Breakfast consumption has no effect on neuropsychological functioning in children: a repeated-measures clinical trial[1–3]

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ABSTRACT

Background: Although many studies have investigated the relation between breakfast consumption and various domains of cognitive functioning within children, some of the reported findings are inconsistent.

Objective: We sought to determine the short-term effects of a breakfast meal on the neuropsychological functioning of healthy school-aged children after an overnight fast.

Design: The study was conducted in a clinical research center with the use of a counterbalanced repeated-measures design among children who either consumed breakfast or were fasting. The administered neuropsychological tests included measures of attention, impulsivity, short-term memory, cognitive processing speed, and verbal learning. The sample consisted of children aged 8–10 y ($n = 128$), of whom 52% were female, 38% were African American, 31% were Hispanic, 28% were white, and 3% were of another race/ethnicity.

Results: There were no significant ($P \geq 0.004$) differences between breakfast meal consumption and fasting for any of the neuropsychological measures administered.

Conclusion: Breakfast consumption had no short-term effect on neuropsychological functioning in healthy school-aged children. This trial was registered at clinicaltrials.gov as NCT01943604. *Am J Clin Nutr* 2016;104:715–21.

Keywords: breakfast consumption, breakfast skipping, cognition, neuropsychological functioning, children

INTRODUCTION

The longest period during a 24-h day when children go without food is typically the period from the beginning of sleep at night to the first meal of the following day. Therefore, the morning suggests an ideal time to examine the effects of fasting on basic processes that underpin learning and behavior. Several systematic reviews of published studies have examined the relation between consuming breakfast and skipping breakfast during childhood on cognitive and academic performance (1–3) and psychological processes (4). Although breakfast consumption generally showed positive associations with all of these outcomes, the results were strongest in nutritionally vulnerable children and were inconsistent across the many specific domains of cognitive and psychological tests administered. For example, problem solving (5), short-term memory (6), attention, and episodic memory (7)

have been negatively associated with breakfast consumption in some studies, whereas a positive association of breakfast consumption has been associated with measures of vigilance, attention, arithmetic (8), problem-solving tasks (9), and logical reasoning (10). The heterogeneity between studies, including the types and composition of meals, the behavioral and cognitive processes that were examined, the effects of a single meal compared to habitual breakfast consumption, and the variations in socioeconomic and nutritional status of the study subjects, limits our ability to draw conclusions and suggests the need for further investigation of these relations.

This study was therefore designed to address inconsistences observed in previous studies by examining healthy low- and middle-income school-aged children and the effects of breakfast consumption and fasting on their neuropsychological functioning. A robust set of psychological measures and measures of multiple domains of cognitive functioning was used. The study was conducted in the controlled environment of a clinical research center with the use of a counterbalanced repeated-measures design to determine the effects of a standardized meal and fasting on the primary outcome of cognitive performance in these children—an outcome of considerable interest in determining components of optimal support for cognitive development during childhood.

METHODS

Participants

Eligible participants consisted of low- and middle-income African American, Hispanic American, and white male and female

children aged 8–10 y. Subjects were recruited and studied from January 2012 through November 2014 from the Houston, Texas metropolitan area. Low-income children were defined as those who received "free" or "reduced-price" lunches from the respective schools within the child's school district; middle-income children were defined as those not on a free/reduced-price school lunch and with a family income <$125,000/y.

Participants were excluded if they had one of the following criteria: *1*) BMI (in kg/m^2) >95th percentile; *2*) hemoglobin <11.0 g/dL; *3*) Tanner stage >2; *4*) history of neurological, neurodevelopmental, or developmental learning disabilities; *5*) history of sensory impairments and mood disorders; *6*) history of attention-deficit hyperactivity disorder; *7*) acute or chronic medical conditions; *8*) reported lactose intolerance, veganism, asthma, and/or tree nut or peanut allergy; or *9*) currently taking prescription medications.

Study design

This crossover clinical trial (NCT01943604) was a repeated-measures design in which each subject was randomly assigned to complete 3 different breakfast conditions in 1 of 6 possible orders. Participants completed the 3 conditions separated by a minimum of 6 d. Each child was studied alone and received the 3 breakfast conditions that were systematically sequenced (i.e., counterbalanced) across all 3 scheduled visits. Participants served as their own control. The 3 breakfast conditions were no breakfast (fasting); breakfast composed of bread and hazelnut spread, milk, and apple slices (hazelnut spread); or breakfast composed of waffles and syrup, milk, and apple slices (waffles). Participants completed the 3 conditions separated by a minimum of 6 d. A predetermined Latin-square design for assigning the 6 possible sequences of the 3 different treatments was created, e.g., *1*) no breakfast, waffles, hazelnut spread; *2*) no breakfast, hazelnut spread, waffles; *3*) waffles, no breakfast, hazelnut spread; *4*) waffles, hazelnut spread, no breakfast; *5*) hazelnut spread, waffles, no breakfast; and *6*) hazelnut spread, no breakfast, waffles. As each new subject was enrolled, the next sequence was assigned to the child. The breakfast foods were chosen because of their popularity among children and to be consistent with current recommendations for foods and nutrients in school breakfast meals (11). The 2 different breakfast entrées were chosen in an effort to examine whether the outcomes could be generalized rather than related to a specific food and to provide participants popular breakfast foods, thereby increasing the likelihood that participants would consume all of them.

A sample size of 154 children with an anticipated 20% dropout rate was designed to detect a mean treatment difference of 0.5 SDs for each outcome measure within each socioeconomic group with a type 1 error of 0.05 and power of 80% so that, for measures that had an SD of 3.0, a true mean difference of 1.5 units between any 2 treatment conditions would be detected. Because this was a crossover study with each child measured under the 3 treatment conditions, there would likely be a positive correlation between the repeated measures for each test. Therefore, this sample size was conservative, and the actual power was likely to be considerably greater than 80%. The effect size of 1.5 units was arbitrary in that we did not specify a difference in a specific measure because we had several outcome measures. A total of 128 children completed all 3 treatment arms of the study. We generated the predetermined

scheme for the random allocation sequence and enrolled and assigned participants according to the next available sequence in the predetermined scheme.

The Baylor College of Medicine Institutional Review Board approved the protocol in August 2011 and continues to review it annually. All parents or guardians gave their written informed consent for their child's participation, and each child gave his/her own verbal assent to participate in the study.

Recruitment

Several research staff members recruited the participants through the distribution of flyers and e-mails to elementary schools, community venues, pediatricians' offices, and children's centers around the Houston metropolitan area. Permission was obtained from all institutions and venues before the flyers were distributed. In addition, children were recruited from families who had contacted the Children's Nutrition Research Center or who had previously participated in children's nutrition studies. Potential participants were thoroughly screened to ensure they met all inclusion criteria and to ensure the subject's willingness to come for 3 separate overnight visits, to complete a total of 6 venipuncture procedures, and to fast for 1 morning.

Diets

Diets of the children were controlled on the day before the breakfast intervention by admitting all children 15 h before the morning experimental procedures began. Children consumed a dinner meal with either a chicken nuggets entrée and other foods or with a macaroni and cheese entrée and other foods; both dinners were similar in energy content and macronutrient composition. After the dinner meal, children were required not to drink or eat any other foods or beverages except for water. The next morning, children received one of the 3 breakfast intervention treatments. The waffle breakfast and hazelnut breakfast had similar energy content and macronutrient compositions. The intent of this study was not to look at the impact of variations in macronutrient composition of breakfast meals on neuropsychological functioning. Rather, it was focused on the short-term (generalized) effects of breakfast consumption on cognitive functioning without being related to a specific food. The dinner and breakfast meal each separately provided approximately one-third and one-fourth, respectively, of the recommended energy and macronutrient amounts for children aged 8–10 y (12). Children were observed during mealtime by the research study coordinator and were required to finish all foods and beverages; ≥80% of foods (by weight) had to be consumed to remain in the study.

Diet preparation was strictly controlled. The meals were designed by the research study registered dietitian and prepared under the supervision of the Metabolic Research Unit (MRU) registered dietitian at the Children's Nutrition Research Center. Each food had detailed specifications for the type, brand, preparation, presentation, and nutrient composition. Research dietary kitchen staff were trained and supervised in all meal preparation procedures. For every meal and every child, each food and container was weighed before and after the meal was eaten. The weight (in grams) of foods and macronutrients served and consumed were computed for every meal.

Experimental protocol procedures

Evening procedures

Children arrived in the early evening for their initial visit to be further screened for final exclusion criteria and to complete written informed consent procedures. Each child tasted the hazelnut spread to determine whether he or she was willing to consume this food, an entrée for one of the breakfasts. Children who were unwilling to consume it were excluded from the study. A history and physical exam was conducted by a physician to screen for general health and conditions that may affect participation status and performance during testing (e.g., history of psychoactive drug use, developmental issues). The physician also assessed puberty status by Tanner staging and for the presence of acanthosis nigricans.

Measurements were taken in duplicate by standardized procedures for height, weight, blood pressure, heart rate, and temperature. A microsample of blood was obtained by a finger stick to determine hemoglobin status and to exclude those who were anemic (only tested on the initial visit) and was analyzed with the use of a STAT-Site MHgb instrument (Stanbio Laboratory). The acceptable range for hemoglobin was ≥11.0 g/dL. A visual screening test was completed to determine whether the child was color blind (13). One of 2 isocaloric dinners, selected by each child, was served to the children. After the dinner meal, all subjects rested quietly and completed quiet activities (e.g., reading, watching television) until retiring to bed in the MRU.

Morning procedures

Participants had their pre- and postbreakfast blood samples tested for glucose and ketone concentrations (Precision Xtra glucose and ketone strips; Abbott Laboratories) to ensure the child's ability to continue with protocol procedures. The study was terminated if the child's glucose concentration was <69 mg/dL. After breakfast, all subjects were involved in quiet activities (e.g., reading, watching television). At 0830, children were served the breakfast assigned that morning (or continued fasting). At 1030, a trained neuropsychological evaluator, blinded to the subject's breakfast condition, administered a battery of 4 tests (13 subscales) to the subject. The neuropsychological tests included standardized normed measures, with the exception of one test that was an experimental version of a computer test typically used to assess attention. Neuropsychological tests were administered in a fixed order separated by a minimum of 6 d. The fixed order was used to reduce the "noise" caused by variable performance with multiple combinations and to help control sequencing and practice effects. On average, it took 1 h of testing for each participant. Parents stayed overnight with their child for all 3 sessions and received dinner and breakfast meals.

Blood collection procedures

Whole-blood samples were collected before breakfast and after neuropsychological testing. Samples were obtained by venipuncture, centrifuged ($1000 \times g$ for 10 min at 4°C), and stored as plasma at −80°C in a freezer for later analysis of insulin and glucose. Real-time measurements of whole-blood glucose and ketones were completed to examine clinically unrecognized hypoglycemia after the overnight fast. A drop of whole blood from the venipuncture was applied to a glucose test strip and another drop applied to a ketone test strip for monitoring purposes (Precision Xtra Monitor Meter with Precision Xtra ketone and glucose strips).

Anthropometric procedures

Weight was measured with a Health o meter electronic scale that was routinely calibrated. Two measurements for weight were completed, and if the second did not agree by 0.3 kg, a third measurement for weight was completed. Height was measured with a Holtain stadiometer that was routinely calibrated. Two measures were obtained for each height; if the 2 measurements for height did not agree by 0.5 cm, a third measurement was taken. The measurement at eye level (standing on chair if necessary) was recorded to the nearest 0.1 cm. CDC percentiles for weight, height, and BMI were computed from http://nccd.cdc.gov/dnpabmi/Calculator.aspx and http://www.cdc.gov/nccdphp/dnpao/growthcharts/resources/sas.htm.

Vital sign procedures

Blood pressure measurements were taken on the dominant arm with the use of the Welch Allyn Spot Vital Signs LXi 1.2 instrument. The nursing personnel determined the correct blood pressure cuff size. When the measurement cycle was completed on the spot vital signs instrument, values were displayed for the systolic, diastolic, and pulse rate measurements. Temperature was also measured with the use of the Welch Allyn Spot Vital Signs LXi 1.2 instrument. Nursing personnel measured the respiration rate of the child. Each vital sign had an age-appropriate normal and acceptable range, and if the measurements of the child were not in the normal range, the study visit was rescheduled.

Primary neuropsychological functioning measures

Continuous Performance Test

The Continuous Performance Test (14) is a computerized test designed to assess selective attention, vigilance, and impulsivity. Reaction times and accuracy are also calculated. This measure can be administered to individuals aged ≥6 y. This task involves the subjects sitting in front of a computer screen while letters of the alphabet are flashed briefly at various interstimulus intervals. The subject is instructed to press the spacebar on the keyboard whenever any letter except for X is seen on the screen.

The Wechsler Intelligence Scale for Children-IV

The Wechsler Intelligence Scale for Children-IV (15) is a comprehensive clinical instrument designed to assess intellectual functioning in children ages 6 y, 0 mo to 16 y, 11 mo. It is individually administered and includes the following subtests.

Digit span. This subtest consists of 2 parts: digit span forward and digit span backward. It is designed as a measure of auditory short-term memory, sequencing skills, attention, and concentration (16). Each of the 2 parts of this subtest involves different discrete areas of cognition.

Letter-number sequencing. This subtest is one of the core working memory composite tests. The subject is provided a sequence of numbers and letters and is asked to recall the numbers in descending order and the letters in alphabetical order. The processing speed for each of the subtests and the distribution of

each age group's total raw scores in this study were converted to the scaled scores with a mean of 10 and SD of 3.

Coding. In addition to processing speed, this subtest measures short-term memory, learning ability, visual perception, visual motor coordination, visual scanning ability, cognitive flexibility, attention, and motivation.

Symbol search. In addition to processing speed, this subtest assesses short-term visual memory, visual-motor coordination, cognitive flexibility, visual discrimination, and concentration (16).

The Wide-Range Assessment of Memory and Learning

The Wide-Range Assessment of Memory and Learning (17) is a battery of subtests designed to examine the memory of individuals aged ≥5. The subtests administered in this study included the verbal learning subtest, which evaluates a person's ability to actively learn unrelated verbal material. For subjects aged ≤8 y, 13 words were used; for subjects ≥9 y, 16 words made up this list-learning task. A subtest scale score was obtained based on the total number of words remembered correctly on the 4 learning trials. We also used the picture memory subtest, which assesses visual memory.

The Test of Memory and Learning

The Test of Memory and Learning (18) is a comprehensive memory battery standardized for use with children and young adults and is administered individually. Visual selective reminding is a nonverbal analog to the word selective reminding subtest of the Test of Memory and Learning. The subjects in this study were required to point to specified dots on a card after a demonstration by the examiner and were reminded only of the items recalled incorrectly. Trials continued until mastery was achieved or until 8 trials were attempted. It was designed to assess learning and immediate recall functions of visual (nonverbal) memory.

Training of psychology interns

Research staff members who administered the neuropsychological measures had undergraduate degrees in psychology and were working on advanced degrees in neuropsychology. They were carefully screened for their interest, experience, and aptitude in research, handling children, and ability to adhere to protocol procedures.

Each intern was trained in testing procedures for administering each standardized exam, scoring the exam, and following all test manual guidelines. Interns rehearsed training until they were proficient in conducting, timing, and scoring the exams. The training also consisted of scenarios for supporting the children to make them feel comfortable, minimize their anxiety, and ensure that the testing session flowed easily. After each visit of testing the children, another intern cross-checked the test scores and data entry of a fellow intern.

Questionnaires

Parents or guardians completed 3 questionnaires at the initial visit. Questionnaires were selected to further assess relevant background factors of the child that may have contributed to the child's nutritional patterns and status or modified the child's performance on the neuropsychological measures.

Demographic questionnaire

At baseline, a demographic questionnaire was used to document age, ethnicity, sex, and socioeconomic status and to verify what kind of lunch the child received (i.e., free, reduced-price, or paid). The socioeconomic portion of the questionnaire was taken from the same questionnaire used by the National Poverty Center for calculating poverty thresholds and to determine whether the family income was at or below the national poverty level.

Breakfast consumption pattern questionnaire

A short survey was conducted to determine the frequency and quality of breakfast typically consumed. The questionnaire comprised 6 open-ended questions to determine the consumption and frequency of 14 common breakfast foods.

Children's Sleep Habits Questionnaire

The Children's Sleep Habits Questionnaire includes items relating to several key sleep domains that encompass the major presenting clinical sleep complaints in this age group: bedtime behavior and sleep onset, sleep duration, anxiety around sleep, behavior occurring during sleep and night waking, sleep-disordered breathing, parasomnias, and morning waking/daytime sleepiness. This measure was used to determine whether subjects had experienced sleep disturbances that might affect their performance on the neuropsychological tests. Parents were asked to recall sleep behaviors occurring over a "typical" recent week. Items were rated on a 3-point scale: "usually" if the sleep behavior occurred 5–7 times/wk, "sometimes" for 2–4 times/wk, and "rarely" for ≤1 time/wk. Some items were reversed to consistently make a higher score indicative of more disturbed sleep. In addition to the items on this questionnaire, an additional list of questions dealing with the child's sleeping history was administered (19).

Statistical analysis

SAS statistical software package version 9.4 was used for all data analyses. Normality and the distribution of neuropsychological outcomes on each scaling variable were assessed by calculating mean, SD, skewness, and kurtosis values and inspecting the graphical methods (i.e., histogram, box plot) as visual aids. Outliers were determined as cases exceeding the median plus 3 times the IQR.

Given the repeated observation of neuropsychological outcomes in different breakfast conditions, linear mixed-effect models were conducted. This technique can be applied to repeated-measures problems in which subjects are measured at different, irregular, and unequally spaced intervals of time. The models' development was based on 3 steps: *1*) select an appropriate covariance structure; *2*) compare the model-fit statistics information from the different covariance structure models by Akaike and Bayesian information criteria on a smaller-is-better basis and test the difference in a −2 log likelihood with the use of chi-square distribution; and *3*) determine the model that best fits the data. After ruling out the covariance structures that clearly were not appropriate for the data and comparing the model-fitting statistics information from running the models with 5 possible covariance structures (simple, unstructured, compound symmetry, first-order autoregressive, and first-order antedependence), the unstructured variance-covariance matrix was used because it fit the data best among the 5 covariance structures.

The series mixed-effect models were carried out to assess whether the neuropsychological outcomes were different by breakfast condition and whether the neuropsychological outcomes were influenced by breakfast condition, which varied across each individual characteristic (e.g., sex, age, race/ethnicity, eating breakfast, and parent's income and education status). These interaction terms tested whether a proposed individual characteristic/background variable affected an outcome more than the breakfast condition. For example, to test the relation between breakfast condition and sex, we assessed whether the outcome scores were different/similar in males or females between the breakfast conditions.

In the models, the neuropsychological outcomes were the dependent variables tested separately for each outcome. Breakfast condition with 3 categories was the within-subject predictor, whereas child's sex, age, race/ethnicity, eating breakfast, and parent's income and education status were treated as the between-subject variables. The correction for multiple testing with the use of the Bonferroni correction resulted in a significance level of $P < 0.004$ for each test.

RESULTS

Sample demographics

As shown in **Supplemental Figure 1**, from the sample of 2338 assessed for eligibility, 2210 were excluded on the basis of exclusion criteria such as age, abnormal health or medical conditions, weight, behavioral or learning problems, and neuropsychological factors; 331 children and families decided not to participate because it was inconvenient for the family, because the family was unable to stay overnight, or because there was no provision for babysitting other siblings; and 673 children were excluded for other reasons, including having moved out of the area, phone number not working, or no response by parents. All exclusions were made before randomizing and beginning the study.

The sample consisted of children aged 8–10 y ($n = 128$), of which 52% were female, 38% were African American, 31% were Hispanic, 28% were white, and 3% were of another race/ethnicity (**Table 1**). Sixty-six percent of the children reported always consuming breakfast, and 55% received free lunch at school. Ninety-eight percent reported sleeping good/very good the night before testing. Mothers of the children were the primary caregiver (92%) who stayed with their child in the 3 overnight stays at the MRU. Fifty percent reported a household annual income <$50,000. Sixty-nine percent of the mothers were married, and 52% had some college or less education.

Impact of breakfast consumption on neuropsychological measures

All children were euglycemic immediately before neuropsychological testing. The least square means and SEs of the 4 neuropsychological measures (13 subscales) scores across the 3 breakfast conditions are included in **Table 2**. There were no significant ($P \geq 0.004$) condition effects for any of the neuropsychological measures administered. The results did not change after controlling for the child's sex, age, frequency of eating breakfast, and parent's income and educational status.

TABLE 1
Descriptive statistics for the sample[1]

	Value
Age, y	9.23 ± 0.83
BMI z score, kg/m^2	0.26 ± 0.81
Sex, n (%)	
Male	62 (48.44)
Female	66 (51.56)
Race/ethnicity, n (%)	
Hispanic American	40 (31.25)
African American	48 (37.50)
White	36 (28.13)
Other	4 (3.13)
Household income, n (%)	
<$20,000	17 (13.28)
$20,000–$50,000	47 (36.72)
>$50,000–$80,000	28 (21.88)
>$80,000–$110,000	24 (18.75)
>$110,000–$125,000	12 (9.38)
Marital status, n (%)	
Married	88 (68.75)
Divorce/separated/other	26 (20.31)
Never married	14 (10.94)
Parent's education, n (%)	
≤Tech school	25 (19.53)
Some college	42 (32.81)
College	38 (29.69)
>College	23 (17.97)
Breakfast, n (%)	
Sometimes	44 (34.38)
Always	84 (65.63)
Free lunch at school, n (%)	
No	58 (45.31)
Yes	70 (54.69)
Sleep on night before test, n (%)	
Very good	29 (22.70)
Good	96 (75.00)
Not good	3 (2.30)

[1] Values reported for age and BMI are means ± SDs. $n = 128$.

DISCUSSION

This study was designed to address the methodologic issues identified by Hoyland et al. (1) and does not confirm a benefit of breakfast consumption on acute neuropsychological functioning in healthy school-aged children from low- and middle-income families. Nutrient inadequacies during childhood can affect brain development and along with concurrent psychosocial stresses can have potential lifelong consequences ranging from diminished academic performance to deficits in cognitive functioning (20, 21). Although several studies have investigated the relation between breakfast consumption and various domains of cognitive functioning within children (2, 22–25), some of the reported findings are inconsistent (20). For example, Cooper et al. (26) found that adolescents randomly assigned to a low glycemic index breakfast condition exhibited greater improvement in response times and accuracy on the Stroop task, Flanker task, and Sternberg paradigm than those randomly assigned to the high glycemic index or breakfast omission conditions. However, Defeyter and Russo (24) were unable to replicate these findings and in contrast found that breakfast consumption did not play an important role in improving performance on cognitively demanding tasks (e.g., the Stroop test).

TABLE 2
Effects of breakfast conditions on short-term neuropsychological functions[1]

	No breakfast	Hazelnut spread	Waffles	Condition effects, P
WISC-IV[2]				
Digit span	10.23 ± 0.22	10.40 ± 0.22	10.14 ± 0.22	0.370
Letter-number sequencing	11.29 ± 0.17	10.92 ± 0.17	10.91 ± 0.17	0.049
Coding	10.44 ± 0.24	10.34 ± 0.24	10.34 ± 0.24	0.882
Symbol search	11.65 ± 0.23	11.66 ± 0.23	11.60 ± 0.23	0.965
TOMAL[2]				
Visual selective reminding immediately	10.77 ± 0.30	10.57 ± 0.30	10.68 ± 0.30	0.847
Visual selective reminding delay	10.05 ± 0.14	9.84 ± 0.14	9.99 ± 0.14	0.368
WRAML2				
Verbal learning immediately[2]	14.01 ± 0.30	13.55 ± 0.30	14.01 ± 0.30	0.367
Picture memory[2]	11.79 ± 0.26	11.55 ± 0.26	11.53 ± 0.26	0.609
Verbal learning delay recall[2]	12.15 ± 0.25	12.02 ± 0.25	12.33 ± 0.25	0.476
WMI	103.30 ± 0.90	103.14 ± 0.90	102.23 ± 0.90	0.335
PSI	106.14 ± 1.18	105.77 ± 1.18	105.73 ± 1.18	0.926
CPT-II				
Omissions total score	53.73 ± 1.02	50.92 ± 1.02	52.53 ± 1.02	0.040
Commissions total score	49.38 ± 1.04	48.68 ± 1.04	48.33 ± 1.04	0.494

[1]Values are least square means $\pm$ SEMs unless otherwise indicated, $n = 128$. The results and testing were from the mixed-effect models, with breakfast condition as the independent variable and neuropsychological outcomes as the dependent variables. A Bonferroni correction resulted in a significance level of $P < 0.004$. CPT, Continuous Performance Test; PSI, processing speed index; TOMAL, Test of Memory and Learning; WISC, Wechsler Intelligence Scale for Children; WMI, working memory index; WRAML, Wide-Range Assessment of Memory and Learning.

[2]Represented as the scaled scores.

Despite some of these inconsistencies, most available research shows that children who eat breakfast on the morning of the assigned task (i.e., a study's direct measure of cognitive functioning) demonstrate more success in various aspects of cognitive performance, such as memory, processing complex visual displays, problem solving, arithmetic, and alertness (1, 21, 27). The improved attentiveness noted during these cognitive tasks related to breakfast consumption often translated to better academic achievement in the classroom.

Nevertheless, methodologic shortcomings with the available evidence base on the association of fasting and a breakfast meal on neuropsychological functioning include *1*) mismatches between breakfast manipulations and energy or volume, *2*) choice of breakfast intervention not driven by a priori hypotheses, and *3*) lack of appropriateness of cognitive testing used by the studies in terms of the level of difficulty, style, and cognitive domain being investigated.

The measures used in this study to assess neuropsychological functioning included a wide variety of domains: memory, attention, reasoning, intellectual vigilance and impulsivity, learning ability, visual and nonverbal memory, visual perception and coordination, cognitive flexibility, attention, and motivation. This is the most comprehensive set of tests used in any single study to our knowledge and was designed to examine neuropsychological function in young children after a fast or meal. All of these tests are standardized with good psychometric properties and are routinely used in clinical child development practice.

Despite the advantages of the study design, some inherent limitations and potential confounders remain. As with any self-reported measures, there is the issue of sensitivity/specificity of the measures that were used and whether the measures were sensitive enough to detect short-term effects. The measures used in this study, however, represent the most reliable in each of the multiple domains examined. It is also important to note that the sample size was determined based on an effect size of 1.5 units, which was arbitrary in that we did not specify a difference for each of the 13 neuropsychological outcome measures.

A major disadvantage of within-subject designs is their ability to produce carryover effects (28). Carryover effects occur when a previous treatment alters the behavior in a subsequent treatment. Sources of carryover include a learning effect, fatigue, sensitization, contrast, and adaptation. One can deal with carryover effects by counterbalancing to even out carryover effects across treatments, and steps to minimize carryover can be taken. The treatment conditions were counterbalanced. The interns were trained with scenarios on ways to interact with the children to make them feel comfortable, minimize their anxiety, and allow the testing session to flow easily. Attempts were also made to ensure that each testing session had a specified amount of time between each visit. Finally, the fixed order was used to reduce noise caused by variable performance with multiple combinations and to help control sequencing and practice effects.

The sample consisted of healthy children, which may also have limited any important beneficial findings from breakfast consumption. Studies have shown that the effect of breakfast consumption on cognitive processes is more apparent in populations more vulnerable to nutritional deficit (4, 27, 29, 30). This study used a once-per-week within-participant design for 3 breakfast conditions separated by a minimum of 6 d. Children consumed 2 breakfasts and no breakfast and then completed a battery of cognitive tests. The 2 breakfasts, waffle and hazelnut spread, were isocaloric with similar macronutrient composition. Studies have reported that breakfast type, macronutrient composition, and glycemic load may have a differential impact on the effect of breakfast consumption on cognitive outcomes (31–35). When we combined the 2 breakfast conditions in the analyses, there still was no effect on the cognitive outcomes. It is also important to note that this study was designed to look at short-term effects. Studies have shown that habitual

breakfast consumption is related to academic performance (36), and thus short-term effects may not be easily detected.

As with any clinical study, there are both strengths and limitations to this study. The strengths include a large and diverse sample size, repeated-measures design, stringent exclusionary criteria, the use of standardized validated neuropsychological measures with normative values for this test population, highly controlled environmental and nutritional conditions, and the assessment of selected biomarkers. More studies are needed regarding habitual breakfast consumption and its effect on neuropsychological functioning in healthy children and those with marginal or subnormal nutritional status.

REFERENCES

1. Hoyland A, Dye L, Lawton CL. A systematic review of the effect of breakfast on the cognitive performance of children and adolescents. Nutr Res Rev 2009;22:220–43.
2. Rampersaud GC, Pereira MA, Girard BL, Adams J, Metzl JD. Breakfast habits, nutritional status, body weight, and academic performance in children and adolescents. J Am Diet Assoc 2005;105:743–60.
3. Edefonti V, Rosato V, Parpinel M, Nebbia G, Fiorica L, Fossali E, Ferraroni M, Decarli A, Agostoni C. The effect of breakfast composition and energy contribution on cognitive and academic performance: a systematic review. Am J Clin Nutr 2014;100:626–56.
4. Adolphus K, Lawton CL, Dye L. The effects of breakfast on behavior and academic performance in children and adolescents. Front Hum Neurosci 2013;7:425.
5. Pollitt E, Lewis NL, Garza C, Shulman RJ. Fasting and cognitive function. J Psychiatr Res 1982;17:169–74.
6. Vaisman N, Voet H, Akivis A, Vakil E. Effect of breakfast timing on the cognitive functions of elementary school students. Arch Pediatr Adolesc Med 1996;150:1089–92.
7. Wesnes KA, Pincock C, Richardson D, Helm G, Hails S. Breakfast reduces declines in attention and memory over the morning in schoolchildren. Appetite 2003;41:329–31.
8. Conners CK, Blouin AG. Nutritional effects on behavior of children. J Psychiatr Res 1982;17:193–201.
9. Pollitt E, Leibel RL, Greenfield D. Brief fasting, stress, and cognition in children. Am J Clin Nutr 1981;34:1526–33.
10. Márquez Acosta M, Sutil de Naranjo R, Rivas de Yepez CE, Rincon Silva M, Torres M, Yepez RD, Portillo Z. [Influence of breakfast on cognitive functions of children from an urban area in Valencia, Venezuela] Arch Latinoam Nutr 2001;51:57–63.
11. USDA. Nutrition standards in the national school lunch and school breakfast programs: final rule [Internet]. Available from: https://www.gpo.gov/fdsys/pkg/FR-2012-01-26/pdf/2012-1010.pdf.
12. Institute of Medicine of the National Academies. [Internet] [cited 2015 Dec 24]. Available from: https://fnic.nal.usda.gov/dietary-guidance/dietary-reference-intakes/dri-nutrient-reports.
13. Waggoner LT. Color vision testing made easy. 1st ed. Gulf Breeze (FL): Waggoner; 2002.
14. Conner CK. Continuous performance test version 5.2. West Sussex (UK): International Psychology Services; 2015.
15. Weschler D. Weschler Intelligence Scale for Children. 4th ed. San Antonio (TX): The Psychological Corporation; 2003.
16. Sattler JM. Assessment of children: cognitive applications. San Diego (CA): Jerome M. Sattler, Publisher, Inc.; 2001.
17. Sheslow D, Adams W. Wide Range Assessment of Memory and Learning (WRAML2). Austin (TX): Pro-ed Inc.; 2003.
18. Reynolds CR, Voress JK. Test of Memory and Learning (TOMAL-2). 2nd ed. Austin (TX): Pro-Ed; 2007.
19. Owens JA, Spirito A, McGuinn M. The Children's Sleep Habits Questionnaire (CSHQ): psychometric properties of a survey instrument for school-aged children. Sleep 2000;23:1043–51.
20. Bellisle F. Effects of diet on behaviour and cognition in children. Br J Nutr 2004;92(Suppl 2):S227–32.
21. Basch CE. Breakfast and the achievement gap among urban minority youth. J Sch Health 2011;81:635–40.
22. Benton D, Parker PY. Breakfast, blood glucose, and cognition. Am J Clin Nutr 1998;67:772S–8S.
23. Benton D, Owens DS. Blood glucose and human memory. Psychopharmacology (Berl) 1993;113:83–8.
24. Defeyter MA, Russo R. The effect of breakfast cereal consumption on adolescents' cognitive performance and mood. Front Hum Neurosci 2013;7:789.
25. López I, de Andraca I, Perales CG, Heresi E, Castillo M, Colombo M. Breakfast omission and cognitive performance of normal, wasted and stunted schoolchildren. Eur J Clin Nutr 1993;47:533–42.
26. Cooper SB, Bandelow S, Nute ML, Morris JG, Nevill ME. Breakfast glycaemic index and cognitive function in adolescent school children. Br J Nutr 2012;107:1823–32.
27. Pollitt E, Mathews R. Breakfast and cognition: an integrative summary. Am J Clin Nutr 1998;67:804S–13S.
28. Keppel G, Wickens TD. Design and analysis: a researcher's handbook. 4th ed. Upper Saddle River (NJ): Pearson; 2004.
29. Cueto S, Jacoby E, Pollitt E. Breakfast prevents delays of attention and memory functions among nutritionally at-risk boys. J Appl Dev Psychol 1998;19:219–33.
30. Pollitt E, Jacoby E, Cueto S. School breakfast and cognition among nutritionally at-risk children in the Peruvian Andes. Nutr Rev 1996;54:S22–6.
31. Hoyland A, Lawton CL, Dye L. Acute effects of macronutrient manipulations on cognitive test performance in healthy young adults: a systematic research review. Neurosci Biobehav Rev 2008;32:72–85.
32. Fischer K, Colombani PC, Langhans W, Wenk C. Cognitive performance and its relationship with postprandial metabolic changes after ingestion of different macronutrients in the morning. Br J Nutr 2001;85:393–405.
33. Nilsson A, Radeborg K, Bjorck I. Effects of differences in postprandial glycaemia on cognitive functions in healthy middle-aged subjects. Eur J Clin Nutr 2009;63:113–20.
34. Mahoney CR, Taylor HA, Kanarek RB, Samuel P. Effect of breakfast composition on cognitive processes in elementary school children. Physiol Behav 2005;85:635–45.
35. Micha R, Rogers PJ, Nelson M. Glycaemic index and glycaemic load of breakfast predict cognitive function and mood in school children: a randomised controlled trial. Br J Nutr 2011;106:1552–61.
36. Adolphus K, Lawton CL, Dye L. The relationship between habitual breakfast consumption frequency and academic performance in British adolescents. Front Public Health 2015;3:68.