medical history. Volunteers were allowed to participate if they were not taking medication and free of learning disabilities and dietary restrictions.

A 7-point Likert scale assessed participants hunger levels before and after each testing session. The questionnaire also addressed mood and energy level.

2.3. Learning materials

The learning materials were presented on a Macintosh computer, using in-house programs. A map task assessed spatial memory. The map consisted of four continents, divided into twenty-five countries. The countries were named after gems.

The verbal task consisted of seven short narratives approximately twenty-five lines each. The texts have been used in previous text comprehension research [28]. Each idea in a text has been weighted by its relationship with other ideas in the text, thus affording higher sensitivity in coding free recall of the texts.

The secondary task involved a taped radio broadcast from a local soft rock station, including combinations of music, disc jockey discussion, and advertisements. Within the broadcast, words from certain categories, along with other non-category words, were electronically added at a random schedule, averaging one word every 30 s. The target category for the tape was body parts (e.g. leg, arm, and nose). The remaining words matched target words for length and familiarity.

2.4. Procedure

Participants reported to the same room, one day a week for 2 weeks. To control for the possible effects of prior food intake, on their scheduled day, participants came for breakfast, returned 3 h later for lunch, and returned again 3 h later for testing. Breakfast and lunch were made so that they were similar in total caloric intake, and the amounts of carbohydrate, fat and protein they contained. Participants were instructed not to eat or drink (with the exception of water) after 10:00 pm the night before testing and not to snack between meals on testing days. All participants were randomly assigned to either the confectionary snack or the placebo condition during the first week of testing.

2.4.1. Week One testing

Participants first received a questionnaire to assess hunger, energy, and mood. Once completed, they received either 50 g of a confectionery product or one cup of an artificially sweetened drink matched for sweetness (see Table 1). They then sat quietly for 15 min. After 15 min, participants began the dual task. During the dual task, participants studied either the map or the set of texts (primary task) while monitoring the simulated radio broadcast for the specific word category (secondary task). During the secondary task, participants pressed a designated button when hearing a word from the target category. Secondary task performance measures included accuracy and response time. The dual task lasted 20 min.

The map group studied a map with country names displayed one at a time on the computer screen. Participants advanced through the country names at their own pace using a designated button. After a complete cycle of country names, the cycle repeated. Participants continued studying for 20 min while listening to the radio broadcast (secondary task). After the 20-min study period, participants filled in a blank map and recalled as many of the secondary task words as possible. Participants were not previously aware of the secondary task recall task. Performance measures included number recalled and placement accuracy of country names, as well as number of secondary task words recalled.

The text condition followed the same procedure, except instead of a map participants viewed seven short stories. Each story appeared one sentence at a time and participants advanced through sentences using the designated button. After the 20-min study time, participants free recalled the stories and the secondary task target words.

Table 1

Per 50 g of confectionery product	
Total carbohydrates	44 g
Glucose	2.5 g
Sucrose	32 g
Maltose	2 g
Higher oligosaccharides	7.5 g
Per 25 g of confectionery product	
Total carbohydrates	22 g
Glucose	12.5 g
Sucrose	16 g
Maltose	1 g
Higher oligosaccharides	3.75 g
Per 1 cup of placebo	
Total carbohydrates	0 g
Sugars	0 g
Protein	0 g
Total fat	0 g
Sodium	0 mg

Confectionery product ingredients: sugar, corn syrup, partially hydrogenated soybean oil, fruit juice from concentrate (orange, lime, grape, strawberry, lemon), less than 2%— citric acid, dextrin, natural and artificial flavors, gelatin, food starch-modified, coloring (includes yellow 5 lake, yellow 6 lake, red 40, blue 2 lake, blue 1 lake, yellow 5, yellow 6, blue 1), ascorbic acid.

Placebo ingredients: citric acid, calcium fumarate, maltodextrin (from corn), aspartame, beta carotene, alpha tocopherol, natural flavor, ascorbic acid, sodium citrate, magnesium oxide, niacinamide, red 40, zinc oxide, calcium pantothenate, artificial color, artificial flavor, vitamin B12, B6, and B2.

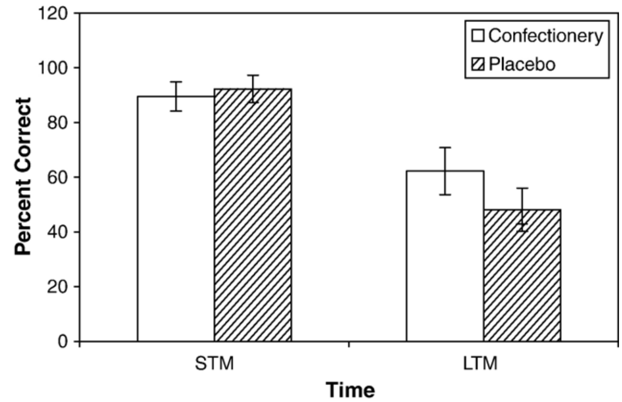

Fig. 1. The proportion of items correctly recalled in the map task as a function of type of memory (short-term vs. long-term) for the confectionery group and the placebo group in Experiment 1.

2.4.2. Week Two testing

Participants returned to the lab the same day of the week and the same times for meals and testing. During testing, they completed a long-term recall for information learned the previous week (either map or stories). The recall tasks were exactly the same as those completed the previous week. After completion of the tasks, the participants were debriefed.

2.4.3. Results

Unless otherwise specified, analysis consisted of ANOVAs with memory type (short- or long-term) as a within-participant variable and materials (map or text) and snack (confectionery product or placebo) as between-participant variables.

2.5. Primary task

Map recall data was coded for correct recall, number of blank countries, and incorrectly placed countries. Analysis of the correct recall showed a significant interaction between snack and memory type (short-term or long-term), F (1, 22)=4.34, $p<.05$. The two snack groups showed similar correct short-term recall (confectionery snack $M=89.5$, SEM=5.4; placebo $M=92.2$, SEM=5.0), but the confectionary snack group ($M=62.2$, SEM=8.6) showed better long-term recall than the placebo group ($M=48.1$, SEM=7.9; see Fig. 1).

Analysis of countries left blank also showed an interaction between snack and memory type, F (1, 22)=9.64, $p<.01$. Similar to correct recall, the percentage of blanks made in short-term recall were similar for both snack groups (confectionery $M=5.6$, SEM=3.5; placebo $M=3.7$, SEM=3.3), but the confectionary group ($M=23.1$, SEM=6.9) left fewer blanks in long-term recall than the placebo group ($M=41.3$, SEM=6.3; see Fig. 2). Analysis of misplaced locations did not show any differences between snack groups. Finally, all measures showed

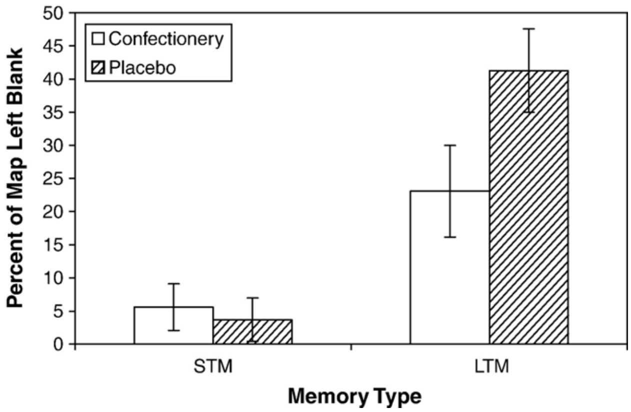

Fig. 2. The proportion of countries left blank in the map task as a function of type of memory (short-term vs. long-term) for the confectionery group and the placebo group in Experiment 1.

standard memory effects, with performance during the short-term memory tests better than the long-term memory test.

Analysis of the text recall data showed only standard memory effects, short-term memory better than long-term memory, but no snack effects.

2.6. Secondary task

Dependent measures for the secondary task included number of hits, misses, and false alarms, as well as reaction time (RT) for hits and false alarms. Analysis showed a significant effect of snack for hit rate, F (1, 41)=4.41, $p<.05$, with confectionary snack participants having fewer hits (M=0.64; SEM=.05) than placebo participants (M=0.85; SEM=.03). Miss rate also showed a significant snack effect, F (1, 41)=4.97, $p<.05$. Confectionary snack participants had more misses (M=0.20; SEM=.03) than placebo participants (M=0.08; SEM=.02). Analysis of false alarms did not show any snack effects.

Analysis of false alarm RTs yielded a significant snack effect, F (1, 40)=4.16, $p<.05$, with the participants who received the confectionery snack responding faster (M=1.61 s; SEM=.09) than those who received the placebo (M=2.46 s; SEM=.21). RT for hits did not differ between the two snack groups.

Recall for the secondary task was broken down into three categories, target, non-target, and wrong. Target words were those words recalled from the correct category (i.e. body parts). Non-target words were those heard on the tape, but not from the target category. Wrong words were those never heard on the tape. There were no significant snack effects on secondary task word recall, although the results did show standard memory effects. Participants recalled more target than non-target words and again showed standard memory effects with better short-term than long-term recall.

2.7. Questionnaire

Analysis of questionnaire responses showed a snack by time interaction for hunger level, F(1, 39)=8.88, $p<.005$, Mse=.90. As would be expected, participants were less hungry 45 min after consuming the confectionery snack than after consuming the placebo drink. These differences reflect a change score from hunger level prior to consumption (before confectionery snack M=4.65; after confectionary snack M=3.84; before placebo M=4.40; after placebo M=4.44). Based on this finding, we used hunger level as a co-variate in the analysis, but found no changes in the original findings.

3. Discussion

Results of Experiment 1 indicate that intake of dietary sugar, from a confectionary snack, improved primary task performance, particularly spatial memory, but hindered secondary task performance. Interestingly, the largest effect was seen with long-term recall. The confectionary group correctly remembered and placed more country names after a week delay than did the placebo group. In other words the confectionary group better remembered both the country identities and their locations. This result is particularly interesting in light of the fact that both snack groups showed similar short-term memory performance. It is possible that the confectionery snack may have also enhanced short-term memory, but the current task was not sufficiently challenging to allow those differences to be detected.

Unlike map recall, text recall showed only standard memory effects and no snack effects. Unfortunately, experimental attrition rates left the snack conditions for the text groups with a dramatic difference in the distribution of volunteers in each snack condition. The uneven distribution of participants across the two snack groups could have contributed to the lack of findings for the text group. However, it is important to note that while numerous studies have found that glucose enhances memory for contextual verbal material [8,27,29,30], other studies have found no effect [6].

While performing better on the primary task, the confectionary group performed more poorly on the secondary task than the placebo group. Results showed lower hit and higher miss rates after the confectionary snack than after the placebo. This finding may reflect a differential allocation of cognitive resources. The confectionary group participants may have devoted more attentional resources to the primary task and been less distracted by the secondary task. This interpretation is further supported by the reaction time results. Confectionary group participants responded faster to false alarms, but not to hits. This suggests that with fewer attentional resources on the secondary task, these participants “jumped the gun” when hearing words in the radio broadcast. One might also argue that this RT finding suggests a speed–accuracy tradeoff. However, if a speed–accuracy tradeoff was evident, reaction times to hits should also have been higher for the confectionery group.

Taken together, these results suggest that the participants who consumed the confectionery snack devoted more attention to the primary task and less to the secondary task than those who consumed the placebo. This result supports previous findings showing that glucose enhances vigilance attention [5]. This result expands previous findings to spatial memory, a previously unexplored cognitive process. Increased attention to the primary task resulted in better memory for country names and locations. These findings also expand previous findings by showing effects in long-term recall after a week delay. However, while the increased attention on the primary task led to enhanced performance, it may also be associated with decreased performance on the secondary task. This may suggest that while the confectionery product enhanced vigilance attention, but monitoring attention was negatively affected.

3.1. Experiment 2

In Experiment 1, a confectionary snack improved primary, but decreased secondary task performance. The current experiment follows up on these results and extends them to a different population, children. Experiment 2 again used a spatial memory task as a primary learning task, coupled with a secondary monitoring task. The same map, but with more age appropriate country names, was used. Use of the same map with the younger population increased the overall difficulty level of this task in hopes of also finding short-term memory effects.

Experiment 2 also attempts to further evaluate the findings of Experiment 1 by incorporating a second task designed to explicitly examine vigilance attention. During the second week of the study, participants completed a continuous performance task (CPT). During the CPT, participants monitor a constant stream of letters for a particular target combination. Previous research has shown improvements on the CPT following ingestion of a confectionery product after a period of fasting [24]. The present work attempts to extend this finding, examining a different time of day, the mid-day snack. Although, the effects of a confectionery snack would be more sensitive after a period of fasting, results from previous research [24,25] suggest that CPT performance might also improve after a confectionary mid-day snack.

4. Method

4.1. Participants

Participants consisted of 38 boys, between the ages of 9 and 11 years, attending local, parochial elementary schools (mean BMI 18.57). All boys were of good health and free of any learning disorders. Parents/guardians of the children were compensated $75 for their child's participation.

4.2. Materials

4.2.1. Questionnaires

Both questionnaires used in Experiment 1 were also used in Experiment 2. Parents/guardians completed the health questionnaire. Boys completed the mood, energy, and hunger questionnaire and a 24 h food recall.

4.2.2. Learning materials

The same map task used in Experiment 1 was also used in Experiment 2, with the exception that the country names were chosen from the earth category (e.g. rock, ocean) to be more age appropriate. The secondary task used the same radio broadcast as in Experiment 1.

4.2.2.1. Attention task. A continuous performance task (CPT) further evaluated vigilance attention. Again, this task was programmed in-house and presented on a Macintosh computer. The program flashed letters in the middle of the screen at a rate of one every second. The designated target combination, e.g. “X” followed by a “B” occurred 20% of the time.

4.2.3. Procedure

4.2.3.1. Screening. A letter describing the purpose of the study and participation requirements was sent to all parents/guardians of fourth and fifth grade boys at local parochial schools. A screening questionnaire was administered to the parents/guardians of all interested volunteers. The questionnaire addressed current dietary and sleeping patterns as well as medical history. Children where allowed to participate in the study if they were of normal weight, and free of medication, learning disabilities, and dietary restrictions. Parents/guardians of the children were compensated $75 for their child's participation. Parents were given a list of suggested meals for their child's breakfast and lunch on testing days.

4.2.3.2. Testing. Participants reported to an assigned room, approximately 3 h after lunch, one day a week for 2 weeks. Participants were randomly assigned to either the confectionary snack or the placebo snack for Week One testing.

4.2.3.2.1. Week One testing. Upon arrival, children completed a food record for that day and a questionnaire. Participants were then given either 25 g of a confectionery product or half a cup of an artificially sweetened drink matching the confectionery product for perceived sweetness. After a 15-min absorption period, participants heard the same instructions used for Experiment 1 concerning the dual task. The remainder of Week 1 testing procedures followed those used in Experiment 1. Participants engaged in the dual learning task for 20 min, followed by the recall tasks.

4.2.3.2.2. Week Two testing. Participants returned to the same room on the same day, the following week. Upon arrival, each participant filled out the questionnaire, assessing mood, hunger and energy level and completed the recall tests for information learned the previous week. After completing the recall, the participants were given the opposite snack from the one they received the week before. Thus, if the child received the confectionery snack in Week One, they were given the artificially sweetened drink. After the 15-min absorption period, each participant engaged in the CPT for 10 min. Upon completion, participants filled out another mood, energy, and hunger questionnaire. Finally, participants were debriefed and thanked for their participation. Debriefings were also sent home.

5. Results

Unless otherwise specified, analysis consisted of repeated measures ANOVAs with memory type (short-term and long-term) as a within-participant variable and snack (confectionery or placebo) as a between-participant variable.

5.1. Primary task

Maps were scored as in Experiment 1. Analysis of correctly recalled items showed a main effect for snack, F (1, 29)=5.14, $p<.05$. The confectionary group recalled and correctly placed more countries in both the long-term and the short-term memory recall (M=12.7; SEM=1.5) than the placebo group (M=8.3; SEM=1.2). Analysis of the number of countries left blank revealed a similar main effect of snack, F (1, 29)=4.49, $p<.05$. The confectionary group left fewer blanks (M=8.9; SEM=1.5) during both long and short-term recall than the placebo group (M=13.0; SEM=1.2). Number of blanks also showed an interaction between snack and type of memory, F (1, 29)=6.38, p<.05. Confectionary participants left fewer blanks (M=7.5; SEM 1.6) than placebo participants (M=9.8; SEM=1.2) during short-term recall and this difference diverged even further for long-term recall (confectionary group M=10.3; SEM=1.6; placebo group M=16.2; SEM=1.3; see Fig. 3). The other map variables showed no significant effects.

5.2. Secondary task

Scoring and dependent measures for the secondary task followed those used in Experiment 1. Analysis of hit rate showed a significant effect of snack, F (1, 19)=5.03, $p<.05$. The participants who consumed the confectionery snack had a higher hit rate (M=14.3; SEM 1.7) than those who consumed the placebo (M=8.4; SEM=2.4). Analysis of miss rate also showed a significant snack effect, F (1, 19)=5.09, $p<.05$. The participants who consumed the confectionary snack had a lower miss rate (M=8.7; SEM=1.7) than those who consumed the placebo (M=14.4; SEM=2.5). No differences between snack groups were found for false alarms or RT.

Coding of secondary task recall followed that used in Experiment 1. Analysis of target words recalled showed an interaction between snack and memory type, F (1, 34)=4.89, $p<.05$. For short-term recall, participants who consumed the confectionery snack recalled more target words (M=5.1; SEM=.64) than those who consumed the placebo (M=3.8; SEM=.67). However, for long-term recall, there was no difference in performance based on snack (confectionary group M=3.8; SEM=0.55; placebo M=4.1; SEM=0.58; see Fig. 4). No significant differences were found between the two snack groups on other recall measures.

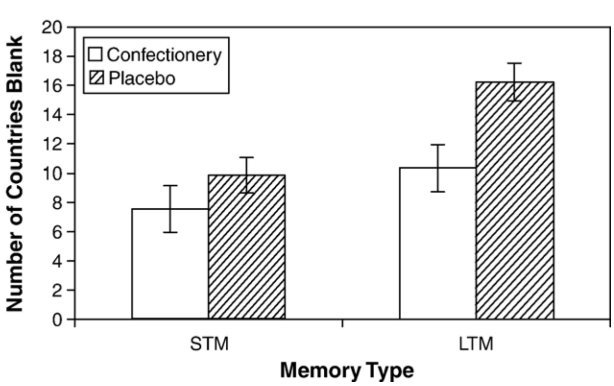

Fig. 3. The mean number of countries left blank in the map task as a function of type of memory (short-term vs. long-term) for the confectionery group and the placebo group in Experiment 2.

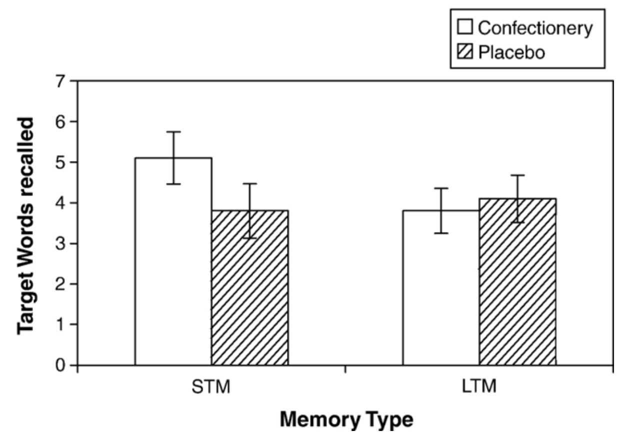

Fig. 4. Mean number of target words recalled in the secondary task as a function of memory type (short-term vs. long-term) for the confectionery group and the placebo group in Experiment 2.

5.3. CPT

Dependent measures for the CPT included hits, misses, and false alarms. Participants had a hit when they correctly responded to the target (X followed by a B). A miss occurred when the participants failed to respond to the target. False alarms include all responses to non-target combinations. Response rates were examined overall and over time. For this latter analysis, the 10-min time period was broken down into three equal intervals. In addition to the response rates, RTs for hits were also examined.

Analysis of hit rate revealed a snack by time interaction, F(2, 58)=6.11, $p<.05$. In the first time interval, participants who consumed the confectionery snack had a higher hit rate (M=30.9; SEM=.82) than those who consumed the placebo (M=28.3; SEM=.79). For the second and third time intervals, no differences between snack groups emerged (see Fig. 5). The other dependent measures showed no significant effects.

5.4. Questionnaire

Analysis of the questionnaire showed a snack by time interaction for how the participants felt overall, F(1, 33)=4.43, $p<.05$. Participants who consumed the confectionery snack felt better 45 min after consumption (M=6.0) compared to before (M=5.6). The placebo group showed no change in overall feeling before (M=6.0) and after the snack, (M=5.8). Applying an overall feeling in an analysis of co-variance did not

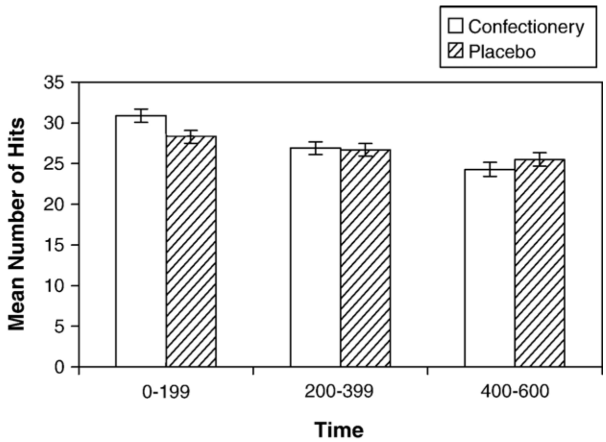

Fig. 5. Mean number of hits during the continuous performance task as a function of time in Experiment 2.

significantly alter the results. No differences were found on measures of mood, alertness, stress, hunger, thirst, fatigue, and relaxation.

6. Discussion

Results of Experiment 2 indicate better performance on both the primary and secondary tasks following the confectionary snack. Children who consumed the confectionery snack recalled and correctly placed more country names in both short-term and long-term recall than those who consumed the placebo snack, indicating that the confectionery snack better enabled the children to devote attentional resources during learning. This effect intensified with delay in recall. Unlike Experiment 1, participants also performed better on the secondary task after consuming the confectionary snack, showing higher hit rates, lower miss rates, and increased target word recall.

The effects seen in Experiment 1 were further extended to a different attention task. Children performed better, particularly during the early part of the CPT task, following the confectionary snack. The improvement did not extend through the entire task duration.

7. General discussion

Results from Experiments 1 and 2 suggest that ingestion of a confectionery snack can improve cognitive performance. Although effects of dietary sugars, in particular glucose, on cognitive performance have been shown previously [3,5–9,27,31–33], the present work extends these findings in several ways. First, the present study examines the mid-day snack, rather than the more commonly studied breakfast and lunch consumption. Second, it explores both attention and memory using a more real-world, dual task procedure. Participants study materials while listening to a radio broadcast. Third, as part of the real-world dual task, we explore spatial memory, a cognitive process that has received relatively little attention in this context. One study examining spatial memory and glucose ingestion found no effects [6]. Fourth, we examine both short-term and long-term retention to see whether dietary sugar consumption can have longer-term effects on cognition. Finally, we examine the effects in two different age groups, adults and children.

As a mid-day snack, dietary sugar intake appears to improve cognitive performance on measures of attention and spatial memory. Experiment 1 showed long-term spatial memory enhancement. Experiment 2 also showed long-term enhancement, coupled with improved short-term recall. The fact that Experiment 1 did not show a short-term effect may be due to a ceiling effect, with the map task being too easy for the adults. By using the same map for the children, the relative difficulty increased and short-term recall effects were seen. Experiment 2 also showed better secondary task performance, indicating that attention may be enhanced by the consumption of a mid-day confectionery snack. Combined, the results from Experiments 1 and 2 are interesting in that they indicate that consumption of an afternoon confectionery snack may influence both attention and memory. Both experiments support previous research that has demonstrated the memory modulating effects of glucose across age groups [2,6–8,26,27] and that an afternoon snack enhances performance on measures of memory and attention [25]. However, when the results from both studies are taken together, they do not provide a clear picture of the effect of a confectionery snack on attention. One explanation for the inconsistency in the results between studies is that the dual task was more demanding for the younger children than for the adults. We see evidence for this in the analyses of the short-term memory recall of the primary spatial learning task, such that the adults achieve near perfect scores in either condition during the short-term memory task, but the children show clear differences in performance between the two conditions. It has been suggested that the amount of cognitive load associated with performance of a task is a predictor of its sensitivity to enhancement by glucose, such that the more demanding the task, the more likely it is to be influenced by the consumption of glucose [34]. The notion is that when a task imposes a high cognitive demand it may deplete extracellular levels of glucose in the brain more than less demanding cognitive task [35]. Finally, it should be noted that the dose of confectionery product was different for the adults and the children. The children received 25 g of the confectionery product, whereas the adults received 50 g. However, the different absolute doses were chosen so that the relative dose (mg/kg) of each volunteer would be approximately equal.

The effects of dietary sugar intake as a mid-day snack may still differ from those after breakfast (or post-fasting) intake. When the confectionery snack is ingested in the morning after period of fasting, performance on a vigilance attention task is improved [24,36]. Performance on the CPT for children in Experiment 2 who consumed the confectionery product as an afternoon snack, showed a similar trend, but the effect was not sustained for the duration of the task. The hit rate was better in the beginning, but did not differ from that of the placebo group in the second and third portions of the task. The most obvious conclusion for the differences in these findings would be that the time of day that the confectionery snack was consumed influenced its effect on attention. For example, lunch intake has been shown to negatively affect performance on vigilance and memory tasks [19,20]. This mid-day performance decline is often referred to as the post-lunch dip and begins approximately 1 h after lunch and continues for at least 1 h [37]. However, evidence suggests that an afternoon confectionery snack can alleviate some of the post-lunch dip effects and improve cognitive performance [25]. If this is the case, then the confectionery snack should reverse any negative effects of lunch.

One concern of the present research regards the nature of the enhancement. In both studies, the placebo, because it needed to be matched for sweetness with the confectionery product, contained aspartame. Thus, the possibility exists that the performance differences between the snacks were not due to an enhancement caused by the confectionery snack, but instead by a decrement caused by the aspartame. This alternative hypothesis seems unlikely in light of research showing that aspartame does not significantly affect behavior or cognitive performance [38]. Thus, differences between the two snack groups are more likely attributed to rising blood glucose levels after ingestion of the confectionery product.

The majority of studies suggest that ingesting glucose facilitates memory and attention [2,6–8,26]. However, there is still some debate as to the mechanism by which memory is enhanced following the ingestion of glucose. Glucose is responsible for the synthesis of neurotransmitters, such as noradrenaline, acetylcholine and serotonin. Enhancement of memory and attention, following glucose consumption, may be caused by the increase in acetylcholine synthesis that results from the metabolism of glucose [39]. Increased uptake of glucose into the brain provides central cholinergic neurons with the only CNS substrate available for acetyl-CoA synthesis, and for the formation of acetylcholine [40]. There is evidence to support acetylcholine's role in the detection, selection and processing of stimuli and associations [41]. For example, in rats, acetylcholine has been shown to improve tasks designed to assess sustained or divided attention [42,43]. Evidence to support acetylcholine's role in cognitive processes comes from studies that show that drugs that impair cholinergic function also impair performance on tasks that require learning and memory, while drugs that enhance cholinergic function improve performance [44].

Previous work has concluded that an increased availability of glucose, in resting conditions, has little effect on acetylcholine levels in animals, but when there is a high demand for the neurotransmitter, a high availability of glucose will increase the rate of synthesis [45]. Learning is one example of a situation in which there is a high demand for acetylcholine. Thus, there is evidence to suggest that one major role for glucose, in memory and attention, is as a substrate for synthesis of acetylcholine.

Alternatively, the changes in memory and attention observed in the present study could be due to an increase in insulin secretion resulting from the sugar ingestion. Evidence that the peripheral release of insulin may influence cognitive activity in both humans and animals by acting in the central nervous system has been growing [46–48]. In particular, insulin release seems to be related to enhanced memory function. In further support of this notion, previous work has shown decrements in the performance of memory tasks in rats with streptozotocin-diabetes [49].

Taken altogether, results from Experiments 1 and 2 support the notion that the ingestion of a confectionery product enhances some types of cognitive performance, namely spatial memory and attention. The intensity of this enhancement, however, may be affected by such factors as time of day, age, and whether of not fasting has occurred. The finding that a mid-day snack enhances cognitive performance in adults and children is interesting especially in light of previous findings demonstrating that lunch intake negatively impacts performance and vigilance. The mechanism by which an afternoon snack may reverse performance decrements associated with the afternoon meal is not clearly understood, but may, in part, be related to endogenous circadian rhythms [50]. In addition, the results also support previous work that rejects the popular social belief that sugar ingestion is followed by an increase in activity and an inability to maintain attention for an appropriate period of time.

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