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Effect of breakfast composition on cognitive processes in elementary school children

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Abstract

The relationship between breakfast composition and cognitive performance was examined in elementary school children. Two experiments compared the effects of two common U.S. breakfast foods and no breakfast on children's cognition. Using a within-participant design, once a week for 3 weeks, children consumed one of two breakfasts or no breakfast and then completed a battery of cognitive tests. The two breakfasts were instant oatmeal and ready-to-eat cereal, which were similar in energy, but differed in macronutrient composition, processing characteristics, effects on digestion and metabolism, and glycemic score. Results with 9 to 11 year-olds replicated previous findings showing that breakfast intake enhances cognitive performance, particularly on tasks requiring processing of a complex visual display. The results extend previous findings by showing differential effects of breakfast type. Boys and girls showed enhanced spatial memory and girls showed improved short-term memory after consuming oatmeal. Results with 6 to 8 year-olds also showed effects of breakfast type. Younger children had better spatial memory and better auditory attention and girls exhibited better short-term memory after consuming oatmeal. Due to compositional differences in protein and fiber content, glycemic scores, and rate of digestion, oatmeal may provide a slower and more sustained energy source and consequently result in cognitive enhancement compared to low-fiber high glycemic ready-to-eat cereal. These results have important practical implications, suggesting the importance of *what* children consume for breakfast before school.

Keywords: Breakfast composition; Carbohydrate; Cognition; Memory; Attention; Children

1. Introduction

Breakfast has been described as the most important meal of the day, contributing substantially to daily nutrient intake and energy needs. For children, breakfast consumption has been associated with learning and better school performance [1–3]. Despite breakfast's positive attributes, many children go to school without breakfast [4–7]. Between 1965 and 1991, breakfast consumption declined by 15% to 20%, resulting in as few as 64% of adolescents consuming breakfast [8].

The importance of breakfast for academic achievement is reflected in the effects of breakfast on cognitive performance [9,10]. Research suggests that skipping breakfast detrimentally affects problem solving [11], short-term memory [3], attention and episodic memory [12] in children. Conversely, when children consume breakfast performance is enhanced on measures of vigilance attention, arithmetic [13], problem solving tasks [14], and logical reasoning [15]. Further, research on confectionery snacks consumed by children in the morning indicated that long-term memory may also be affected by food consumption [16].

However, not all studies show positive effects of breakfast consumption on cognitive behavior. Differences in breakfast composition may account for some of the contradictory results across studies. For example, children who ate

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Table 1
The macronutrient content of the two breakfast interventions in Experiments 1 and 2

	Serving size	Total carbohydrate (g)	Sugars (g)	Fiber (g)	Protein (g)	Fat (g)	Energy
Oatmeal	43 g (1 packet)	32	13	3	4	2	160
	With 1/2 cup skim milk	38	19	3	8	2	200
Ready-to-eat cereal	36 g (1 cup)	30	16	1	1	1.5	150
	With 1/2 cup skim milk	36	22	1	5	1.5	200

a high-compared to low-energy breakfast showed improvements in creativity, physical endurance, mathematical addition [17], and short-term memory [18]. In addition, a low-fat, high carbohydrate breakfast has been shown to produce a reduction in subjective fatigue compared to a moderate carbohydrate, high-fat breakfast [19] and a high-fiber, carbohydrate-rich meal was associated with enhanced subjective alertness ratings after breakfast versus a low-fiber or fat-rich breakfast [20]. The relationship between a high-energy, and/or high-fiber carbohydrate-rich breakfast and improved cognitive performance may be related to their effect on blood glucose levels. Studies showing that glucose administration improved cognitive performance support this notion [21–30].

Glucose is essential for brain function, suggesting that the nature of glucose facilitation to the brain may affect food-induced cognitive performance. For example, a prolonged elevation of blood glucose may increase the duration of food-induced cognitive enhancement. One way to assess the effect of carbohydrate containing foods on blood glucose is through the use of the Glycemic Index (GI), which is a score ascribed to a food or meal based on blood glucose response after a meal [31]. In general, rapidly digested low-fiber high-carbohydrate foods show an initial sharp blood glucose peak (high GI), with an overall lower circulating blood glucose after a 2-h period. Conversely, low GI foods cause a lower blood glucose peak, and generally result in a more sustained blood sugar response. Applying the GI to common U.S. breakfast foods, instant oatmeal would be considered a low to moderate GI food while most ready-to-eat cereals tend to have a higher GI score [32,33]. This assumption was confirmed by analyses of blood glucose levels in adults after consumption of the test meals used in the experiments reported here [32].

Inconsistent results from previous research examining breakfast consumption and cognition raises two important questions. First, how does an extended fast affect a child's cognitive performance? Second, having consumed breakfast, how does breakfast composition affect learning? The present research aimed to evaluate the effect of two common U.S. breakfast foods (oatmeal and ready-to-eat cereal) compared to no breakfast on children's cognitive performance. The two breakfast foods provided approximately equal amounts of fat, sugar and energy (see Table 1), but differed in nutrient composition, processing characteristics, digestion rate, and glycemic score. The oatmeal breakfast was higher in fiber and protein. These characteristics, as well as oatmeal's whole grain characteristics, lead to slower gastric emptying and more sustained blood glucose levels [32], which in turn may influence cognitive performance.

2. Experiment 1

2.1. Participants and methods

2.1.1. Participants

The participants were 15 male and 15 female students, aged 9 to 11 (See Table 3 for BMI data). Participants came from a middle class background and attended a private catholic elementary school in the United States during the 2000/2001 school year. Participants were in good health and free of learning disorders. The children's parents/guardians received a monetary incentive for their child's participation.

2.1.2. Cognitive tasks

2.1.2.1. Spatial memory. A map task assessed spatial learning. Three fictitious maps were created to control for previous exposure. Each map consisted of twenty-four countries within four continents. Names of the countries were chosen from three categories, nature, animals, and colors. For example, a few of the country names from the "nature" map were Soil, Rock and Ocean. The "color" map included countries such as Green, Red and Brown (see Fig. 1). During the task, country names appeared on the screen one at a time. Participants advanced through the country names at their own pace using a designated

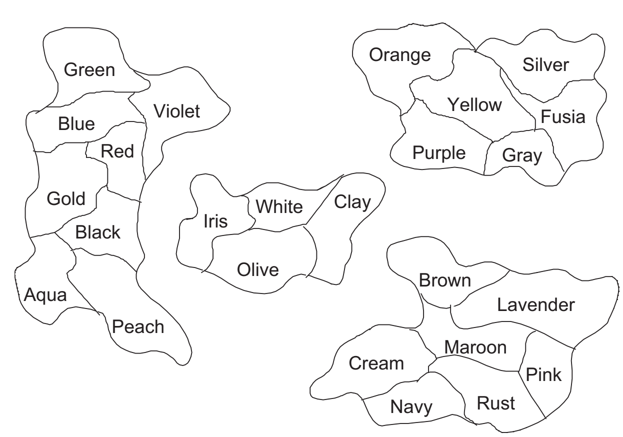

Fig. 1. One of the three maps that will be used to examine spatial memory in Experiment 1.

computer key. Once a participant cycled through all twenty-four countries, the names started from the beginning, appearing in the same order each time. Each participant studied for eight minutes, cycling through the country names as many times as they liked during that time. Once the study portion was complete, the children received a blank map and filled in as many country names as they could recall.

2.1.2.2. Short term memory. A digit span task assessed short-term memory. The children heard groups of numbers and were instructed to listen carefully and then repeat them to the experimenter. For example, if the experimenter said "1 2 3", the child would repeat "1 2 3." After a correct repetition, the next set of numbers increased by one. If the participant did not repeat the numbers correctly, the experimenter gave another set of the same length. Two incorrect repetitions resulted in termination of the test. The participants received both a forward and backward version of this task. The backward version required the child to repeat the numbers in the reverse order. For the above example, the child would repeat "3 2 1."

2.1.2.3. Visual perception. The Rey Complex Figure Copy and Recall Test examined visual perception [34]. Children received one of three equally complex figures and a blank piece of paper. They were asked to copy the figure as exactly as possible, without tracing. Twenty minutes and again 50 min later, they were given a blank page to draw the figure from memory.

2.1.2.4. Visual attention. A continuous performance task (CPT) evaluated visual vigilance. The children watched letters flash on a computer screen at a rate of one per second for 10 min. They were instructed to look for a target combination (e.g., "X" immediately followed by "B") and to hit the space bar when they saw this combination.

2.1.2.5. Auditory attention. A CPT also assessed auditory vigilance. The children listened to words, at a rate of 1/s, through headphones hooked up to a computer. They were to listen for a target combination of words (e.g., "mouse" followed by "house") and to hit the space bar whenever they heard this combination.

2.1.2.6. Verbal memory. The verbal task consisted of two one-paragraph stories containing 15–20 lines. Participants had 5 min to read the stories as many times as they wanted. After the study time, the participant orally related the stories to the experimenter (and tape recorder) in as much detail as they could remember.

2.1.3. Questionnaires

2.1.3.1. Screening questionnaire. All parents/guardians of interested volunteers filled out a screening questionnaire that addressed current dietary and sleeping patterns and medical history. Those children not taking medication and free of learning disabilities and dietary restrictions could participate.

2.1.3.2. Mini-questionnaire. Participants completed a short questionnaire, used to assess mood, energy level, and hunger level before breakfast and before and after testing. The questionnaire consisted of eight questions on a 7-point Likert scale.

2.1.3.3. Diet and opinion survey. A short survey determine how often children consumed breakfast before school, the quality of their normal breakfast, and their opinions on the breakfasts used in the study.

2.1.4. Ethics

All procedures followed were reviewed by and approved in accordance with the ethical standards of the Tufts University Human Subjects Review Board (IRB).

2.1.5. Procedure

Children participated at school 1 day a week for 4 weeks. Parents were instructed not to feed their children after 10:00 PM the night before testing and to send the children to school the day of testing without breakfast. Reminder phone calls were made the night before a scheduled test day. On test days, children arrived at school at the regularly scheduled time. Once attendance was taken, children were escorted to the cafeteria for the test breakfast.

For the first 3 weeks, each child filled out a mini-questionnaire and then received one of three breakfasts. The breakfasts consisted of one cup of ready-to-eat cereal with one-half cup of fat-free milk, 1 package of flavored instant oatmeal cooked and served with one-half cup of fat-free milk, or no breakfast (see Table 1). Children were required to consume the entire test meal each morning. Across the experiment, each participant received all three breakfast conditions, thus serving as his/her own control (see Table 2 for example test schedule). The order of the

Table 2
Testing schedule used in Experiments 1 and 2

	Week 1	Week 2	Week 3	Week 4
8:00–8:15		Long-term recall	Long-term recall	Long-term recall
8:15–8:30	Breakfast (B1 or B2)	Breakfast (B1 or B2)	Breakfast (B1 or B2)	Breakfast (all groups)
9:30–10:30	Testing	Testing	Testing	
10:30	Breakfast for B3 group	Breakfast for B3 group	Breakfast for B3 group	

breakfast conditions was counterbalanced and experimenters were blind to the breakfast conditions. Participants in the no breakfast condition received breakfast immediately after testing. Children returned to class after breakfast and then an hour later returned to the test room to complete the cognitive test battery. Task order was counterbalanced across participants.

During weeks 2 to 4, children completed a long-term memory test, immediately before breakfast. They were asked to recall material learned the previous week during the visual perception, the spatial learning, and the verbal memory tasks. In the final week, children completed the diet and opinion survey after finishing the long-term recall. They then received the breakfast of their choice.

2.1.6. Statistical analysis

Unless otherwise specified, analysis consisted of a repeated measures analysis of variance (ANOVA) with breakfast condition (ready-to-eat cereal, oatmeal, or no breakfast) as a within subject variable and sex as a between subjects variable.

2.2. Results

Results are given for only those tasks that yielded significant effects.

2.2.1. Spatial memory

Map recall was coded into four categories. Correctly recalled, correctly placed country names received *correct* codes. Correctly recalled, but incorrectly placed country names received *incorrect location* codes. Country names that did not exist on the original map received *incorrect* codes and finally, the *blank* code was given when countries were not filled in.

Analysis of *correct* items during short term recall showed a significant effect of breakfast type, $F(2,44)=3.98$, $p<.05$, MSe = 12.33. Participants correctly recalled the most items after consuming oatmeal ($M=17.0$, SEM = 1.12), followed by the ready-to-eat cereal condition ($M=15.7$, SEM = 1.21), and finally the no breakfast condition ($M=14.0$, SEM = 1.42). Post hoc analyses revealed significant differences between the oatmeal and no breakfast conditions. Long-term recall was not affected by breakfast condition. However, there was a main effect of time, $F(1,20)=167.4$, $p<.05$, MSe = 22.20, in which participants across all breakfast types showed better short-term ($M=15.5$, SEM = 1.18) than long-term recall ($M=4.8$, SEM = .58).

Analysis of *blank* items during the short term recall, mirrored the *correct* results, $F(2,44)=3.68$, $p<.05$, MSe = 8.96. When participants ate oatmeal, they left the fewest countries blank ($M=6.0$, SEM = 1.00), followed by ready-to-eat cereal ($M=7.1$, SEM = 1.04), and finally no breakfast ($M=8.4$, SEM = 1.17). Post hoc analyses revealed that significance occurred between the oatmeal and no breakfast conditions. Analysis of long-term recall revealed no breakfast condition differences. The usual short-term/long-term memory effect was again apparent, $F(1,20)=97.18$, $p<.05$, MSe = 23.53. Participants across all breakfast types left fewer blanks during short-term ($M=7.1$, SEM = .98) than during long-term recall ($M=15.5$, SEM = .86).

No significant differences between breakfast types were found in analysis of incorrect and incorrect location items. However, both yielded the usual short-term/long-term memory effect.

2.2.2. Short-term memory

Mean number of digits recalled served as the dependent variable for the short-term memory test. Analysis of the backward digit span data revealed a breakfast type by sex interaction, $F(2,54)=4.46$, $p<.05$, MSe = 1.25. Post hoc analyses revealed that when girls ate oatmeal, they remembered significantly more digits ($M=5.0$, SEM = .37) than when they ate ready-to-eat cereal ($M=4.00$, SEM = .14) or no breakfast ($M=3.9$, SEM = .32). Boys showed no performance differences based on the breakfast conditions (oatmeal $M=3.8$, SEM = .33; ready-to-eat cereal $M=4.0$, SEM = .41; no breakfast $M=4.4$, SEM = .33; see Fig. 2). No differences between breakfast types were found in the forward digit span test.

2.2.3. Visual perception

The dependent variables for the visual perception task were accuracy (number of lines correctly drawn in the appropriate location), drawing time and accuracy over time (copy score, delayed recall scores, and long-term memory score). Analysis of the copy measure revealed a main effect of breakfast type, $F(2,52)=5.13$, $p<.05$, MSe = 11.06. Post hoc analyses revealed that when participants had either the oatmeal or the ready-to-eat cereal, copy scores were better than when they had no breakfast (ready-to-eat cereal, $M=31.8$, SEM = .74; oatmeal, 31.7, SEM = .83; no breakfast, 29.3, SEM = .96). No significant differences between breakfast conditions were found in scores of delayed recall (30 or 50 min) and long-term memory.

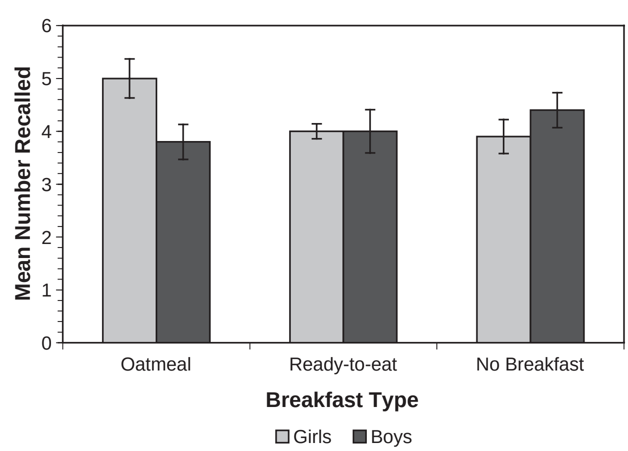

Fig. 2. Mean number of digits recalled, with standard error, in the backwards digit span task for each meal as a function of sex.

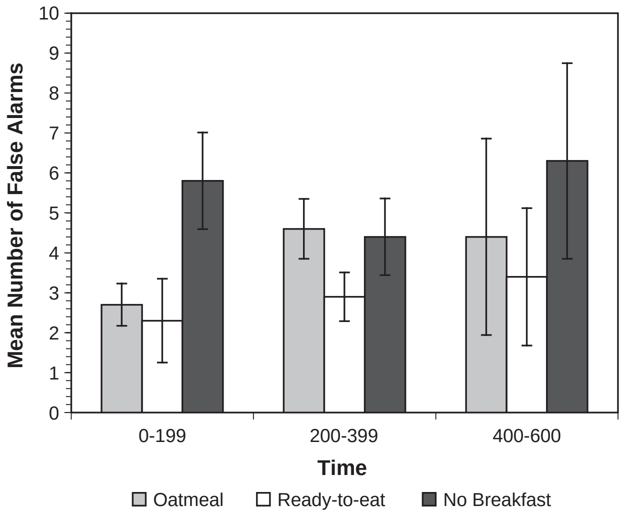

Fig. 3. Mean number of false alarms, with standard error, for the auditory vigilance task for each breakfast condition as a function of time.

2.2.4. Visual attention

Dependent measures included three response rates (hits, misses, and false alarms). Participants had a *hit* when they correctly responded to the target combination. A *miss* occurred when participants failed to respond to the target. False alarms included responses to non-target combinations. Response rates were examined overall and broken down into three equivalent time intervals across the 10-min task (0–199 s; 200–399 s; 400–600 s). The measure over time assessed the stability of attention. In addition to the response rates, dependent measures included response times (RT) for hits and false alarms.

Analyses of all the dependent measures failed to show any effect of breakfast type. Analysis of misses revealed a standard main effect of task duration, $F(2,48)=5.84$, $p<.05$, MSe = 10.39, in which the number of misses increased as a function of task duration (Time 1: $M=5.3$, SEM = .63; Time 2: $M=5.7$, SEM = .67; Time 3: $M=7.0$, SEM = .73).

2.2.5. Auditory attention

The auditory attention dependent measures were the same as for visual attention. Neither hits nor misses showed an effect of breakfast type, but both showed effects of task duration, $F(2,50)=9.81$, $p<.05$, MSe = 11.39 for hits and $F(2,46)=4.41$, $p<.05$, Mse = 7.42 for misses. Both measures showed that participant performance declined as a function of task duration (Time 1: M = 12.6 hits and 4.2 misses; Time 2: M = 11.9 hits and 4.9 misses; Time 3: = 10.2 hits and 5.6 misses).

Analysis of false alarms did not show the main effect for task duration, but did reveal a breakfast type by task duration interaction, $F(4,92)=2.79$, $p<.05$, MSe = 6.22. When participants consumed either breakfast, they made fewer false alarms early in the task than when they had no breakfast (see Fig. 3). There were no performance differences between breakfast interventions during the other time intervals.

2.2.6. Mini-questionnaire

Analysis of the hunger rating revealed significant, albeit expected effects. This analysis showed a significant main effect for breakfast type, $F(2,46)=12.12$, $p<.05$, MSe = 3.68. Post hoc analyses revealed that participants rated themselves as more hungry when they did not receive breakfast ($M=5.6$, SEM = .28) than when they did receive breakfast (ready-to-eat cereal, $M=4.2$, SEM = .37; oatmeal, $M=4.3$, SEM = .33). There was also a main effect of time, $F(2,46)=19.92$, $p<.05$, MSe = 1.78, with participants becoming more hungry as the morning progressed. There was a breakfast type by time interaction, $F(4,92)=4.60$, $p<.05$, MSe = 1.86. Post hoc analysis revealed that in all conditions, children were equally hungry before breakfast. Half an hour after breakfast, children were significantly less hungry after having either of the breakfasts than no breakfast. Again, after testing, when children consumed either breakfast, they were significantly less hungry than when they did not consume breakfast.

Analysis of motivation revealed a breakfast type main effect, $F(2,44)=3.23$, $p<.05$, MSe = 1.70. Post hoc analyses revealed that participants felt more motivated after eating the ready-to-eat cereal ($M=5.4$, SEM = .62) compared to no breakfast ($M=4.8$, SEM = .30). There was no difference in motivation between the oatmeal condition and the other two breakfast conditions (oatmeal $M=5.3$, SEM = .27). In addition, there was a breakfast type by time interaction, $F(4,88)=2.55$, $p<.05$, MSe = .70. Post hoc analyses revealed that there was no difference between breakfast conditions in reported motivation levels before breakfast and before testing. After testing, children rated themselves as more motivated after consuming either breakfast compared to no breakfast.

There were no differences on how tired, happy, relaxed, thirsty, alert, or stressed children were feeling, or on rating of overall mood.

2.2.7. Diet and opinion survey

Results from the diet survey show that 22% of the children reported regularly being sent to school without breakfast. An additional 26% reported eating breakfast only about half of the time. Finally, only 52% of the children reported eating breakfast on a regular basis (see Fig. 4 for

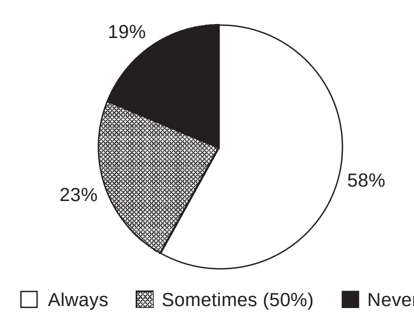

Fig. 4. Normal breakfast consumption self reports by middle class children, aged 6–11 in the United States for Experiments 1 and 2.

children's mean breakfast consumption in Experiments 1 and 2). The type of breakfast consumed by the children who normally ate breakfast varied from a granola bar to ready-to-eat cereal to spaghetti.

3. Experiment 2

Experiment 2 examined the effects of breakfast composition on younger children's (ages 6 to 8 years) cognitive performance. Younger children are interesting to examine for two reasons. First, the younger the individual, the greater the metabolic stress induced by an overnight fast and a missed morning meal [14]. It is argued that this occurs because the higher the ratio of brain to liver weight and the greater the metabolic rate per unit of brain weight, the greater the demand on glycogen stores [14]. In addition, an individual's amount of muscle mass affects the amount of gluconeogenesis that can occur. Because of these metabolic factors, cognitive performance may be affected more dramatically in younger children. Second, children learn many basic reading, writing and arithmetic concepts during these years, later building on these basics. Difficulty learning these skills may lead to long-term disadvantages.

Based on previous findings showing that consuming breakfast improves some areas of school performance [3,35] and the results of Experiment 1 suggesting that breakfast composition may make a difference, it was hypothesized that younger children may not only be more susceptible to changes in cognitive performance due to nutrient composition differences in breakfast, but they may also benefit more from these differences.

3.1. Participants and methods

3.1.1. Participants

The participants were 15 male and 15 female students, aged 6 to 8 (see Table 3 for BMI data). Participants came from a middle class background and attended a private catholic elementary school in the United States during the 2000/2001 school year. Participants were in good health and free of learning disorders. The children's parents/guardians received a monetary incentive for their child's participation.

Table 3
Body Mass Index Data (BMI) for children in Experiments 1 and 2

BMI Experiment 1	
Mean	20.97
Standard error	1.37
Median	19.22
Standard deviation	6.13
Minimum	14.65
Maximum	37.97
BMI Experiment 2	
Mean	17.68
Standard error	1.16
Median	15.91
Standard deviation	4.78
Minimum	10.76
Maximum	30.93

3.1.2. Tasks

The same battery of cognitive tasks used in Experiment 1 was used in Experiment 2. Age appropriate modifications were made to the verbal memory and the spatial learning tasks.

3.1.2.1. Spatial learning. Two changes were made to the map task used in Experiment 1. First, the countries contained pictures of category items, such as animals, sports, and food, rather than words. Second, instead of recalling the country, the participants had stickers of each picture and placed them where they belonged on the map (see Fig. 5).

3.1.2.2. Verbal memory. Each child listened to a single story, between 15–20 lines, through a set of headphones. They listened to the story two times in a row. Then, each child was asked to tell the experimenter, in as much detail as they could remember, the story that they had just heard. Again, the recall was recorded.

3.1.3. Questionnaires

The screening questionnaire, the mini-questionnaire, and the diet and opinion survey described in Experiment 1 were used.

3.1.4. Procedure

The procedure for Experiment 2 followed that outlined in Experiment 1.

3.1.5. Statistical analysis

Statistical analyses followed those used in Experiment 1.

3.2. Results

3.2.1. Spatial memory

Map recall was broken down into three categories. Pictures placed in the correct location were labeled *correct*. Pictures placed in the wrong location were labeled *incorrect*. Countries with no stickers were labeled *blank*.

Breakfast type significantly altered short-term recall of correct items $F(2,40)=3.65$, $p<.05$, MSe=13.01. Post hoc analyses revealed that when children had instant oatmeal, they correctly placed more pictures on the map ($M=15.9$, SEM=.47) than when they did not consume breakfast ($M=13.0$, SEM=1.12). There was no difference in the number of items placed correctly on the map when children had ready-to-eat cereal ($M=14.1$, SEM=.92), compared to the other breakfast conditions. The breakfast type effect did not carry over to long-term recall. There was a standard short term/long-term memory effect, $F(1,40)=150.17$, $p<.05$, MSe=10.06. Participants correctly placed more countries on

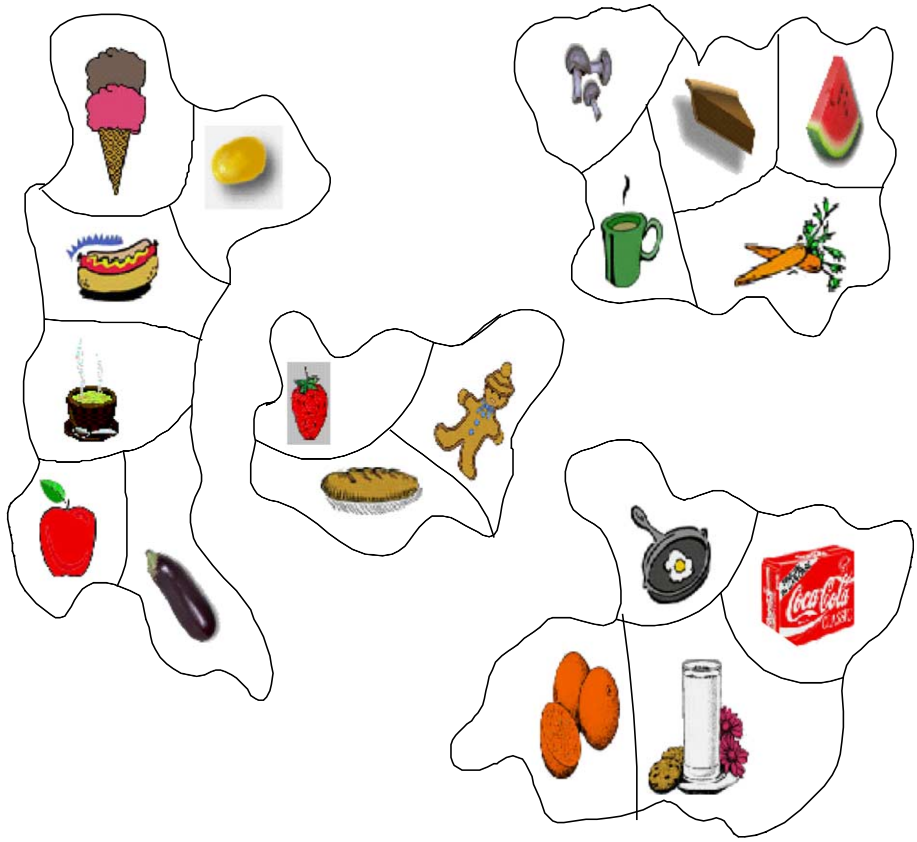

Fig. 5. One of the three maps used to examine spatial memory in Experiment 2.

the map during short-term (M = 14.3, SEM = .61) than during long-term recall (M = 7.4, SEM = .77).

Analysis of incorrectly placed map items during short term recall also revealed a main effect of breakfast type, $F(2,40) = 3.58$, $p < .05$, MSe = 12.94. Post hoc analyses revealed that the children incorrectly placed more pictures on the map following no breakfast (M = 4.9, SEM = 1.12), than following oatmeal (M = 2.0, SEM = .47). There was no significant difference between the ready-to-eat cereal condition and the other two breakfast conditions. Again, this effect did not carry over to long-term recall. The standard short-term/long-term effect again emerged, $F(1,20) = 140.87$, $p < .05$, MSe = 10.18. Participants placed fewer countries incorrectly on the map during the short-term memory test (M = 3.63, SEM = .60) than during the long-term memory test (M = 10.34, SEM = .74).

There were no differences between the breakfast conditions on the number of countries left blank.

3.2.2. Short term memory

Analyses or the backward digit span data revealed a breakfast type by sex interaction, $F(2,52) = 4.74$, $p < .05$, MSe = .67. Post hoc analyses revealed boys' performance did not differ as a function of breakfast type (ready-to-eat cereal M = 3.3, SEM = .30; oatmeal M = 3.0, SEM = .35; no breakfast M = 3.1, SEM = .25). However, girls recalled more digits after oatmeal (M = 3.6, SEM = .37) than ready-to-eat cereal (M = 2.5, SEM = .32; see Fig. 6). There were no significant differences in performance between either breakfast condition and the no breakfast condition (M = 2.9, SEM = .27). No significant differences between breakfast types were found in scores on the forward digit span test.

3.2.3. Visual perception

Analysis of the copy measure revealed an interaction between breakfast type and sex, $F(2,48) = 5.94$, $p < .05$,

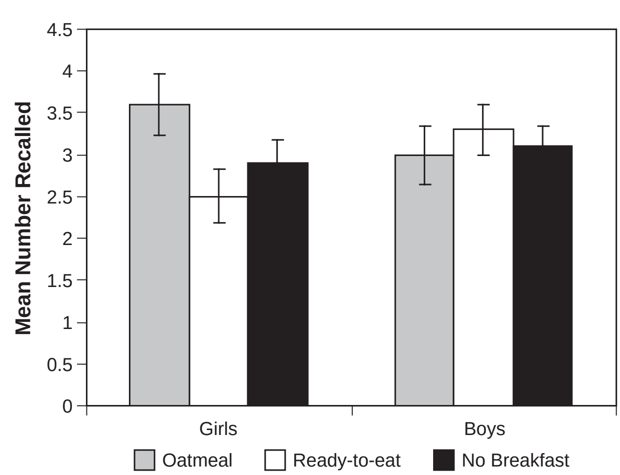

Fig. 6. Mean number of digits recalled, with standard error, for the backward digit span task for each sex.

MSe = 19.50. Post hoc analyses indicated that for the boys, performance was significantly better after ready-to-eat cereal (ready-to-eat cereal $M = 21.3$, SEM = 2.64) than after no breakfast ($M = 17.5$, SEM = 1.67). The difference in performance after oatmeal ($M = 21.6$, SEM = 2.3) was not significantly different than the other two conditions. For the girls, performance was significantly better after no breakfast ($M = 20.4$, SEM = 2.25) than after ready-to-eat cereal (15.8, SEM = 2.37). Again, oatmeal did not differ between the other two conditions ($M = 19.0$, SEM = 1.71; see Fig. 7). No other measures showed significant differences between breakfast conditions.

3.2.4. Auditory attention

As in Experiment 1, response rates were examined overall and over the duration of the task. In addition to the response rates, dependent measures also included RTs for hits and false alarms.

Analysis of hits revealed a main effect of breakfast type, $F(2,38) = 3.54$, $p < .05$, MSe = 123.90. When children consumed oatmeal, they had the most hits ($M = 36.6$, SEM = 2.42), followed by the no breakfast condition ($M = 29.5$, SEM = 2.91) and finally the ready-to-eat cereal condition ($M = 26.8$, SEM = 3.03). Further analysis revealed that performance after oatmeal was significantly better than after ready-to-eat cereal. Analysis of miss rates mirrored the main effect of breakfast type, $F(2,38) = 5.37$, $p < .05$, MSe = 97.59. When participants consumed the oatmeal, they had fewer misses ($M = 13.4$, SEM = 2.36) than when they did not have breakfast ($M = 17.2$, SEM = 2.31) or had the ready-to-eat cereal ($M = 24.3$, SEM = 2.65). Post hoc analyses revealed that participants have significantly fewer misses after oatmeal or no breakfast than after ready-to-eat cereal.

There were no significant differences between breakfast types for the number of false alarms or the reaction times to hits or false alarms.

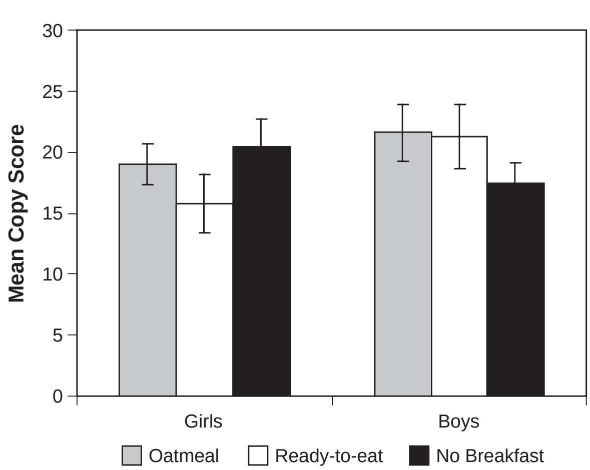

Fig. 7. Mean score, with standard error, for the copy portion of the Visual perception task for each breakfast condition as a function of sex.

3.2.5. Mini-questionnaire

Analyses of the mini-questionnaire revealed a significant interaction between breakfast condition and time for hunger rating $F(4,76) = 2.80$, $p < .05$, MSe = 3.14. Post hoc analyses indicate that there was no difference in hunger level before breakfast. When children ate oatmeal, they rated themselves as less hungry an hour after breakfast compared to when they consumed ready-to-eat cereal or no breakfast. There was no difference between hunger ratings across breakfast conditions 2 h after breakfast.

Analyses of the mini-questionnaire also revealed an interaction between breakfast type and time for ratings of alertness, $F(4,80) = 2.66$, $p < .05$, MSe = 2.74. Post hoc analyses showed that for the no breakfast condition, ratings of alertness did not change over time. When children had the ready-to-eat cereal, they rated themselves as more alert an hour after breakfast and 2 h after breakfast than before consuming breakfast. When children consumed oatmeal, they rated themselves more alert an hour after breakfast than either before breakfast or 2 h after breakfast.

No significant differences were found between breakfast conditions on how relaxed, tired, motivated, or happy the children felt or on a rating of overall feeling.

3.2.6. Diet and opinion survey

Results from the diet survey show that 16% of the children tested reported regularly being sent to school without breakfast. An additional 20% of children report eating breakfast only about 50% of the time. Only 64% of the children tested reported eating breakfast on a regular basis before school (see Fig. 4 for mean breakfast consumption for Experiments 1 and 2). The type of breakfast consumed by the children who normally ate breakfast varied from ready-to-eat cereal, to pancakes to Kentucky Fried Chicken.

4. Discussion

This research examined the effects of breakfast composition versus no breakfast on cognitive performance. Results suggest that performance on most measures is enhanced by breakfast consumption and that the composition of breakfast can also influence children's cognitive performance on some measures, particularly spatial memory, short-term memory, and auditory attention. Collectively, these results expand previous research suggesting that breakfast consumption influences some aspects of cognitive performance, such as immediate recall, delayed recall and recognition memory [2] by showing that nutrient composition differences of breakfast meals could affect a range of cognitive tasks that include spatial memory, short-term memory, visual perception, and auditory attention.

Results from Experiments 1 and 2 support the general benefit of breakfast consumption on cognition [1,12]. When the children completed a visual perception task or a spatial memory task, they generally performed better after consuming either breakfast versus no breakfast at all. The benefit is most likely facilitated via the blood glucose response following a meal. Modest increases in circulating glucose enhance learning and memory [36], perhaps through the synthesis of acetylcholine [37]. However, only limited data suggests that the type of breakfast also influences cognitive functioning [17,18,20,28]. The current results also suggest that for some cognitive tasks the composition of the meal may influence performance. For example, the children in Experiment 1 performed better on a short term memory task after consuming the oatmeal breakfast compared to when they consumed the ready-to-eat cereal or no breakfast and when the younger children in Experiment 2 consumed the oatmeal breakfast, they performed better on a short term memory task and an auditory attention task than when they had the ready-to-eat cereal.

One way that meal composition may influence cognition is through digestion rate. A higher fiber–lower GI and more slowly digested meal will maintain a more sustained release of glucose into the blood stream and to the brain. The oatmeal in the present study is characterized by a more sustained glucose release (measured in adults), compared to the sharper rise and fall in blood glucose associated with the high-GI ready-to-eat cereal [32,33]. The influence of GI on cognition has not been adequately examined. Results from recent studies suggest that low GI carbohydrate foods improve memory in young adults and rats [28] while another study showed similar effects between low and high GI carbohydrates in older adults with poor memory and poor glucose regulation [38]. However, prior to the current study no research to date had examined the effects of foods of different GI on cognitive function in children with normal memory and normal glucose regulation. Glucose has been shown to enhance cognitive performance in people of different ages [29] and recent data also suggest that these enhanced effects may depend on task difficulty as well as level of glucose in the blood stream [29,39].

Meals can also influence the synthesis of brain neurotransmitters [40]. For example, a meal rich in carbohydrates increases the amount of brain tryptophan, which results in an increase in serotonin synthesis [41]. This effect can easily be reversed, however, if a meal contains a small amount of protein. Protein rich meals lead to increases in the tyrosine levels, which result in increased dopamine and norepinephrine synthesis [41]. Tryptophan and tyrosine appear to play a role in alertness, which has implications for cognitive performance. Lieberman and colleagues [41] found that consumption of a tryptophan pill led to lower ratings of alertness and vigor and higher fatigue ratings compared to consumption of tyrosine pill or a placebo [41]. Participants also had slower reaction times after tryptophan than after the tyrosine. Some studies have shown that carbohydrate rich meals have an effect similar to tryptophan pills, increasing drowsiness and calmness compared to protein rich meals [42], while other studies have found that a low-fat/high-carbohydrate breakfast is associated with a decline in fatigue compared to a medium fat/medium carbohydrate breakfast and a high fat/low-carbohydrate breakfast [19]. In the present study, while the oatmeal breakfast supplied the same amount of carbohydrate and fat as the ready-to-eat cereal, it contained more fiber and more protein, which may have contributed to improved performance in some cognitive tasks and differences in reported alertness and motivation.

Results from this study also suggest that breakfast composition may affect younger children more dramatically than older children. This is evident in the increased number of measures affected. Both older and younger children showed improved spatial and short-term memory after oatmeal. In younger children oatmeal also improved performance on a task of auditory memory. These performance differences may be due to differences in metabolism rates between older and younger children, or differences in the amount of physical stress following an overnight fast. Younger children rated themselves as less hungry after oatmeal than after ready-to-eat cereal or no breakfast an hour later, but 2 h later showed no differences in hunger ratings. In contrast, older children rated themselves as less hungry after either meal than after no breakfast both 1 and 2 h after eating. These differences may also be a result of the amount of food needed to suppress hunger across different age groups.

In addition to age, sex also appears to influence the way breakfast composition affects cognitive processes. Girls seemed more affected than boys, benefiting from the lower GI breakfast and suffering more from not consuming breakfast. This was apparent in the measure of short-term memory for both age groups. Two contradictions in our findings also deserve some attention: younger girls performed better on the visual perception task after no breakfast compared to ready-to-eat cereal and the younger boys performed better on the visual perception task after ready-to-eat cereal compared to no breakfast. In both cases, the oatmeal breakfast was not significantly different than either of the other two breakfast conditions. The reason why boys and girls are affected differently by breakfast consumption on some cognitive measures is unclear. Mood may play a role, but the interaction between breakfast composition and sex on mood has not been appropriately explored. One study reported that meal composition affects mood differently in males and females [43]; females reported feeling more tired after carbohydrate than after protein while males reported a greater calmness after carbohydrate than after protein. However, this finding may be due to sex differences in defining tired and calm [43]. Further, the current study found no sex or breakfast differences in reports of tiredness. Another possibility is that differences in normal breakfast habit may have influenced performance on that particular task.

Analyses of the diet and opinion survey show that only 58% of children report being regularly sent to school with breakfast and 42% report either never eating breakfast or only eating breakfast 50% of the time. This is a startling figure when it is considered that breakfast follows the longest period of fasting in the 24-h cycle. It would not be uncommon for a child who comes to school without breakfast to endure 15–17 h without food. This raises the question as to whether a child's normal breakfast habit could have influenced their response to the experimental breakfasts. If breakfast content differs from what the child normally eats, could this affect cognition and behavior? This question has received little attention. Two studies, examined the effects of light and heavy meals on performance as a function of normal meal habit. Results from one study showed that a heavy meal hindered performance more than a light meal, but did not do so for a person who normally consumed a heavy meal [44]. However, this study was done with the afternoon meal and its applicability to a morning meal is unclear. Time of day, meal timing, and the nature of the meals may all influence this finding. The information collected about regular breakfast habit from the children participating in this study was incorporated into the analyses as a between subjects variable. It seems that a child's normal breakfast habit can influence performance after meals of varied composition or no breakfast. However, there does not seem to be a clear pattern of results across studies. These interactions suggest that a child's normal breakfast habit can affect performance on some tasks as a function of breakfast intervention. However, the manner in which performance may be affected is unclear from the present results. It was also unclear if sex differences in breakfast consumption influenced performance or mood. In most cases, the children performed better after consuming breakfast, but the type of children (always eat breakfast, never eat breakfast, or eat it only 50% of the time) that performed better differed with the type of task. Clearly, this is an important question and should be addressed more thoroughly in future research.

In summary, the present research evaluated the effects of two common U.S. breakfast foods versus no breakfast on children's learning and memory. The results indicated that breakfast consumption and breakfast type affected cognitive performance, particularly spatial memory, short-term memory, visual perception, and auditory vigilance. Further, the effects seemed more pronounced in younger children and girls seemed to garner greater benefits from the lower GI breakfast than boys. Although the exact reason for these effects is not fully understood, likely mechanisms include glucose uptake in the brain which differ as a result of the rates at which each breakfast was metabolized and the neurotransmitter synthesis resulting from glucose utilization and meal macronutrient content.

The practical value of these results lies in the importance of breakfast. The participants in these studies were middle class students, aged 6 to 11, attending a local catholic elementary school in the United States, where dinner is typically consumed between the hours of 5–7 pm and followed by a period of approximately 10 h before the morning meal. Despite breakfast's importance after such a period fasting, the diet and opinion survey suggested that only a little over 50% of children ages 6 to 11 regularly eat breakfast. The rest of the children were evenly split between never eating breakfast and only eating breakfast half of the time. These results taken in combination with a study conducted in 1991 which reported that 64% of children eat breakfast everyday [8] suggest that the number of children skipping breakfast is on the rise. Yet, breakfast consumption and composition affect cognitive performance. Previous research suggests that adolescent girls are the group most likely to skip breakfast. This finding is of utmost concern because, as the results of the present work suggest that girls seem to be the most affected by missing breakfast and benefit the most from the more slowly digested oatmeal breakfast. While this data supports previous research showing that breakfast, compared to no breakfast, improves school performance, it also suggests that what children eat could also make a difference. This may be particularly important for parents' decisions about what to feed children before school. These data are novel because while numerous studies have shown that breakfast improves some aspects of cognitive performance, no studies to date have investigated the difference in cognitive performance after consumption of common everyday U.S. breakfast meals that are inherently different with respect to their nutrient composition, processing characteristics, digestion and metabolism, and glycemic score.

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