Fasting and cognition in well- and undernourished schoolchildren: a review of three experimental studies[1,2]

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ABSTRACT This paper reviews three experiments on the effects of an overnight and morning fast on attention and memory processes among 9–11-y-old children. Two of the experiments focused on middle-class, well-nourished boys and girls in the United States; the third involved boys from low-income families with and without nutritional risk in Huaraz, Peru. All experiments used the same crossover design and followed similar experimental procedures to control the subjects' intakes and motor activity during the study period. The children were admitted to a research center on two different evenings, ≈7 d apart. After arrival the children ate dinner, played table games or watched television, and went to bed. They were awakened at 0730 and, by design, were either served breakfast (≈2301 kJ) or not. At 1100 they took psychologic tests that assessed recall from working memory and competence in discriminating visual stimuli. At 1200 the children were discharged. The consequences of the overnight and morning fast, particularly among the children who were nutritionally at risk, included slower stimulus discrimination, increased errors, and slower memory recall. We propose that these alterations result from a state of metabolic stress in which homeostatic mechanisms work to maintain circulating glucose concentrations. *Am J Clin Nutr* 1998;67(suppl): 779S–84S.

KEY WORDS Fasting, cognition, schoolchildren, school feeding, school performance, Peruvian National Breakfast Program, breakfast

INTRODUCTION

This paper reviews three experiments that tested the effects of an overnight and morning fast on cognition among 9–11-y-old children. The experiments tested the working hypothesis that such an extended fast interferes with attention and working memory processes (1). The first two focused on well-nourished, middle-class boys and girls in the United States and were exclusively concerned with the cognitive effects of an overnight and morning fast; the results were published in the early 1980s (2, 3). The third experiment examined both well- and undernourished boys in the Andean town of Huaraz, Peru. Along with a field trial, this experiment was part of an evaluation of the Peruvian National Breakfast Program launched by the Peruvian government in 1993. A complete report of the data from experiment 3 is in press (4); the results of the field trial have been published (5). The evaluation was published as a book in Spanish in 1996 (6).

The comparative analysis presented here takes advantage of the crossover design of the experiments, the similarity of their protocols, and the inclusion of subjects of similar age who consumed a breakfast of about the same energy value. Because experiment 3 used computerized cognition tests that were not available for the first two experiments, its test outcomes are more exact than those of experiments 1 and 2. In addition, whereas the experiments 1 and 2 studied children of both sexes, experiment 3 restricted its sample to boys.

The three experiments used the working hypothesis that the effects of an extended fast on cognition can be observed in particular aspects of information processing and can also be experimentally activated by stimuli presented over short periods (seconds). There was neither a theoretical reason nor an empirical basis for an assumption that the extended fast would affect the complex mental abilities that are generally included as components of intelligence.

EXPERIMENTS 1 AND 2

Subjects and Methods

Unless otherwise noted, the following description applies to both experiments. The subjects were 9–11-y-old children meeting the following criteria: height and weight between the 10th and 90th percentiles of the US National Center for Health Statistics (NCHS) standards (7), no history of hypoglycemia or of any other metabolic disease, and good health. There were 23 girls and 9 boys in the first experiment, and 20 girls and 19 boys in the second. Self-selection explains the difference in the number of boys and girls in experiment 1. A notice for recruitment of subjects was published in a university newsletter.

All subjects were admitted to a clinical research center on two evenings ≈7 d apart. At the first admission, medical personnel recorded complete medical histories and conducted physical examinations for all subjects. On both admissions, the subjects ate dinner at 1700, went to bed at ≈1900, and were awakened at

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0720 the next morning for breakfast, served between 0800 and 0830. The nutritional composition of the breakfast meals is shown in **Table 1**. The investigators randomly assigned the subjects to either breakfast (BR) or a placebo (NBR) on the morning of the first admission, and reversed the treatments on the second. The children engaged in quiet activities (eg, watching television or playing table games) until 1115, at which time two psychologists, blinded to the treatment, administered a series of behavioral tests. Afterward the investigators took blood samples (15 mL) and discharged the children at 1200.

The psychologic test battery included the Matching Familiar Figures Test (MFFT) (8) and the Hagen Central Incidental Test (HCIT) (9). The MFFT assessed competence in discriminating among similar visual stimuli. The number of correct responses (out of six or eight displayed alternatives) was the main indicator of performance. The two levels of difficulty were determined by the number (ie, six or eight) of stimuli that the child was asked to assess and judge on each trial. Other studies have shown that errors in the MFFT are correlated negatively with educational achievement test scores (10) and positively with anxiety (11). For example, in the experiment we are describing, the correlations between MFFT errors and scores in the Iowa Test of Basic Skills (12), after controlling for reaction time, were −0.40 ($P < 0.01$) for 9- and −0.47 ($P < 0.01$) for 11-y-old children.

The HCIT taps attention processes related to those assessed in the MFFT and adds a memory component. The test consists of six cards presented sequentially, each with a drawing of an animal and an object (eg, car). Once all the cards are presented, the child is shown a single card with a picture of only an animal, and the child is asked to identify the serial position occupied by that animal in the first presentation of the series. At the beginning of the test the child is told to pay attention only to the animals, as the objects are incidental to the task.

Two scores are generated: central (ie, correct recall of animals) and incidental (correct recall of objects). In other studies, incidental scores correlated positively with anxiety (11) and negatively with age (13). A test of verbal intelligence [ie, Peabody Picture Vocabulary Test (PPVT) (14)] was included in experiment 1, whereas experiment 2 used the Slossum Intelligence Scale (15).

The investigators in experiment 1 tested blood samples for β-hydroxybutyrate (BHB), glucose, lactate, and fatty acids. Measurements were obtained at 2100 the evening of the admission and again at noon the next day. Experiment 2 restricted the biochemical determinations to glucose and insulin. Blood samples were again collected on the evening of admission and at noon the day of the two experimental treatments.

TABLE 1
Nutritional composition of dinner and breakfast in experiments 1 and 2[1]

Meal composition	Experiment 1	Experiment 2
Dinner		
Carbohydrate (g)	145	105
Protein (g)	40	31
Fat (g)	25	27
Energy (kJ)	4016.6	3292.8
Breakfast		
Carbohydrate (g)	75	65
Protein (g)	15	12
Fat (g)	20	16
Energy (kJ)	2238.4	1874.4

[1] From references 2 and 3.

Experiment 1: results

The mean concentration of BHB (in nmol/L) on the evening before BR (0.114, $P < 0.05$) was significantly lower than the same measurement obtained at 1200 the day of the fast (0.37). This latter measurement was also significantly greater than that obtained at 1200 after BR (0.068). Mean glucose concentrations (in mol/L) on the morning of NBR (4.26) were significantly different from those of the BR day (4.44); however, there were no significant differences between this latter value and that of the preceding evening (4.69). Regarding lactate (in mol/L), the only significant difference observed was between the NBR (1.3) and the BR (1.5) conditions. Fatty acids (in mmol/L) were not measured in the evening; however, the difference between the measurements at noon was statistically significant. Glucose, as noted below, was associated with cognitive test performance; however, the other metabolic indicators were not (*see* **Figures 1** and **2**).

In this experiment, the interaction between treatment (BR or NBR) and intelligence quotient (IQ) accounted for a significant portion of the variance in errors on the MFFT. In subjects with an IQ below the median for the group, performance of the five easy tasks of the MFFT was poorer ($P < 0.05$) for those who had been fasting. In addition, the magnitude of the difference in glucose concentrations at 1200 between those who ate breakfast and those who did not was negatively associated with a change in the number of errors; as glucose concentrations dropped, the number of errors increased ($P < 0.05$).

An analysis of the incidental scores on the HCIT was restricted to the first day of admission because of the potential transfer of learning associated with repeated measures. As expected, the incidental score was significantly higher after NBR than after BR. However, the HCIT yielded an unexpected finding; recall of the last central item in the series was significantly better after the overnight and morning fast than after breakfast consumption. Moreover, the subjects whose glucose values fell below the median for the respective distribution were also more likely to show the recency effect than those with glucose values above the median.

Neither the IQ test nor the continuous performance task showed any effects of treatment. The sex of the subjects also had no effect on the scores on any of the tests administered.

Experiment 2: results

The mean glucose concentration (5.19 mol/L) at 1200 after BR was significantly higher than the same value after NBR (4.75 mol/L). The difference in the respective insulin values on those 2 d (BR: 20.1; NBR: 17.1 mol/L) was also statistically significant.

Independent of the subjects' IQs, the overnight and morning fast influenced performance on the MFFT: errors were significantly greater ($P < 0.05$) after NBR than after BR. Errors after NBR also showed a statistically significant ($P < 0.05$) negative correlation with insulin ($r = -0.41$) and glucose ($r = -0.28$) values.

The results of experiment 2 on the HCIT agreed in part with those of experiment 1. After NBR, incidental scores were higher than after BR, and insulin was negatively correlated with incidental recall ($r = -0.40$; $P < 0.05$). On the day of BR, neither glucose nor insulin concentration correlated with performance. The recency effect in memory observed in experiment 1 was not observed in experiment 2.

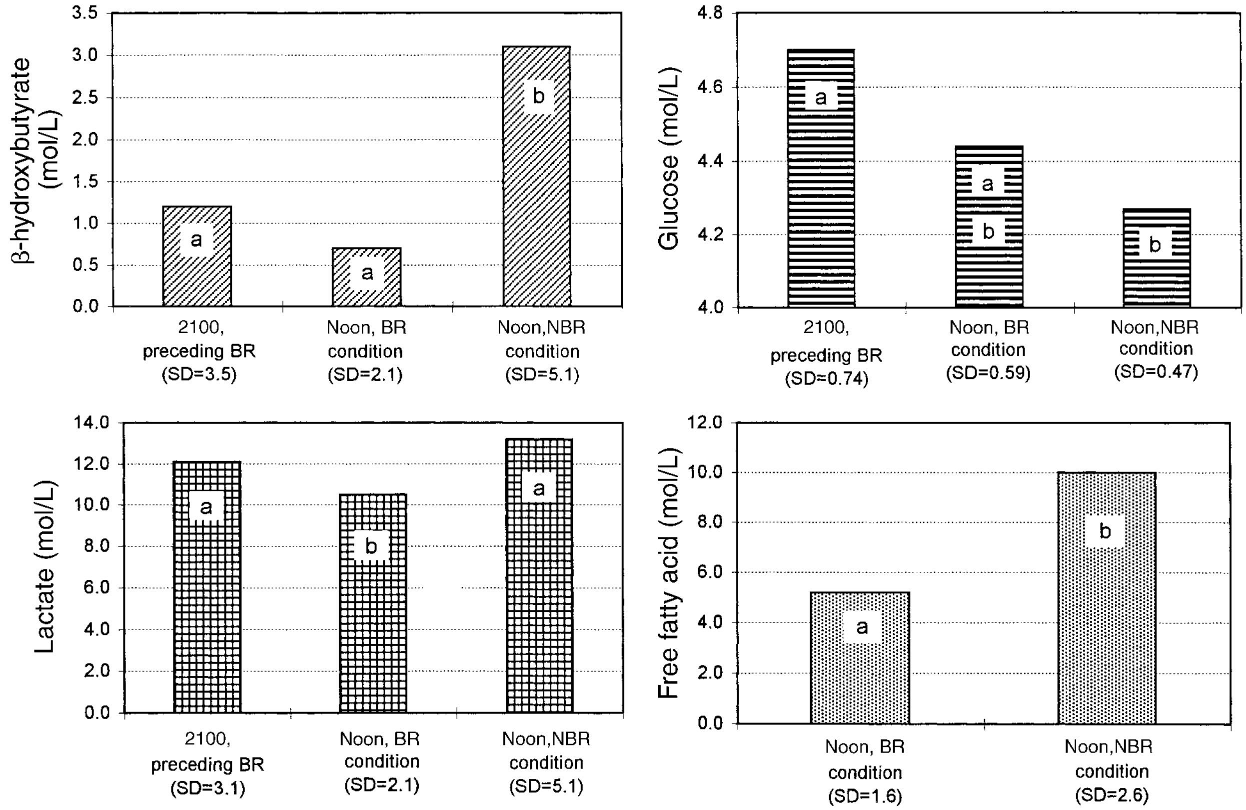

FIGURE 1. Mean plasma biochemical values determined at 2100 preceding breakfast (BR) and at 1200 on the day of treatment for both breakfast (BR) and no breakfast (NBR) conditions. Blocks with different letters are significantly different from each other.

As in experiment 1, intelligence test scores in this second study did not discriminate between the BR and the NBR conditions, nor did they moderate the effects of treatment on the other cognitive tests or show any sex effects on performance.

EXPERIMENT 3

Subjects and methods

This experiment included well- and undernourished children whose parents, unlike those of the participants in experiments 1 and 2, had neither a college education nor a middle-class income. The families were lower-middle class by Peruvian standards. The subjects were 23 undernourished and 29 well-nourished 9–11-y-old boys. Criteria for sample selection were as follows: *1*) male sex [girls were excluded to avoid the potential confounding effect of early menarche on cognitive function (16)], *2*) enrollment in the fourth or fifth primary school grade, *3*) adequate nutritional status (no risk) (height-for-age > −1 SD and weight-for-height ≥ 0 SD of NCHS standards) or at-risk (height-for-age ≤ −1 SD and weight-for-height ≤ −0.5 SD), *4*) no signs of poor vision, delay in neuromotor development, or seizures, and no history of reactive hypoglycemia, and *5*) a score of one or two on the sexual maturation scale (17), to avoid the possible confounding effect of puberty.

As with the first two experiments, experiment 3 used the subjects as their own controls. The procedures in experiment 3 closely followed the same protocol as the others but with small variations in the motor activity schedule.

Breakfast consisted of a small cake (80 g) and a beverage similar in taste and color to milk (50 g) (Amilac; Instituto de Investigación Nutricional, Lima, Peru). The nutritional content of the breakfast provided, for an average primary school child (aged 5–10 y), 30% of energy requirements as defined by the World Health Organization (18), 60% of dietary allowances for minerals and vitamins, and 100% of iron. A diet soda without

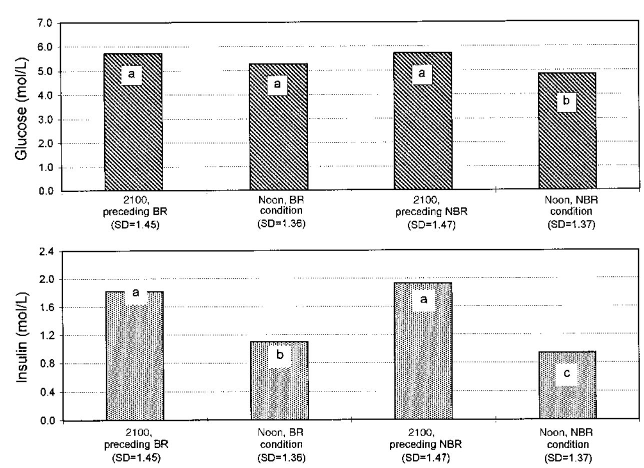

FIGURE 2. Mean glucose and insulin concentrations for both breakfast (BR) and no breakfast (NBR) conditions determined at 2100 the preceding day and at 1200 on the day of treatment. Blocks with different letters are significantly different ($P < 0.05$) from each other.

TABLE 2

Outcomes of expected and observed recall in visual memory and working memory: summary of findings of three experiments involving school-age children with and without nutritional risk[1]

	Visual attention				Working memory			
	MFFT[2]		STD[3]		HCIT[4]		SMST[5]	
	Correct	Time	Correct	Time	Incidental correct	Central correct	Time	Slope
	(n)	*(s)*	*(n)*	*(s)*	*(n)*		*(s)*	
Expected Results	B > NB	NB > B	B > NB	NB > B	NB > B	B > NB	NB > B	B = NB
Experiment 1 (2), *n* = 32	B[6] > NB[7]	NB = B			NB > B[7]	NB > B[8]		
Experiment 2 (3), *n* = 39	B > NB[7]	NB = B			NB > B[7]	NB = B		
Experiment 3 (4)								
Nutritionally at-risk, *n* = 23			NB = B	NB < B			NB = B	NB = B
Nutritionally adequate, *n* = 29			NB = B	NB > B[7]			NB > B[7]	NB = B

[1] B, breakfast treatment; HCIT, Hagen's Central Incidental Test; MFFT, Matching Familiar Figure Test; NB, no breakfast treatment; SDT, Stimulus Discrimination Test; SMST, Sternberg Memory Search Test.

[2] Outcomes are number of errors and response time.

[3] Part of the Cognitive Abilities Tests developed by Detterman (20). Outcomes are number of errors and decision time.

[4] Outcomes include scores for correct recall of incidental and central stimuli.

[5] The two main outcomes are intercept and coefficient of slope of decision time on block size. Intercept is a measure of scanning time, and slope reflects the temporal increment from block to block.

[6] The effects of the treatment were modified by IQ. Among those with an IQ below the median of the respective distributions, the number of correct responses was higher under the BR than under the NBR condition.

[7] Predicted results were observed.

[8] The direction of the difference does not refer to the total central recall score. The difference in favor of the NBR condition was restricted to the last item in the card series, indicating a stronger recency effect for NBR.

caffeine was used as a placebo for the NBR subjects. For glucose determinations, blood samples were taken at 1130 after the two treatments.

The battery of psychologic tests included three paper-and-pencil tests [number discrimination, PPVT, and the Raven Progressive Matrices (19)] and three computerized tests [Simple Reaction Time, Stimulus Discrimination (SDT), and Sternberg Memory Search Test (SMST)], which are included in the Cognitive Abilities Test battery developed by Detterman (20). The SDT and SMST discriminated between treatments and are described below in greater detail.

The SMST requires the subject to memorize one or more stimuli per trial and decide whether a new stimulus is present or absent (144 trials). According to the size of the ensemble (up to four stimuli), the trials are classified into blocks. Theory predicts that increments in the size of the ensemble predict time increments from one decision to the next. Thus, the outcome of the test is measured in speed rather than retrieval errors. In particular, the outcomes include the intercept and the slope of the regressions of decision time on block size (separately for new stimulus present or absent).

The SDT task was to select a match for one geometric stimulus out of six possible choices. The subject had to correctly score 72 trials by the end of the test. Outcomes were decision time, movement time, and number of errors.

Results

Performance on the SMST was adversely affected by the NBR treatment among the at-risk children; their speed in scanning memory was comparatively slower than that of the BR group after the overnight and morning fast. However, the at-risk subjects showed no treatment differences in increments of decision time as a function of block size, and the intercept generated from the differences between treatment conditions was significantly different from zero. Performance on the SDT test was also affected among the nutritionally at-risk subjects; decision time was shorter on the day they ate breakfast than on the day they fasted.

In contrast to experiments 1 and 2, the treatment in experiment 3 had no detrimental effects on cognition among the well-nourished children; contrary to expectations, the scores in the SDT and PPVT were better ($P < 0.05$) after NBR than after BR.

Comparisons among experiments

The expected and observed results of the three experiments are compared in **Table 2**. The four tests of cognition have been classified into visual attention and working memory, whereas the PPVT, Raven Progressive Matrices and Slossum Intelligence Scale have been excluded. The analysis is therefore restricted to 16 comparisons (slope; *see* Table 2). Eight of the comparisons followed the expected direction, whereas two yielded unexpected results. Contrary to predictions, the subjects in experiment 1 showed a higher recency effect after NBR than after BR, and the subjects without nutritional risk in experiment 3 were comparatively quicker after NBR on the SDT. Finally, six comparisons showed no directional effects.

DISCUSSION

The overnight and morning fast induced in the three experiments did not result in a blood glucose concentration associated with clinical symptoms of low blood glucose. However, the intraindividual changes in lactate, BHB, and fatty acid concentrations observed in experiment 1 suggest that the extended fast was stressful. It was associated with a negative correlation between glucose and BHB ($r = -0.29$, $P = 0.05$) and a positive correlation ($r = 0.78$, $P < 0.01$) between BHB and lactate and between BHB and fatty acid ($r = 0.36$, $P < 0.05$). None of these correlations was observed on the day the subjects ate breakfast.

The pattern of correlations in the fasting state is consistent with a relative elevation in adrenal corticosteroid and catecholamine and a relative drop in plasma insulin concentrations in those children with the lowest blood glucose concentrations.

In the discussion of the report in experiment 1, Pollitt et al (2) proposed that the elevation in fatty acid and BHB concentrations reflected a shift toward an alternative fuel source (fat) to compensate for reduced availability of carbohydrates (hepatic glycogen). The quantitative aspects of the metabolic profile suggest that fasting had, relative to the BR condition, diminished plasma insulin concentrations and elevated plasma cortisol and catecholamine concentrations. In agreement with this suggestion, experiment 1 showed that the subjects' insulin concentrations on the day of fasting were significantly lower than those on the day of breakfast consumption.

Briefly, the combination of elevated catecholamine and corticosteroid and reduced insulin reflects a state of stress that is either causally related to, or associated with, other metabolic changes that account for the alterations observed in attention and memory. It remains to be determined whether the metabolic changes observed in well-nourished US children are similar to or more severe than those in nutritionally at-risk children, such as the subjects in experiment 3. Of anecdotal importance is that, in experiment 3, glucose was not associated with performance on any of the administered cognitive tests. This lack of consistency in the relation between glucose and performance in the three experiments also places into question the validity of the metabolic explanation for the observed effects. But the results of the SMST for the nutritionally at-risk children in Peru also suggest that metabolic changes mediate the effects of fasting on cognition. Sternberg (21) determined that the rate of scanning from working memory is higher than that for covert speech and, on this basis, concluded that memory search is not conscious. Whereas we did not try to replicate this finding, informal observations of the speed of test responses suggest that the children in Peru were not aware of the scanning process.

At least two factors justify the conclusion that attentional processes are particularly vulnerable to the metabolic changes induced by fasting. First, the subjects' performances on the MFFT in experiments 1 and 2 were better on the day they had breakfast, and their incidental scores were higher on the day of fasting. In the third experiment, fasting delayed the subjects' responses on the SDT. In each of these three tests (HCIT, MFFT, and SDT) performance depends in part on the selection of visual information. Secondly, the increased recall time for incidental stimuli in the HCIT in the first two studies showed that an extended fast led to poor discrimination between meaningful and irrelevant cues to the task at hand.

Experiment 3 showed that recall in the SMST was delayed in the fasting state. Other investigators have also shown that working memory is sensitive to fasting (22) and that the administration of glucose benefits memory function (23). However, as noted, we found no evidence of an association between glucose concentration and memory function.

Experiment 3 found that nutritionally at-risk children were more vulnerable to the adverse effects of fasting than well-nourished children. This finding concurs with a previous report on the poor performance of malnourished schoolchildren on a working memory test in Jamaica (24). The data from our experiment agreed with those of the Jamaican study in the absence of effects of fasting among well-nourished children. Future studies are called for to determine the moderating role of nutrition status in the relation between fasting and cognition.

In the United States, the children participating in experiments 1 and 2 were probably representative of their peers at the schools they attended in Cambridge, MA, and Houston, respectively. This was not true for the children of Huaraz, where we had difficulty finding children who met the anthropometric criteria of no nutritional risk. The no-risk children were thus rather atypical. We would have to learn their sociopsychologic, medical, and nutritional history to better understand their resilience to the effects of fasting.

In our comparative analysis of the three experiments, the data suggest, although inconclusively, that an overnight and morning fast among schoolchildren has adverse effects on attention and memory processes—effects that may be mediated by metabolic changes in plasma glucose regulation in the brain.

REFERENCES

1. Pollitt E. Does breakfast make a difference in school? J Am Diet Assoc 1995;95:1134–9.
2. Pollitt E, Leibel RL, Greenfield D. Brief fasting, stress, and cognition. Am J Clin Nutr 1981;34:1526–33.
3. Pollitt E, Lewis NL, Garza C, Shulman RJ. Fasting and cognitive function. J Psychiatr Res 1982–83;7:169–74.
4. Cueto S, Jacoby E, Pollitt E. Breakfast prevents delays of attention and memory functions among growth-retarded children. J Appl Dev Psychol (in press).
5. Jacoby E, Cueto S, Pollitt E. Benefits of a school breakfast program among Andean children in Huaraz, Peru. Food Nutr Bull 1996;17:54–64.
6. Pollitt E, Jacoby E, Cueto S. Desayuno Escolar y Rendimiento: a propósito del Programa de Desayunos Escolares de Foncodes en el Perú. (School breakfast and performance: reference to the National Breakfast Program funded by the Fund for Compensation and Social Security of the Peruvian Government.) Lima, Perú: Apoyo Comunicaciones SA, 1996 (in Spanish).
7. National Center for Health Statistics, Centers for Disease Control. NCHS growth curves for children, birth-18 years. Washington, DC: US Government Printing Office, 1978. [Series 11, 165. DHEW publication (PHS) 78 1650].
8. Kagan J, Rosman BL, Day D, Albert J, Phillips W. Information processing in the child: significance of analytic and reflective attitudes. Psychol Monogr 1964;78:578–89.
9. Hagen JW. The effect of distraction on selective attention. Child Dev 1967;38:685–93.
10. Haskins R, McKinney JD. Relative effects of response tempo and accuracy on problem solving and academic achievement. Child Dev 1976;47:690–701.
11. Dusek JB, Mergler NL, Kermis MD. Attention, encoding, and information processing in low- and high-test anxious children. Child Dev 1976;47:201.
12. Iowa Test of Basic Skills. Iowa test of basic skills. Itaska, IL: Riverside Publishing, 1995.
13. Hagen JW, Stanovich KE. Memory: strategies of acquisition. In: Kail RV, Hagen JW, eds. Perspectives on the development of memory and cognition. New York: Lawrence Erlbaum, 1978:89.
14. Peabody Picture Vocabulary. Peabody picture vocabulary test, revised. Circle Pines, MN: Dunn & Dunn, 1981.
15. Slossum, RL. Slossum Intelligence Test for children and adults. New York: Slossum Education Publications, 1963.
16. Waber DP. Cognitive abilities and sex-related variations in the maturation of cerebral cortical functions. In: Wittig MA, Peterson AC, eds. Sex-related differences in cognitive functioning. New York: Academic Press, 1979.

17. Tanner JM. Growth and adolescence. 2nd ed. Oxford, United Kingdom: Blackwell Scientific Publications, 1962.
18. World Health Organization. Energy and protein requirements: report of a joint FAO/WHO/UNU expert consultation. Geneva: Bull World Health Organ Tech Rep Ser 1985; 724.
19. Raven JC. Guide to using standard progressive matrices. London: Lewis, 1960.
20. Detterman DK. Cognitive abilities test. Cleveland: Case Western Reserve University, 1988.
21. Sternberg S. Memory scanning: new findings and current controversies. Q J Exp Psychol 1975;27:1–32.
22. Benton D, Parker PY. Breakfast, blood glucose, and cognition. Am J Clin Nutr 1998:67(suppl);772S–778S.
23. Korol DL, Gold P. Glucose, memory, and aging. Am J Clin Nutr 1998:67(suppl);764S–71S.
24. Simeon DT, Grantham-McGregor S. Effects of missing breakfast on the cognitive functions of school children of differing nutritional status. Am J Clin Nutr 1989;49:646–53.