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A systematic review of the effect of breakfast on the cognitive performance of children and adolescents

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Breakfast is recommended as part of a healthy diet because it is associated with healthier macro- and micronutrient intakes, BMI and lifestyle. Breakfast is also widely promoted to improve cognitive function and academic performance, leading to the provision of breakfast initiatives by public health bodies. Despite this positive and intuitive perception of cognitive benefits, there has been no systematic review of the evidence. Systematic review methodology was employed to evaluate the effects of breakfast on cognitive performance in well-nourished children and nutritionally at-risk or stunted children. Acute experimental studies, school feeding programmes and studies of habitual breakfast intake are reviewed. Comparisons of breakfast *v.* no breakfast and breakfasts differing in energy and macronutrient composition are discussed. Included are forty-five studies described in forty-one papers published between 1950 and 2008. The evidence indicates that breakfast consumption is more beneficial than skipping breakfast, but this effect is more apparent in children whose nutritional status is compromised. There is a lack of research comparing breakfast type, precluding recommendations for the size and composition of an optimal breakfast for children's cognitive function. Few studies examined adolescents. Studies of school breakfast programmes suggest that such interventions can have positive effects on academic performance, but this may be in part explained by the increased school attendance that programmes encourage. The present systematic review considers methodological issues in this field and makes recommendations for future research design and policy priorities.

Breakfast: Cognition: Children: Adolescents: Learning

Introduction

Breakfast consumers tend to have higher micronutrient intakes, partly because of the fortification of breakfast cereals, and a better macronutrient profile than breakfast skippers[1]. Regular breakfast cereal consumers have healthier body weights but also tend to engage in healthier lifestyle behaviours than those who skip breakfast[2]. Similarly, children who regularly eat breakfast tend to have a lower BMI and are less likely to be overweight than those who eat breakfast less frequently[3]. Studies in children suggest that breakfast eaters are more likely to meet daily nutrient intake guidelines compared with children who eat breakfast infrequently or skip breakfast[4]. Despite this, breakfast skipping increased in the USA from 14 % to 25 % between 1965 and 1991[5]. Moreover, the percentage of children eating breakfast in the UK has declined along with the nutrient quality of breakfast foods selected[6], with implications for nutrient status and energy intake.

A good deal of research has considered the importance of breakfast consumption for cognitive performance[7]. Much of this research has been undertaken in healthy young adults, particularly undergraduate students. The premise that acute interventions can enhance mental performance in this population, in whom cognitive function is well protected, is now being reconsidered[8]. Increasingly, interest has turned towards groups who may be more vulnerable to nutritional deficits or cognitive impairment, for example, children and the elderly[9].

Breakfast consumption, as with other meals, provides fuel for preferential oxidation of glucose. In children aged between 3 and 11 years, the brain has been shown to account for more than 50 % of body oxygen consumption[10]. Children have a higher ratio of brain weight to liver weight (1·4–1·6 *v.* 0·73 in adults) and a 50 % greater metabolic rate per unit brain weight. Thus children exert greater demands on glycogen stores during overnight fasts which are often longer than in adults. The child's relatively small muscle mass, in turn, limits the availability of glucogenic amino acids for hepatic gluconeogenesis[10]. Average global cerebral blood flow and O_2 utilisation are 1·8 and 1·3 times higher in children than adults, respectively[11]. Positron emission tomography studies of thirty children, aged 0–18 years, demonstrate that

Abbreviations: GI, glycaemic index; GL, glycaemic load.

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the higher cerebral metabolic rate of glucose utilisation gradually declines from the age of 10 years, stabilising at age 16–18 years[12,13]. The higher metabolic turnover of children, their rapid growth rates and the importance of their cognitive function for academic achievement underlie the need for optimal nutrition.

Previous reviews give mixed support for the effects of breakfast provision in experimental and school settings on cognitive or scholastic performance[14–16]. Pollitt & Mathews[17] concluded that there was no convincing evidence for '. . .either long or short term effects of breakfast on cognition and school learning. . .' (p. 804S). Common to these reviews is the inclusion of studies of variable scientific quality, the lack of a clear classification of effects across particular cognitive domains and the failure to identify confounds. These reviews have not systematically evaluated all available published studies selected on the basis of the quality of research design and do not acknowledge the very likely publication bias which results in publication of a greater proportion of studies with positive findings.

Two recent publications have systematically reviewed the effect of nutritional interventions, including school feeding programmes, on physical development, school attendance and performance. One considered a range of nutritional interventions, including breakfast, sugar intake on attention deficit–hyperactivity disorder, and fish oil supplementation[18], concluding that there was insufficient evidence to identify any effect of nutrition on learning of children from the developed world. In contrast, a Cochrane review of school meal provision to disadvantaged children suggested some small benefits for physical and psychosocial health[19]. Although the application of systematic review methodology to children's nutrition is timely and desirable[20], there has not been a focused systematic review to evaluate the cognitive effects of breakfast in children. Such a review would inform government initiatives in the UK, the USA and elsewhere which aim to improve the diet of children with positive consequences for cognitive function.

The aim of the present review, therefore, was to provide a systematic examination of the best evidence from controlled studies of the effects of breakfast on the cognitive performance of school-aged children. The review examines whether the effects of breakfast on cognitive performance are consistent across populations of differing nutritional status with the aim of evaluating whether breakfast interventions can have an impact on the cognitive performance of well-nourished children in the developed world as well as those of or at risk of poor nutritional status. A further aim was to identify the nature of the breakfast which was associated with the clearest positive effects on cognitive function. Nutritional parameters which could account for breakfast effects on cognition include the macronutrient composition, energy provision and glycaemic properties of the breakfast meal.

Literature search

Search strategy and search terms

Electronic databases were searched on 20 January 2009. The databases queried were MedLine (1950 to January 2009), PsycInfo (1967 to January 2009) and Web of Science (1955 to January 2009). Table 1 provides the search strings used as text words and keywords in each database. Additional search strategies involved scanning reference lists of review articles identified. This yielded three further articles. Following removal of duplicates (*n* 253), 350 citations were retrieved for possible inclusion in the present review.

Inclusion and exclusion criteria

Papers were included or excluded according to the following criteria.

Participants. Studies of children or adolescents (aged 4–18 years) of either sex were included. Studies were excluded if they examined adult, elderly or patient samples.

Manipulations. Any type of breakfast manipulation, including studies comparing breakfast with no breakfast, and studies of different breakfast types were included. Studies of the effects of glucose ingestion or of intake at other mealtimes were excluded. Breakfast was defined according to the descriptions of the meals or foods consumed provided in the papers reviewed. These varied but generally considered breakfast to be the first food consumed that day although this was not the case for some interventions where prior intake was not controlled. Studies were not excluded on the basis of the content of the meal; for example, studies that included interventions using drinks and/or snacks were included.

Outcome measures. Studies including any standardised outcome measures of cognitive performance were included. Studies solely examining fatigue or employing only qualitative measures of cognitive performance were excluded. Studies involving teachers' subjective ratings of

Table 1. Search terms

	Search string*
1	Breakfast AND (children OR adolescents) AND cogniti$
2	Breakfast AND (children OR adolescents) AND memory
3	Breakfast AND (children OR adolescents) AND attention
4	Breakfast AND (children OR adolescents) AND vigilance
5	Breakfast AND (children OR adolescents) AND reaction time
6	Breakfast AND (children OR adolescents) AND spatial
7	Breakfast AND (children OR adolescents) AND visuo-spatial
8	Breakfast AND (children OR adolescents) AND psychomotor
9	Breakfast AND (children OR adolescents) AND tracking
10	Breakfast AND (children OR adolescents) AND problem solving
11	Breakfast AND (children OR adolescents) AND logic
12	Breakfast AND (children OR adolescents) AND reasoning
13	Breakfast AND (children OR adolescents) AND recall
14	Carbohydrate AND (children OR adolescents) AND cogniti$
15	Glucose AND (children OR adolescents) AND cogniti$
16	Breakfast AND (children OR adolescents) AND cogniti$ AND school
17	Breakfast AND (children OR adolescents) AND cogniti$ AND program

* $ denotes word truncation.

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performance were excluded since these do not provide an objective measure of cognitive function. Acute (where performance was assessed within 12 h of breakfast consumption) and habitual effects of breakfast manipulations (for example, school breakfast programmes) were included.

Study selection process

Figure 1 details the study selection process and the number of papers retrieved and excluded at each stage. Of the 350 studies retrieved, 300 exclusions were made, most commonly because the studies examined adult or elderly samples; assessed breakfast programme delivery or efficiency only; measured breakfast behaviours only; took measures of appetite only. Also excluded were nine review papers. Some papers contained multiple studies[21–24]. Therefore, forty-one articles were extracted providing forty-five studies for review.

Each study appears in the data tables only once, irrespective of whether the data were reported in more than one paper (Grantham-McGregor[15] was also reported in Chandler *et al.* [25]; Pollitt *et al.* [23] Study 1 was also reported in Pollitt *et al.* [26]; Simeon & Grantham-McGregor[27] was also reported in Simeon & Grantham-McGregor[28] and Simeon[29] Study 2).

Tabulation of studies

Tables 2–5 were produced to summarise the main characteristics of each study. The studies were categorised according to the intervention duration (acute, long term or habitual) and the study participants (well nourished or of differing nutritional status). Representation by sex and age range as well as mean and SD and were included if details were provided. The study design was classified as repeated

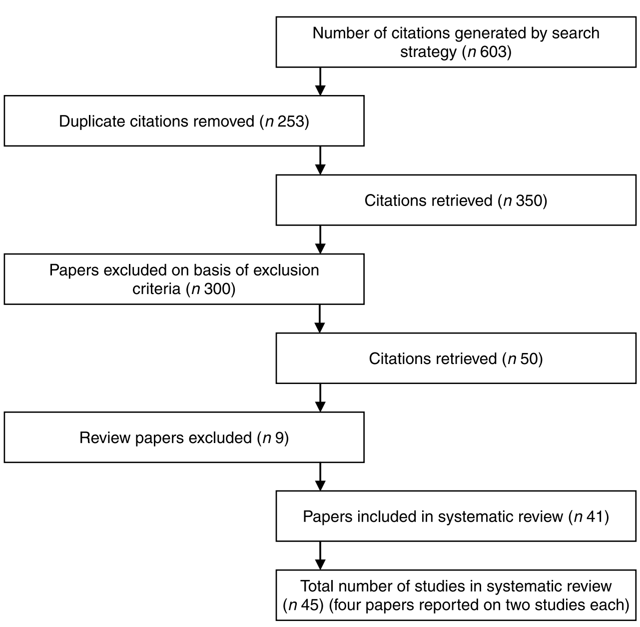

Fig. 1. Flow diagram of the study selection process.

measures (where participants received each intervention) or independent groups (where participants were assigned to receive one intervention arm only). Randomisation, counterbalancing or cross-over strategies were noted if sufficient detail was evident to confirm that these experimental controls were employed. The duration of the test battery and the time post-breakfast consumption of administration were included in the tables if these could be determined. Explicitly stated fasting periods were recorded.

Cognitive tests were listed with their respective outcome measures (dependent variables) if specified. The cognitive domain assessed by each test is provided where description of the test features was sufficiently detailed.

Where enough detail was provided, the energy content of the breakfasts was calculated from the macronutrient composition of the interventions. The statistical analysis performed on the data by each study is also provided. The comments provided for each study in the tables consider study quality in terms of design, analysis and conclusions drawn and indicate the sponsor or funding body where provided.

Quality assessment

Each study was rated for quality using pre-defined assessment criteria by two of the authors independently. The inter-rater correlation for ratings was r 0·85 and discrepancies were discussed as a panel with the third author to reach consensus. Validated tools for the assessment of clinical trials (for example, Jadad *et al.* [30]) do not lend themselves to the design features and experimental manipulations or comparisons made by breakfast studies. Therefore, we devised an eighteen-item tool which covered key elements of study aims and design, sample selection, breakfast manipulation, controls, analysis and outcomes (see Appendix). This tool was based on others developed to assess barriers to healthy eating in children[31] and parental decision making for child health[32]. All criteria were equally weighted and a score of 1 was obtained if the criterion was satisfied. Quality assessment (QA) ratings appear in Tables 2–5 next to each study reference. Due to insufficient details, five studies could not be assigned a QA rating (see Tables 2–5). We chose not to exclude studies on the basis of quality threshold because there was a limited number of studies in some categories and a large variation in the adequacy of descriptions provided. Hence we provide a quality assessment critique for each type of study.

Results

Studies are grouped into four categories according to the type of investigation undertaken. Of the forty-five studies, twenty-eight were examinations of the acute effects of breakfast *v.* no breakfast or breakfast type on cognitive performance. This is broken down into studies in well-nourished children (*n* 21) and in children of differing nutritional status (*n* 7). Of the studies, thirteen examined the long-term effects of school breakfast programmes and breakfast clubs on cognitive performance. Lastly, four studies examined the effect of the quality of habitual breakfast intake on cognitive

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Table 2. Acute experimental intervention studies in well-nourished children (twenty-one studies, reported in nineteen papers)

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
Benton *et al.* (2007)[41]	11	Nineteen lower-SES school children (nine male, ten female), mean age 6 years 10 months, age range 5 years 11 months to 7 years 8 months	UK	4-week school BF club. Unbalanced RM with three breakfasts designed to be equi-energetic (a) High GL: cornflakes, semi-skimmed milk, sugar, waffle, maple syrup. Mean 820 (SD 335) kJ (b) Medium GL: scrambled egg, bread, jam, low-fat spread, low-energy yogurt. Mean 703 (SD 159) kJ (c) Low GL: ham, cheese, soya and linseed bread, low-fat spread. Mean 657 (SD 439) kJ Amount offered more than consumed BF at 08.15 until 08.45 hours, blind testing at 10.35 until 11.45 hours	Memory (I&D): British Ability Scale object recall (verbal) Object location recall (spatial) Sustained attention: Shakow paradigm: respond to light stimulus with auditory warning 3 s or 12 s prior	ANOVA: no effect on memory or attention Correlations: GL inversely related to immediate (not delayed) memory. GL had effect on attention under specific conditions (improved on 2nd test with 12 s warning)	Breakfasts differed significantly in macronutrient content. Large intake variability Design unbalanced. Independence assumption not met, degrees of freedom do not concur with design High risk of type 1 error in multiple correlational analyses BBC
Busch *et al.* (2002)[34]	16	Twenty-one boys aged 9–12 years, normal weight. No: medication, learning disability, dietary restrictions	USA	Counterbalanced cross-over with two BF conditions: (a) 25 g confectionery snack (mainly simple CHO) (b) Half cup aspartame drink matched for sweetness 1-week washout 45 min CT battery at + 15 min post-BF	Attention: CPT Memory: Map task (spatial) Story recall (verbal) Digit span (working) Visual perception: Rey Complex Figure Copy	Attention: better after snack than drink. Snack decreased number of false alarms and prevented increase in misses with time on task No effects on other tests	Monetary incentive to parents Mars Inc.
Connors & Blouin (1983)[14]	8	Ten children aged 9–11 years	USA	RM with BF (milk, cereal with sugar, egg, juice and toast) and no-BF conditions Each condition administered twice after 12 h fast 30 min CT battery at 09.50, 11.00 and 12.10 hours	CPT Arithmetic test EEG visual evoked potentials test	CPT: fewer errors and less variability after BF Arithmetic: better performance mid-morning after BF EEG: BF reduced cardiac acceleration and amplitude of evoked potentials	EEG effects suggest BF may influence neural processes mediating performance
Cromer *et al.* (1990)[37]	17	Thirty-four middle-class, suburban high school children, overall mean age 14·2 (SD 0·4) years	USA	IG	Memory:	No effect of BF condition on cognition	Monetary incentive to participants

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
		School BF group: eighteen children (eleven female, seven male), mean IQ 102 Low-energy control group: sixteen children (nine female, seven male), mean IQ 108		In-patient stay with self-selected evening meal at 19.00 hours and blood sampling at 21.00, 06.00, 08.00 and 11.00 hours BF at 07.00 hours: (a) School BF: 2 oz doughnut, 8 oz chocolate milk, 4 oz orange juice (1774 kJ: 63·9 g CHO, 11·5 g protein, 14·1 g fat) (b) Low-energy control BF: 8 oz sugar-free powdered drink; half cup sugar-free gelatine (50 kJ: 1 g CHO, 1·6 g protein, trace fat) CT at + 60 min and + 240 min after BF Peabody Picture Vocabulary task used to screen for IQ	RAVLT Visual perception: MFFT Attention: CPT	No difference in BF blood glucose profiles	National Institutes of Health, USA
Dickie & Bender (1982) Study 1[21]	10	487 mixed SES comprehensive school children Two age groups: (a) 227 children, mean age 12·5 years (b) 260 children, mean age 15·3 years	UK (London)	IG with four conditions: 1. BF + snack 2. BF 3. No BF + snack 4. No BF Own food consumed BF = solid food before school Snack = food/drink at break time Repeated 1 week later with proportion of sample CT pre- and post-lunch	Letter cancellation test (visual acuity, attentiveness, vigilance)	No effects	Cognitive test measurement confounded by lunch consumption Problematic one-way Kruskal–Wallis with four groups of unequal size Kellogg Co., UK
Dickie & Bender (1982) Study 2[21]	12	108 children from four boarding schools, SES unknown Investigation 1: fifty-five children, mean age 17 years Investigation 2: fifty-three children, mean age 16·2 years	UK	IG with two conditions: (a) BF week 1 and BF week 2 (b) BF week 1 and no BF week 2 BF = usual BF (about 2000 kJ) served by school at 07.45 hours 20 min CT battery at about 11.00 hours on three consecutive days of 2 weeks	Investigation 1: MAST (visual search) Simple addition Investigation 2: Sentence verification	Performance poorer on MAST(6) in experimental group on 1 d in the no-BF condition Overall, little evidence of association of BF omission and poorer performance	No counter-balancing Inappropriate statistical analysis – *t* tests or Mann Whitney *U* tests on each three test days Risk of type 1 errors Kellogg Co., UK

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
Ingwersen *et al.* (2007)[39]	15	Sixty-four children in three age groups: (1) Eighteen children (ten female, eight male), aged 7 years (range 6 years 3 months to 7 years 11 months), mean BMI 15·9 kg/m^2 (2) Twenty-three children (ten female, thirteen male), aged 9 years (range 8 years 2 months to 9 years 11 months), mean BMI 17·9 kg/m^2 (3) Twenty-three children (eighteen female, five male), aged 11 years (range 10 years 0 months to eleven years 7 months), mean BMI 18·7 kg/m^2	UK	RM counterbalanced with two conditions on consecutive days: (a) High-GI BF: Coco Pops (35 g) + 125 ml semi-skimmed milk (b) Low-GI BF: All Bran (35 g) + 125 ml semi-skimmed milk 25 min CT battery at + 10 min, +70 min and + 130 min post-BF	Word recall (I&D) SRT CRT Digit vigilance Spatial memory Numeric memory Word recognition Picture recognition	Accuracy of attention factor: performance poorer at + 130 min after high-GI BF Secondary memory factor: attenuation of decline in performance after low-GI BF at + 10 min and + 130 min but not + 70 min No effect of BF on other factors: speed of attention, working memory or speed of memory	Breakfasts differed in energy content. Analysis based on change from baseline Scores on previously derived factors used as outcomes. Individual tests not reported Cambridge Laboratories, UK
Ma *et al.* (1999)[65]	np	151 children, grade 3, aged about 7 years	China	Random allocation to two conditions on each of five consecutive days: (a) High-energy BF (b) Low-energy BF CT on days 2–5 in late morning	Addition Multiplication Number checking Logic Creativity	No effect of energy intake at BF	No analysis strategy stated
Mahoney *et al.* (2005) Expt 1[22]	16	Thirty children, fifteen male aged 9–11 years, fifteen female aged 9–11 years; mean BMI 21 kg/m^2, range 14·7–38 kg/m^2; no learning disability; middle-class SES; private elementary school	USA	RM counterbalanced with three conditions: (a) Oatmeal cereal (43 g), half cup skimmed milk – 837 kJ (38 g CHO, 19 g sugars) (b) RTE cereal (36 g) + half cup skimmed milk – 753 kJ (36 g CHO, 22 g sugars) (c) No BF Blind CT testing at + 60 min post-BF Tested four times (once per week) with preferred BF repeated on test day 4	Memory: Map task (spatial) I&D Digit span – forwards and backwards (working) Story recall (verbal) Visual perception: Rey Complex Figure – copy and recall Attention: CPT visual CPT auditory	Map: better immediate recall after oatmeal than no BF Backward digit span: girls performed better after oatmeal than RTE or no BF. No effect in boys Rey: copy accuracy better after oatmeal and RTE than no BF CPT auditory: fewer false alarms after oatmeal and RTE than no BF No effect on story recall and CPT visual	Monetary incentive to parents Breakfasts differ in energy – oatmeal 84 kJ more than RTE (wrongly calculated in paper)

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
Mahoney *et al.* (2005) Expt 2[22]	16	Thirty children of middle-class SES with no learning difficulties from a private elementary school, fifteen male (aged 6–8 years), fifteen female (aged 6–8 years), mean BMI 17·7 (range 10·8–31) kg/m^2	USA	As Mahoney *et al.* (2005) Expt 1[22]	As Expt 1 with modifications for age of participants	Map: better immediate recall after oatmeal than no BF Backward digit span: girls better after oatmeal than RTE or no BF. No effect in boys Rey: boys better after RTE than no BF. Girls better after no BF than RTE CPT auditory: better hit rate for oatmeal than RTE. Better miss rate for oatmeal than RTE No effect on story recall and CPT visual	Monetary incentive to parents Same size BF administered to both age groups in Expts 1 and 2 Sponsor not stated, authors affiliated to Quaker Oats Co., USA
Marquez Acosta *et al.* (2001)[66]	np	Sixty-eight private school children aged 9–10 years	Venezuela	RM with BF and no-BF conditions (no details of intake)	Raven's logical reasoning Lepez (attention)	BF consumption improved logical reasoning	No analysis strategy stated
Michaud *et al.* (1991)[67]	12	319 subjects, aged 13–20 years; 150 male, mean age 16·1 (SD 1·3) years; 169 female, mean age 15·9 (SD 1·3) years	France	RM cluster randomised cross-over Day 1: usual BF (kJ unknown) Day 14: more energy than usual BF, stratified by amount extra consumed: 1. 0–416 kJ 2. 417–834 kJ 3. 835–1253 kJ 4. 1255–1670 kJ 5. 1671 + kJ BF taken at home 10 min CT battery at 11.00 hours Glucose measured at 11.30 hours	Short-term spatial memory Visual word search	Memory performance improved on day 14 Visual search performance decreased on day 14 No effect of BF size on memory or visual search	No counterbalancing of BF conditions but 35 % ate more at day 1 than day 14 so test days reversed Diététique et Santé S.A., St Hubert S.A. and Sopad Nestlé
Morrell & Atkinson (1977)[68]	np	Fifty-two children aged 4–11 years enrolled in free SBP for 20 d	USA	IG, random allocation to: (a) Usual school BF: cereal or bread and half a pint of milk (11 g protein, high sugar content), or (b) high-protein–low-CHO BF (about 24 g protein) CT pre- and post-BF in late morning	Digit span	No effect of BF	

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
Morris & Sarll (2001)[69]	14	Eighty A level students (thirty-six female, forty-four male), mean age 21·2 (SD 4·4) years, minimum age 17 years	UK	IG, blind, random allocation to: (a) 300 ml orange juice (50 g glucose in 250 ml water, 40 ml orange squash + 10 ml lemon juice), or (b) 300 ml orange juice (2 g Sweetex in 250 ml water, 40 ml orange squash + 10 ml lemon juice) Matched drinks CT immediately before and + 20 min after drink	Daneman–Carpenter listening span test (immediate recall)	Interaction of drink × time. Recall improved significantly after glucose drink	
Pollitt *et al.* (1981)[35]	16	Thirty-four children (twenty-two female, twelve male), mean age 10 years 4 months, age range 9–11 years, between 10 and 90 percentile for weight, mostly prepubertal, medical diagnosis of 'good health'	USA	RM counterbalanced in-patient stay with BF and no-BF conditions BF: waffles and syrup, margarine, orange juice, milk (2238 kJ, 15 g protein, 20 g fat, 75 g CHO) Standard evening meal at 17.00 hours, blood sample at 21.00 and 12.00 hours CT testing at + 180 min Peabody Picture Vocabulary task used to measure IQ	Visual perception: MFFT Attention: CPT – HCI task (sequential memory for objects)	MFFT: benefit of BF in lower IQ only. Decrease in glucose associated with more errors HCI: fewer errors after no BF but only for those whose blood glucose was lower in no-BF than in BF condition	Large energy intervention yet few effects on performance IQ median split used as factor in analysis Ford Foundation
Pollitt *et al.* (1982–3)[38]	14	Thirty-nine children (twenty female, nineteen male), mean age 10 years 4 months, age range 9–11 years, between 10 and 90 percentile for weight, mostly prepubertal, medical diagnosis of 'good health'	USA	RM counterbalanced in-patient stay with BF and no-BF conditions BF: waffles and syrup, margarine, orange juice, milk (1874 kJ, 12 g protein, 16 g fat, 65 g CHO) Standard evening meal at 17.00 hours, BF at 08.00 hours Blind CT testing at + 180 min Peabody Picture Vocabulary task used to measure IQ	Visual perception: MFFT Attention: HCI Short-term memory: Xylophone tapping Digit span	MFFT: more errors after no BF than BF on hard version only HCI: better recall after no BF than BF but IQ not included in analysis	IQ median split used as factor in analysis Data combined with Pollitt *et al.* (1981)[35] with no adjustment for differing BF sizes Ford Foundation

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
Pollitt *et al.* (1998)[26]	14	Thirty-two children (twenty-three female, nine male), aged 9–11 years, between 10 and 90 % percentile for weight, mostly prepubertal, medical diagnosis of 'good health'	USA	RM counterbalanced in-patient stay with BF (2238 kJ, 15 g protein, 20 g fat, 75 g CHO) and no-BF conditions Standard evening meal at 17.00 hours, BF at 08.00 hours Blind CT testing at +180 min Peabody Picture Vocabulary task used to measure IQ	Visual perception: MFFT Attention: HCI CPT	MFFT: poorer performance after no BF than BF in lower-IQ group only HCI: better recall in no BF than BF CPT: no effect	IQ median split used as factor in analysis
Vaisman *et al.* (1996)[36]	14	569 children (279 female, 290 male) from different SES, age range 11–13 years	Israel	Unbalanced IG Baseline: BF at home or no BF (fasted) 14 d chronic intervention: BF at school (two-thirds) or no BF instruction (one-third) BF: 30 g sugared cornflakes + 200 ml (3 % fat) milk CT testing + 120 min post-BF (BF at home) or + 30 min post-BF (BF at school)	Memory: RAVLT (I&D, recognition) Benton Visual Retention test (visuospatial) Wechsler Memory Scale revised – story (logical)	Baseline: better immediate verbal recall after BF. No differences on acquisition, delayed recognition and delayed recall factors Post-intervention: RVALT: better mean learning, best learning, retroactive inhibition and recognition for BF at school than BF at home and no BF. Better delayed recall and temporal order for BF at school than BF at home only Benton and Wechsler: better after BF at school than BF at home No differences on factors	Unbalanced design. Weighted means used to account for the unequal cell sizes. Dropout from each condition not reported No consideration of SES Secondary analysis: principal components to derive factors reflecting performance. Cross-sectional analysis difficult to separate from post-intervention analysis
Wesnes *et al.* (2003)[33]	14	Twenty-nine children of similar SES; fifteen female, mean age 12·3 years, age range 9–16 years; fourteen male, mean age 12·1 years, age range 9–16 years	UK	RM with four conditions over four consecutive days: (a) Shreddies (45 g) + semi-skimmed milk (125 ml): 854 kJ, 38·3 g CHO (25·2 g complex CHO, 6·9 g sucrose, 6·25 g lactose) (b) Cheerios (30 g) + semi-skimmed milk (125 ml): 686 kJ, 28·7 g CHO (16 g complex CHO, 6·4 g sucrose, 6·25 g lactose)	Word recall (I&D) SRT CRT Digit vigilance Spatial memory Numeric memory Word recognition Picture recognition	General pattern of performance decline after no BF across morning. Cereal breakfasts attenuated decline Factor-based analysis: cereal breakfasts better for power of attention and quality of episodic memory factors. Trends for other factors	Scores on previously derived factors used as outcomes No analysis of individual tests provided No differences between the cereal breakfasts Age not included as a covariate in analysis Monetary incentive to participants Cereal Partners, UK

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Table 2. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comments
				(c) Orange-flavoured drink (330 ml): 602 kJ, 38·3 g CHO (glucose) (d) No BF 25 min CT testing at +20, +80, +140, +200 min post-BF		Immediate word recall at 12.00 hours: No BF: −12 %; glucose: −27 %; Cheerios: +3 %; Shreddies: +5 % (relative to baseline)	
Widenhorn-Müller *et al.* (2008)[70]	15	104 children (fifty female, fifty-four male), aged 17·2 (SD 1·6) years, range 13–20 years; 88 % regular BF eaters (i.e. five or more times per week)	Germany	RM counterbalanced cross-over with 7 d wash-out (a) BF: 60 g wholewheat bread, 20 g butter, 20 g nougat spread, 30 g strawberry jam, *ad libitum* water and unsweetened peppermint tea (1992 kJ) (b) No BF BF at 07.30 hours. CT at +45 min post-BF Unbalanced design with respect to treatment order: 91 BF–no BF; 67 no BF–BF	Attention: d2 test (visual search) Memory: Object recall Trail route (spatial) Logos (picture recall) Turkish vocabulary (recognition) Telephone numbers (paired associate) Fact cued recall	d2: trend for improved concentration after BF but BF × order interaction Memory: positive effect of BF in males for trail task but presence of order effects and no significant effects on subtests No effects in females except trend for positive effect of BF in telephone number task with presence of order effect	For d2 task *n* 70 Separate analysis by sex Order of testing and unbalanced design make evaluation of effects of BF on multiple tests included difficult
Wyon *et al.* (1997)[71]	8	195 suburban school children aged 10 years	Sweden and Denmark	IG with ‘good’ and ‘bad’ BF conditions eaten at home (a) Good: high variety, good macronutrient balance. Selected from yoghurt/sour milk product, cereal, sandwiches with cheese or liver paste, orange juice, milk, tea or hot chocolate. Mean 2130 kJ (b) Bad: lacking in variety, low protein. Typically a sweet drink, bread, jam or sweetbread. Mean 840 kJ CT in late morning	Addition Multiplication Grammatical logic Number checking (visual search) Reading – speed and comprehension Word recognition Creativity	Better speed and fewer errors on creativity test after the ‘good’ BF	Various reports of these data with differing sample sizes and findings available Swedish National Dairy Association

QA, quality assessment; SES, socio-economic status; BF, breakfast; RM, repeated measures; GL, glycaemic load; I&D, immediate and delayed (memory); BBC, British Broadcasting Corporation; CHO, carbohydrate; CT, cognitive test(s); CPT, Continuous Performance Test; EEG, electro-encephalography; IG, independent groups; MFFT, Matched Familiar Figures Test; MAST, Memory and Search Test; GI, glycaemic index; SRT, simple reaction time; CRT, choice reaction time; np, quality assessment not possible; RTE, ready-to-eat; SBP, school breakfast programme; IQ, intelligence quotient; HCI, Hagen Central Incidental Task; RAVLT, Rey Auditory-Verbal Learning Test.

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Table 3. Acute experimental intervention studies in children with differing nutritional status (seven studies)

Reference	QA	Sample	Country	Design and intervention	Cognitive measure	Reported findings	Comment
Cueto *et al.* (1998)[72]	16	Fifty-four male subjects classified as: (1) At risk: < −1 SD NCHS height for age and < −0·5 SD weight for height (*n* 23) (2) Not at risk (*n* 31)	Peru	RM counterbalanced cross-over in-patient stay with two conditions: (a) BF: 80 g cake + 50 g protein drink (2134 kJ; 82 g CHO, 14 g protein, 12 g fat, 7·2 mg Fe, 240 µg vitamin A, 27 mg vitamin C) (b) No BF Standard evening meal (2510 kJ) BF at 08.00 hours CT at 11.00 hours. Blood glucose measured during testing	Number discrimination (visual search) Sternberg memory search (short-term memory) Peabody Picture Vocabulary Test (long-term memory and verbal ability) Raven's Progressive Matrices CRT Stimulus discrimination	Stimulus discrimination and Sternberg: slower decision time after no BF in at-risk group only	Order entered as covariate in analysis Participants received gifts for participating Kellogg's Co. and Government of Peru
Grantham-McGregor *et al.* (1998)[73] and Chandler *et al.* (1995)[74]	9	197 subjects classified as: (1) Undernourished (−1 SD below NCHS weight-for-age standard) (*n* 97) (2) Well-nourished (*n* 100) Groups matched on school, class and sex	Jamaica	RM counterbalanced cross-over with two conditions: (a) BF (at school, no details given) (b) Control (slice of orange) CT 2 weeks apart, shortly after BF	Visual search Digit span Categoric fluency Speed of decision making	Fluency: better after BF but only in undernourished group No effects on other tests	No details of composition or energy content of BF Nestlé Nutrition Support Grant
López *et al.* (1993)[42]	11	279 low-SES children (134 male, 145 female), mean age 10 years 3 months (SD 0·5 years); classified as normal (*n* 106), wasted (*n* 73) or stunted (*n* 100)	Chile	IG with two conditions: (a) BF: two cakes, 200 ml flavoured milk (1648 kJ, 6 g protein) (b) No BF 24 min CT at + 60 min post-BF	Digit span Domino test (problem solving) Attention test	No effect of treatment Stunted children made more errors than normal or wasted children on attention test	ANCOVA performed with IQ, SES, food intake on previous day and glycaemia level as covariates Nestlé Nutrition and Ministry of Education, Chile
Muthayya *et al.* (2007)[75]	16	Seventy-three children of different SES: (1) Thirty-four low SES (nineteen female, fifteen male), mean age 7·6 (SD 0·6) years. 32 % wasted, 21 % stunted (2) Thirty-five high SES (thirteen female, twenty-two male), mean age 7·6 (SD 1·1) years	India	RM counterbalanced, three equi-energetic conditions with 1-week washout (3515 kJ total): (A) Small BF (782 kJ), snack (640 kJ), standard lunch (2092 kJ) (B) Standard BF (1423 kJ), snack, small lunch (1452 kJ) (C) Control: standard BF, no snack, standard lunch BF: chapatti and potato curry	Memory: Picture recognition (I&D) Attention: CPT Psychomotor: Finger tapping	Low SES: better immediate recognition after condition B than control at + 150 min. Condition B slowed performance decline. Decline in delayed recognition attenuated by snack in condition A compared with control. Fewer false alarms after snack in condition B compared with control High SES: greater decline in immediate	Separate analyses for SES groups. Low SES more vulnerable in memory domain only. Energy distribution important – snack at mid-morning attenuated decline Low SES given more energy than usual Unilever NL

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Table 3. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measure	Reported findings	Comment
				Snack: mango-flavoured co-extruded bar Lunch: vegetable rice, chickpea curry and vermicelli dessert BF at 08.00 hours, snack at 10.30 hours 22 min CT at baseline, +30 min, +150 min, +300 min		recognition but fewer false alarms after condition B than control Fewer false alarms after snack in condition A or B compared with control No effects for CPT or tapping.	
Noriega (2000)[76]	np	900 children; 450 rural, 450 urban (extreme poverty)	South America	Four IG (BF = SBP): (1) BF rural (*n* 300) (2) No BF rural (*n* 150) (3) BF urban (*n* 300) (4) No BF urban (*n* 150)	Test of attention and discrimination memory	Faster time and better performance after BF for rural only. No effect in urban children	Detail lacking
Pollitt *et al.* (1996)[23] and Pollitt *et al.* (1998)[26]	12	Fifty-four children (aged 9–11 years): (1) At risk (−1 SD height for age and −0·5 SD weight for height) (*n* 23) (2) Not at risk (*n* 31)	Peru	RM counterbalanced in-patient stay with two conditions: (a) BF: 80 g cake + 50 g Amilac (similar to milk) (b) No BF: diet soda without caffeine Standard evening meal at 17.00 hours, BF at 08.00 hours Blind CT at + 180 min Peabody Picture Vocabulary task used to measure IQ	Number discrimination Raven Progressive Matrices RT Stimulus discrimination Sternberg Memory Search	Slower short-term memory in Sternberg and discrimination tasks after no BF in at-risk children only. No other effects	No analysis strategy stated
Simeon *et al.* (1989)[27], Simeon & Grantham-McGregor (1987)[28] and Simeon (1998) Study 2[29]	15	Ninety children (age range 9–10·5 years) in three groups: (1) Thirty malnourished children (nineteen male, eleven female), hospitalised for malnutrition in 1st 2 years (2) Thirty stunted children (fifteen male, fifteen female) (height for age −2 SD) (3) Control group of thirty non-stunted children (fifteen male, fifteen female)	Jamaica	RM counterbalanced, cross-over in-patient stay with: (a) BF: Nutribun, milk and cheese (2469 kJ, 91 g CHO, 29 g protein, 12 g fat) (b) No BF: 185 ml tea, aspartame sweetened Standard evening meal at 17.00 hours, BF at 08.00 hours 45 min blind CT at + 180 min Peabody Picture Vocabulary task used to measure IQ	Wechsler IQ scale for children: Arithmetic Digit span Coding (short-term memory) Fluency and listening comprehension (attention, auditory short-term memory, comprehension) MFFT HCI	Fluency, coding, digit span (backwards), MFFT: poorer after no BF in malnourished groups than controls Arithmetic: better after no BF in controls only	Only control and stunted groups matched for sex and residence area Nestlé Nutrition Research Grant, The Wellcome Trust, Grace Kennedy & Co. and Restaurants of Jamaica Ltd

QA, quality assessment; NCHS, National Center for Health Statistics; RM, repeated measures; BF, breakfast; CHO, carbohydrate; CT, cognitive test(s); CRT, choice reaction time; IG, independent groups; ANCOVA, analysis of covariance; SES, socio-economic status; IQ, intelligence quotient; I&D, immediate and delayed (memory); CPT, Continuous Performance Test; np, quality assessment not possible; SBP, school breakfast programme; RT, reaction time; MFFT, Matched Familiar Figures Test; HCI, Hagen Central Incidental Task.

performance. Of the forty-five studies, only ten examined participants over the age of 13 years.

Studies of acute effects of breakfast in well-nourished children

There were twenty-one studies of the acute effects of breakfast in well-nourished children identified and included in the review (see Table 2). Of the studies, nine were performed in the USA and six were from the UK. Of these studies, four came from the same two research groups. The rest were conducted in Europe, Israel, China and Venezuela. Details provided by each article varied considerably.

A repeated-measures design was employed by thirteen studies. A large number of cognitive measures were employed. Some cognitive domains were examined more frequently; for example, six studies employed continuous performance tests which assess sustained attention, and nine studies used other measures of attention such as visual search and checking tasks. Of the studies, nine employed tests of verbal memory and seven employed spatial memory. Digit span was used in six studies. Not all studies assessed more than one aspect of cognitive function and the timing of tests post-ingestion also varied. Studies often considered more than two treatments, commonly including breakfast and no-breakfast conditions within the design. The inclusion of multiple breakfast conditions within the same (often small) sample has implications for the statistical analysis such that degrees of freedom and power are reduced.

Effects of breakfast v. *no breakfast*. The majority of these studies demonstrate positive effects of breakfast compared with no breakfast. However, effects vary over cognitive domain. Benefits of breakfast consumption were most evident on measures of memory and in terms of fewer errors on attention tasks especially later in the morning when performance decrements become apparent on the no-breakfast conditions. Effects on memory and attention are also clearest because more studies have used the same or comparable measures across these domains.

When verbal memory was assessed following breakfast–no-breakfast interventions, six studies report null findings and four studies show positive effects of breakfast. Of the six studies which assessed spatial memory, three report a benefit of breakfast consumption, two show better performance in the no-breakfast condition and one shows no difference. In the study by Wesnes *et al.* [33], it is not possible to distinguish verbal and non-verbal memory performance because a composite factor 'quality of episodic memory' (derived by principal components analysis) is reported. On this factor, there is a notable advantage for breakfast over no breakfast but immediate or delayed verbal performance cannot be distinguished from other memory measures. However, factors were derived from studies in adults and factor scores were not weighted for loading on the factors. Hence the factor structure and loadings may not be the same in children.

There are three well-designed studies that showed no effects of breakfast *v.* no breakfast comparisons on verbal memory[22,34,35]. Each used a repeated-measures design and the breakfasts provided between 753 kJ[22] and 2238 kJ[35]. Mahoney *et al.* [22] demonstrated positive effects of breakfast using a spatial memory task but not with story recall (verbal memory). Vaisman *et al.* [36] showed positive effects of breakfast at school compared with breakfast at home or no breakfast on immediate verbal recall. However, this study was an unbalanced design with no consideration of change over time or time of testing post-consumption, which differed for breakfast consumed at school or home.

Wesnes *et al.* [33] also documented an effect of breakfast *v.* no breakfast on his 'quality of episodic memory' factor. Age was not included as a covariate in the analysis although the study included children aged from 9 to 16 years. The matching familiar figures test was not sensitive in Cromer *et al.*'s[37] study of children with average IQ but more errors were made on the harder version of the task[38] and in children with lower IQ[17] after no breakfast. Visual perception might only be susceptible to nutritional intervention in more vulnerable samples.

Therefore, breakfast *v.* no breakfast comparisons show some positive benefits particularly if testing occurs later in the morning, with the effect more easily discernible where tests are more demanding and consider error rates.

Comparisons of different breakfasts. Fewer studies find effects on cognitive function when different breakfasts are compared. In total, nine studies compared at least two breakfasts that provided solid food, for example, cereals, doughnuts or toast. However, published studies do not always provide sufficiently detailed descriptions of the breakfasts that were administered to permit calculation of exact energy and macronutrient composition. Two studies[22,33] compared cereal breakfasts with similar energy contents but which varied in terms of carbohydrate quality. Wesnes *et al.* [33] included cereals that varied in amount of complex carbohydrate and Mahoney *et al.* [22] compared an oatmeal breakfast against a ready-to-eat cereal. The two breakfast comparisons in each study were advantageous relative to the no-breakfast and glucose-drink conditions but performance did not differ between the cereal breakfasts in either study.

Only one study has explicitly compared the glycaemic index (GI) of two breakfasts[39], but details of GI determination were not provided. GI may be calculated or estimated from international tables of GI values[40], but potential differences in the glycaemic responses of adults and children are not well understood since GI studies have not been conducted in children. Glycaemic load (GL) of breakfasts was considered in one study of 6- to 7-year-old children[41]. GL is calculated by multiplying the amount of available carbohydrate in a food item by the GI of the food and dividing this by 100. The three breakfasts provided by Benton *et al.* [41] varied in GL from 2·5 to 17·86 but more importantly the energy content of the breakfasts prescribed also varied from 657 to 820 kJ and actual intake was not consistent between participants.

Time of testing post-consumption may be important. The strongest effects have been found in the late morning, at + 130 min[39] and + 200 min[33]. Mahoney *et al.* [22] tested only at 1 h post-consumption and found an effect of breakfast *v.* no breakfast but no strong effects between two types of breakfast. Pollitt *et al.* [17,35] administered one

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Table 4. School breakfast programmes (SBP) in well-nourished children and children of differing nutritional status (thirteen studies)

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comment
Cueto & Chinen (2008)[46]	14	590 children (4th grade 'full-' and 'multi-grade' schools with two-thirds −2 SD NCHS height for age), two groups: (1) SBP, 300 children (52 % male, 48 % female), mean age 11·87 (SD 1·77) years (2) No intervention, 290 children (50 % male, 50 % female), mean age 11·87 (SD 1·9) years	Peru	IG with two conditions: (a) SBP at school after earlier BF at home. Cup of milk-like drink (no lactose), six small biscuits (2510 kJ; 22·5 g protein, 20 g fat), provided 60 % of RDA for various vitamins and minerals, 100 % RDA Fe (b) No intervention – BF at home only BF at 10.00–11.00 hours CT on 1 d of ongoing SBP	Pictorial short-term visual memory test Coding test (from Wechsler) Achievement tests: Arithmetic Reading Spanish comprehension	Positive effect of SBP on memory and achievement test scores in multi-grade pupils No effect of SBP on full-grade pupils Time spent in classroom reduced by SBP	Analysis controlled for bilingualism/Spanish proficiency Both groups likely to eat BF at home before walking to school Lower SES in no-SBP group Better school attendance in SBP group Effects only in multi-grade pupils
Kleinman *et al.* (2002)[77]	13	Ninety-seven 3rd–6th grade children of low SES with 70 % eligible for free meals, two groups: (1) Low nutrient intake (*n* 29) (2) Not at risk (*n* 68)	USA	IG with CT pre- and post-6 month SBP intervention BF: no details	Actual school grades for pre- and post-SBP year: Mathematics Reading Science Social studies	At baseline, lower nutrient intake associated with lower grades. Only mathematics grades improved with SBP. Children who improved nutrient intake also decreased absenteeism	Data on academic performance from *n* 79 only Project Bread/The Walk for Hunger, Boston, USA
Lieberman *et al.* (1976)[78]	11	617 children, 3rd–6th grade, predominantly black, low income, well nourished	USA	IG 8 months SBP intervention: (a) School BF (b) No school BF	Concentration Memory Abstract thought Class work	No effects between groups	
Meyers *et al.* (1989)[79]	13	1023 children, 3rd–6th grade, predominantly Hispanic, two groups: (1) SBP, 335 children; 163 female, 171 male (2) Non-SBP, 688 children; 340 female, 347 male	USA	IG with two conditions (SBP or non-SBP) 3-month intervention with CT pre and post BF: no details	Comprehensive tests of basic skills, sub-scales for: Language Reading Mathematics	SBP group had lower baseline scores than and scores significantly increased post-intervention relative to controls (total and language scales). SBP also reduced absenteeism	Baseline scores were from school year before study William T Grant Foundation, NY and Helmut Wolfgang Schumann Foundation, Hannover, USA
Murphy *et al.* (1998)[80]	15	133 children, 3rd–8th grades, predominantly black, low income; three groups of SBP participation: (1) Rarely (eighty-three children; thirty-six male, forty-seven f emale) (2) Sometimes (twenty-six children; twelve male, fourteen female)	USA	IG with three conditions (rarely, sometimes or often frequency of SBP participation) or non-SBP) CT pre- and post-intervention BF: no details	School grades in autumn and spring terms: Mathematics Science Social studies Reading	Higher mathematics grades in 'often' participation group, compared with 'rarely' or 'sometimes' groups No effects for other subjects	Only objective performance measure was mathematics grade

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Table 4. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comment
		(3) Often (twenty-four children; ten male, fourteen female)					
Pollitt *et al.* (1996)[23]	7	Sixty children, 4th and 5th grade recipients of Government lunch programme to be provided BF	Peru (Huaraz, 3300 m elevation)	IG with two conditions: (a) 1-month SBP intervention (increased energy, protein and Fe intake) (b) No SBP	Digit discrimination Reading comprehension Vocabulary Mathematics Wechsler IQ scale: Coding Digit span	Positive effect across time on vocabulary but no significant effect of SBP alone	Attendance increased in experimental group and decreased in controls No analysis strategy stated Kellogg's, USA
Richter *et al.* (1997)[43]	12	108 children (aged 5–7 years) in two groups: (1) SBP group: undernourished farm school (socially disadvantaged), fifty-five children, aged 10·5 (SD 1·9) years, age range 7–14 years (2) Controls, well-nourished inner city school, fifty-five children aged 8·3 (SD 0·8) years, age range 7–10 years	South Africa	IG 6-week intervention with pre- and post-testing and two conditions: (a) SBP group (b) Non-SBP group BF: no details given	Attention Distractibility Short-term memory	Increase in performance from pre- to post-intervention in SBP group	No detail of subtests Unmatched groups. Experimental group were significantly older and more undernourished than controls, and had a different background. Not a fair comparison
Shemilt *et al.* (2004)[45]	12	8209 children (predominantly white) in two groups: (1) SBP intervention: 69 % free school meal entitlement, mean age 9·6 (SD 2·96) years (2) Controls, 64 % free school meal entitlement, mean age 10·13 (SD 3·9) years	UK	IG with two conditions: (a) 3-month funding for school BF club (b) No funding	Reitan trail-making test	Time to complete trail-making part A was faster in school BF group at 3 months Reduced absenteeism in school BF group	Intention-to-treat analysis with group, baseline, sex and free meal eligibility as explanatory variables in adjusted analysis Contamination between study arms DoH, UK
Simeon (1998)[29]	9	115 children aged 12–13 years, poor rural school	Jamaica	IG with three conditions: (a) School BF: cake and 100 ml milk (1602 kJ) or meat pie and 100 ml milk (3059 kJ), *n* 44 (b) Syrup drink: 134 kJ, *n* 33 (c) No BF: *n* 38 BF at 09.00 hours CT at start of 1st semester,	Wide-range achievement test including arithmetic, spelling and reading	No difference between syrup drink and no BF, so combined in analysis Increased attendance in school BF group Higher arithmetic scores in school BF group. Effect	Commonwealth Caribbean Research Council

Table 4. *Continued*

Reference	QA	Sample	Country	Design and intervention	Cognitive measures	Reported findings	Comment
				start and end of 2nd semester		maintained when attendance and weight gain controlled for	
Vera Noriega *et al.* (2000)[44]	np	450 children, aged 4–6 years, extremely poor areas	Mexico	IG with pre- and post-testing. Two conditions: (a) School BF: no details given, *n* 300 (b) No school BF, *n* 150 No details of intervention duration	Tests of memory, attention and cognition	No-school-BF group had better scores at baseline. Post-test performance similar in both groups School BF group showed improved stimulus selection and reproduction (memory) from pre to post. No effect on RT	Insufficient detail about tests
Wahlstrom & Begalle (1999)[81]	4	2901 children of elementary school age	USA	3-year intervention BF programme *v.* no BF programme	Standardised achievement tests	School BF associated with general increase in mathematics and reading scores	Reports selective findings only
Worobey & Worobey (1999) Study 1[24]	12	Twelve children (five female, seven male), age range 3 years 10 months to 5 years 2 months, middle class	USA	2-week baseline assessment with random allocation to CT in week 1 or 2. Followed by 6-week school BF intervention Compared baseline (BF at home) with post-intervention (BF at school) School BF: similar in energy to usual BF at home (1096 kJ and 1151 kJ). Higher in CHO, lower in sugar 20–30 min CT at + 30 min after BF	Mazes (psychomotor) Embedded figures (restructuring ability) Pattern match Same or different (visual perception and discrimination) Memory: Short-term verbal Numerical	Performance post-intervention was better on mazes, pattern match and same/ different tasks	Possible practice, learning and age confounds
Worobey & Worobey (1999) Study 2[24]	12	Sixteen children in two groups: (1) SBP, six female and three male, age range 3 years 11 months to 4 years 6 months (2) Control, four female and three male, age range 3 years 10 months to 4 years 5 months	USA	As Study 1 except: School BF lower in energy (about 670 kJ) than usual BF at home (858 kJ) but higher in CHO and lower in sugar	Animal House (psychomotor) MFFT Cookie Hunt (visual perception and classification) Same or different	Better performance after school BF than controls School BF showed improvement on Animal House, MFFT and Same or different tasks. More errors on MFFT and Cookie Hunt by controls than school BF group	Paired and independent *t* tests performed. Sample size too small for ANOVA

QA, quality assessment; NCHS, National Center for Health Statistics; IG, independent groups; BF, breakfast; CT, cognitive test(s); SES, socio-economic status; IQ, intelligence quotient; DoH, Department of Health; RT, reaction time; np, quality assessment not possible; CHO, carbohydrate; MFFT, Matched Familiar Figures Test.

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Table 5. Habitual breakfast in well-nourished children (four studies)

Reference	QA	Sample	Country	Design	Cognitive measure	Reported findings	Comment
Herrero Lozano *et al.* (2006)[47]	7	141 children (seventy-one female, seventy male) aged 12–13 years	Spain	Four IG based on BF recalled on previous day: (a) Good quality (at least one dairy, cereal, fruit) (b) Improvable quality (lacks one food group) (c) Insufficient quality (lacks two food groups) (d) No BF Quality of snack consumption considered. Teachers blind to condition	Scholastic performance	Higher end-of-year school marks associated with increased BF quality. Adding a good-quality snack to poor-quality or no BF increased performance	–
Lien (2007)[82]	14	7305 children (3694 female, 3611 male), age range 15–16 years, 74 % Norwegian/Western	Norway	Population-based survey of parental education, family structure, soft-drink intake, smoking and dieting behaviour completed in junior high school. BF frequency (not quality) reported	Average most recent grade for mathematics, written Norwegian, English and social science on 0- to 6-point scale. Dichotomised to ≤ 3 and > 3	Skipping BF (0 times per week) associated with twice likelihood of grades ≤ 3 in both males and females. Infrequent BF intake (one or two times per week) associated with grades ≤ 3 in males only	Adjustment for parental education, family structure, soft-drink intake, smoking and dieting Part of Oslo Health Study 2000–2001
Lopez-Sobaler *et al.* (2003)[83]	11	180 children, age range 9–13 years; 103 male (aged 11·6 (SD 1) years), seventy-seven female (aged 11·4 (SD 1) years)	Spain	IG based on 7 d food diary (a) Adequate BF: >20 % daily energy requirements (b) Inadequate BF: <20 % daily energy requirements	Scholastic aptitude test (verbal, reasoning, calculation abilities)	Better breakfast quality associated with better performance. Of children with low scores, 66 % had inadequate BF	Accuracy issues related to diary records. Statistical analysis not powerful Danone, España
Morales *et al.* (2008)[84]	10	467 children aged 12–17 years	Spain	7 d BF diary. Quality of BF groups: (a) Optimal: 25 % daily energy requirements, dairy, cereals, fruits, fats (b) Good: dairy, cereals, fruits, fats (c) Adequate: one food group missing (d) Inadequate: two food groups missing (e) No BF	Scholastic performance (mean score between 2002–3 for range of subjects)	Better BF quality associated with better mean score	–

QA, quality assessment; IG, independent groups; BF, breakfast.

cognitive test battery at + 180 min and found effects in children with lower IQ only. Benton *et al.*[41] tested children between 140 and 210 min post-ingestion, with the possibility that the period between ingestion and testing varied between conditions and children.

There is less robust evidence for effects across other cognitive domains or between breakfasts providing similar energy but varying in macronutrient composition, GL or GI. It is difficult to confirm effects of breakfast quality in well-nourished children in mainstream education based on these acute studies.

Studies of acute effects of breakfast in children of differing nutritional status

There are seven studies that examined the effects of providing breakfast to children of differing nutritional status (see Table 3). Four studies were performed in South America, two in Jamaica and one in India. These studies compared the effects of breakfast in well-nourished and stunted and/or wasted children or children considered nutritionally at risk. Nutritional status was classified on the basis of height for age (−1 SD) and weight for age (−0·5 SD) in four studies. These studies showed that cognitive performance was better following breakfast in the at-risk or undernourished group, with few if any effects on the well-nourished and not-at-risk control children. López *et al.*[42] reported more errors in stunted children irrespective of treatment. However, some authors (for example, Grantham-McGregor[15]) do not support the view that nutritional status is an important determinant of the effect of breakfast on cognitive function. In studies where details were provided, breakfasts delivered a substantial proportion of the energy requirements for these children.

Cognitive tasks susceptible to nutritional intervention in nutritionally vulnerable children appear to be verbal fluency and memory tasks, particularly short-term recognition (a hippocampal task), Sternberg memory search, as well as the matching familiar figures test (a measure of visual perception). It would appear that nutritionally at-risk children are more vulnerable in terms of memory performance and that these effects are not evident in geographically matched well-nourished control children.

Studies of long-term effects of school breakfast programmes and breakfast clubs

There are thirteen studies that examined breakfast provision at school (see Table 4). Generally, these evaluated government-funded breakfast provision which was free to low-income children. Of the studies, seven were conducted in the USA in children of low socio-economic status, one study took place in the UK and the rest were undertaken in South America (in undernourished, at-risk children), South Africa and Jamaica. The interventions employed were predominantly school breakfast *v.* no school breakfast (either breakfast at home or no breakfast). The duration of the school breakfast programme during these studies ranged from 4 weeks to 3 years but the majority of evaluation studies had a duration of 6–12 weeks. The children in these studies tended to be younger (between 3 and 8 years of age) than in other studies included in the present review. No studies considered effects in adolescents.

Scholastic achievement tests were used as measures of cognitive function in seven studies. These studies, taken together, showed improvement mainly in mathematics or arithmetic scores post-intervention. School breakfast programmes were associated with increased attendance or decreased absenteeism, a possible explanation for the improved performance. This is especially likely where scholastic achievement tests are employed as post-intervention measures. Benefits were not greater or confined to undernourished or at-risk groups in studies that also included well-nourished controls with one exception[43].

In seven studies specific tests of cognitive function were employed. Of these, one study[44] showed improved memory, another reported improved concentration[45] while a third found no effect on a range of tests[23]. Worobey & Worobey[24] found a positive effect of a school breakfast programme on a range of mainly spatial cognitive tests in two separate samples of school children. Cueto & Chinen[46] report acute effects of breakfast provision in full-grade and multiple-grade schools, confined to tests of memory, arithmetic and, to a lesser degree, reading in the multiple-grade schools. Multiple-grade schools include children of different ages within the same class. They are associated with more poverty and lower achievement than full-grade schools and are therefore more likely to include children who are nutritionally at risk.

Provision of breakfast at school seems to have positive effects in all but two studies, particularly in these younger children who were participating in a free, universal school feeding programme. Despite the lack of detail of the nutrient composition and energy provided by the breakfasts at school, the effects of breakfast seem positive. These effects could, however, be an artifact of the increased school attendance that such provision encourages. One pitfall of school breakfast programmes is the potentially negative impact of breakfast provision on class time and pupil–teacher contact. This depends on whether breakfast is provided before the school day or during time normally allocated for teaching. In some studies, particularly in the developing world, breakfast was provided during teaching time[46].

Studies of effects of habitual breakfast quality

There were only four studies that considered habitual breakfast intake (see Table 5). Of the studies, three were conducted in Spain, utilising food diaries to determine the quality of breakfast intake based on target food groups. These studies suggest a positive effect of breakfast quality on scholastic performance. It was indicated by one study that snack provision could ameliorate the negative effect of a poor-quality or no breakfast[47]. The studies did not include measures of cognitive function other than school performance.

Discussion

The present review has identified relatively few good-quality studies that examine the effects of breakfast on the cognitive performance of school-aged children. We

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identified forty-five studies presented in forty-two articles published between 1950 and 2008 as suitable for inclusion, although many lacked scientific rigour. This is despite intense public and scientific interest and confident claims in the media on behalf of governments and the nutrition industry regarding the effects of breakfast. The majority of the studies reviewed were sponsored in whole or in part by industry. A recent development is the consideration of the impact of habitual breakfast on performance. The four studies in this category were all conducted in the last decade. Across all categories there is a predominance of studies in younger children and far fewer in adolescents in whom metabolic and cognitive effects could be different.

Overall, the quality of studies was poor. Some studies were not counterbalanced or allocation to condition was not randomised. It was sometimes unclear whether testing was performed blind to treatment condition where possible. Socio-economic status, if specified and not deliberately selected for, was predominantly middle class and monetary incentives were provided to parents in a number of studies. Studies included in Table 2 assume that the children were well nourished since they were all described as healthy and no consideration of the nutritional or weight status of the sample was provided. However, it is probable that samples included children across a range of body weights but these were not reported. Weight is likely to be positively skewed, reflecting the distribution of body weight in the populations from which they were recruited (i.e. predominantly white, middle class). Quality assessment scores reflected almost the whole range of possible scores (range 4–17). Differences in quality scores by category were small and decade of publication did not appear to influence study quality. However, habitual breakfast studies tended to score lower than other categories probably due to confounds inherent in these designs. Lifestyle factors are difficult to account for, socio-economic status may be associated with breakfast quality, and the free-living nature of the studies and reliance on food diaries reduce experimental control.

Arguably, studies in undernourished children are more difficult to design and execute. However, the studies of undernourished or at-risk children reviewed were equally well performed, scoring across a similar range to the acute healthy investigations (9–16 out of a maximum 18). The majority employed repeated-measures designs (five studies), details of breakfasts provided were good, the cognitive tests employed comparable and, where stated, the analysis was appropriate.

Difficulties also present in evaluations of school breakfast programmes. These are logistically challenging to conduct since it is difficult to match samples and the introduction of contamination between treatment arms can have a serious impact on the study. For example, Shemilt *et al.*[45] experienced high attrition and contamination, such that participants in the intervention and non-intervention arms became aware of each other's condition. Therefore, the data could not be analysed using the intended method.

Methodological issues

Breakfast intervention. Breakfast manipulations were often not matched for energy or volume and no mention is made of palatability, which could affect cognitive, affective and behavioural responses. Studies varied in the amount of each breakfast consumed, rendering conditions unmatched in terms of energy content when the variable of interest was carbohydrate quality or GL. In this respect studies were generally poorly conducted. Few firm conclusions can be made from studies of school breakfast programmes which do not tend to record or report the nature or quantity of the breakfast. Habitual breakfast studies rely on food diaries which are subject to the same bias of under- and over-reporting in children as in adults[48].

Often, choice of breakfast intervention was not driven by *a priori* hypotheses about the mechanisms by which breakfast could have an impact on cognitive performance. School breakfast programme evaluations are bound by the constraints of the programme. Other studies may be guided by the commercial interests of the study sponsor. However, recent studies have attempted to evaluate whether food characteristics such as GI and GL are related to the effects of breakfast on cognitive function[39,41]. Ingwersen *et al.*[39] found advantageous performance after a low-GI breakfast whereas Benton *et al.*[41] report benefits after low-GL breakfasts. Moreover, Benton *et al.*[41] calculated the GL of the breakfasts used in Ingwersen *et al.*'s[39] study and report that the low-GI breakfast was also low GL. Hence it is difficult to attribute the effects observed to GI or GL. There is also no agreement as to the relative importance of GI *v.* GL in terms of which best predicts health outcomes in adults[49]. Importantly, these studies have not profiled the metabolic response to breakfasts varying in GI or GL in children and the assumption is that the responses are the same as in adults.

Cognitive performance testing. Some issues relate to the appropriateness of cognitive testing employed by the studies to date in terms of their difficulty level, style and cognitive domain under study. Moreover, the suitability of some of the tests employed for children of different ages, developmental stages and intellectual level is often not considered. The cognitive tests employed in experimental studies were fairly limited, and these were not necessarily selected for their sensitivity to nutrient intervention or change over time. Some studies used global neuropsychological tests, more usually employed for diagnostic purposes. Across studies, tests were not readily comparable and accuracy and error rates were not provided by all studies. Although ecologically valid, end-of-year school performance may not provide the most sensitive indicator of the effect of a school breakfast programme. Many studies do not control for other factors which are likely to influence school grade, including home environment, parental involvement, school system and quality.

Performance on many of the cognitive tasks is evaluated in terms of accuracy scores. Little consideration is given to motivation and effort including the ability to sustain performance over time. However, breakfast consumption might facilitate motivation and reduce the underlying 'maintenance costs' of sustained performance. Sustaining concentration and retaining information are cognitive processes of key importance for scholastic achievement. The cost of maintaining these processes may vary between

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children and this may be a partial explanation why positive effects of breakfast are most easily identifiable in nutritionally at-risk children. Thus, future assessment of cognitive performance should include measures of motivation, such as number of trials attempted or frustration tolerance, in addition to accuracy.

Cognitive performance testing: design. Studies in adults suggest that glucoregulation following macronutrient manipulation, rather than absolute levels of blood glucose, may be most important for cognition[50,51]. Better glucoregulation has been associated with superior short-term and delayed verbal memory[52]. Smaller blood glucose excursions, rather than sharp fluctuations, reflect lighter metabolic stress and may be better for cognition. If glucoregulatory processes moderate the relationship between food and cognition in children, then repeated-measures designs are necessary. Participants are likely to demonstrate inter-individual variability in glucoregulation, and independent-groups designs will not control for the potential error that this introduces. This issue is of particular importance in studies of children because of their relatively faster metabolism[13].

Cognitive performance testing: analysis. In some of the studies reviewed, the statistical analysis was inappropriate to the design of the study. Often more powerful analyses could have been performed. Some studies failed to describe the statistical procedures and no or limited critical values were reported, precluding meta-analyses of these data. The age of the study had some bearing on the complexity of the statistical analysis performed, with older studies tending towards simpler, non-parametric statistical procedures, possibly due to the lack of available computing power.

Mechanisms. Mechanisms for the facilitation of cognitive performance by breakfast are not well established[8]. There are likely to be different mechanisms of action responsible for short- and long-term effects of breakfast consumption. Moreover, these purported mechanisms may not necessarily be the same in adults as in young children, whose brain metabolic requirements are relatively much greater than those of the adult brain. In addition, metabolic processes of adolescents' brains begin to resemble those of adults during puberty but do not reach adult levels until 16–18 years[13].

Mechanisms: physiological. While some studies suggest that glucose ingestion facilitates cognitive performance[53–56], others report no direct relationship between performance and glucose levels following breakfast consumption[57,58]. Rather than a direct effect of glucose on cognitive performance, the mechanism of action may involve one or many correlates of blood glucose. Glucose ingestion gives rise to changes in levels of acetylcholine, insulin, serotonin, glutamate and cortisol, all of which can affect cognitive function[58–61]. It is possible that any or a combination of these central and peripheral changes are involved in the impact of breakfast on performance.

Therefore, we are currently lacking a strong theoretical or evidence base to relate specific neurochemical or physiological activity to specific cognitive functions. These potential biomarkers for cognitive function are more difficult to measure than the actual function itself. This is particularly pertinent in children in whom invasive measures are ethically and practically difficult. Some physiological measures of autonomic nervous system activity such as heart rate and electroencephalogram which have been shown to vary in relation to cognitive demand[62] may be more easily applied in studies of children. Appropriate methods to track biomarkers during cognitive activity are required in order to elucidate the mechanisms by which breakfast may affect performance.

The use of physiological biomarkers relies on the assumption that peripheral measures reflect central activity. Indeed, peripheral glucose and its metabolites are well regulated in healthy individuals to maintain homeostasis and elicit appropriately rapid postprandial responses. Peripheral glucose regulation and metabolism in children may not be the same as in adults[63].

In the long term, breakfast consumption may lead to beneficial physiological changes in nutrient status. Thus positive effects of breakfast on cognitive performance may be the product of better nutritional profiles rather than transient changes in blood parameters. Achieving better nutrient and vitamin status or rectifying deficiencies, as demonstrated by some studies in the developing world, may be responsible for the effects seen on performance.

Behavioural mechanisms

While physiological explanations for the effects of breakfast on cognitive performance are appealing, behavioural mechanisms may play an important role in the cognitive response to breakfast. In the short term, breakfast consumption may function to heighten subjective feelings of alertness and motivation to concentrate and learn. This could occur because of the learned association between breakfast consumption and feelings of wellbeing, or the reduction of hunger (for example, Wesnes *et al.* [33], Dye & Blundell[9] and Gibson[58]). Unfortunately, few studies incorporate measures of both appetite and mood alongside objective cognitive measures.

In the long term, studies indicate that school breakfast programmes increase scholastic performance. This outcome could be a direct effect of the repeated consumption of breakfast and the development of a learned association of this with wellbeing or ability to concentrate. Alternatively, positive effects could be a result of the improved nutritional state which is known to result from regular breakfast consumption[1,64]. The effects seen in response to school breakfast programmes could simply be explained as an artifact of increased school attendance, motivated to attend by the provision of the breakfast[23,29,46].

Conclusions

Overall, evidence suggests that breakfast consumption has generally positive effects on cognitive performance in comparison with breakfast omission. This effect appears to be pervasive in both acute studies and longer-term school breakfast programmes. However, the apparent beneficial effects of school breakfast programmes may be linked to

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increased attendance and reduced absenteeism, and effects of such provision in older children are not known. In addition, breakfast effects are more easily demonstrable in nutritionally vulnerable children.

It is difficult to recommend an optimal breakfast for cognitive function based on the currently available research. One study has suggested that solid breakfasts may be advantageous over liquid breakfasts[33], perhaps due to differing rates of gastric emptying. In addition, some studies indicate that low-GI or low-GL breakfasts may confer benefits but it is hard to differentiate between these two indicators of glycaemic response in the few studies that have examined these food characteristics.

The majority of studies have concentrated on the measurement of memory and attention performance, with less examination of tasks that engage other cognitive domains, processes and aptitudes. There have been few examinations of problem solving and psychomotor skill, for example. However, from the studies reviewed, it is difficult to conclude which specific cognitive domains are most sensitive to nutritional manipulations at breakfast time, although there is most abundant support for effects on memory.

Recommendations for future work

The present review has highlighted problems in this research area which could be addressed by the following recommendations for future work.

Future studies should test focused hypotheses, based on a small number of theoretically selected breakfast conditions, presented according to carefully counterbalanced repeated-measures designs with large samples which yield sufficient power. Breakfasts must be matched for energy but should differ sufficiently in key features, for example, macronutrient composition, style or glycaemic response, in order to experimentally investigate potential mechanisms of action. Tasks that span a wide range of cognitive domains with demonstrated sensitivity to nutritional manipulations should be used so that null findings can be ascribed to true lack of effect rather than test insensitivity. In acute studies, effects of breakfast may be more pronounced some time after consumption when the metabolic challenge of food consumption has subsided. Late-morning testing rather than immediate post-breakfast testing merits further exploration. Enduring and meaningful effects are likely to result from chronic interventions of at least 12 weeks with appropriate timing of the tests of cognitive and/or scholastic performance. Lastly, the present review has highlighted the need for greater examination of the effect of breakfast in adolescents.

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References

1. Ruxton CHS & Kirk TR (1997) Breakfast: a review of associations with measures of dietary intake, physiology and biochemistry. *Br J Nutr* **78**, 199–213.
2. de la Hunty A & Ashwell M (2006) Are people who regularly eat breakfast cereals slimmer than those who don't? A systematic review of the evidence. *Nutr Bull* **32**, 118–128.
3. Hansen K & Joshi H (2008) *Millennium Cohort Study Third Survey: A User's Guide to Initial Findings*, p. 162. London: Centre for Longitudinal Studies, Institute of Education.
4. Sjöberg A, Hallberg L, Höglund D, *et al*. (2003) Meal pattern, food choice, nutrient intake and lifestyle factors in The Göteborg Adolescence Study. *Eur J Clin Nutr* **57**, 1569–1578.
5. Haines PS, Guilkey DK & Popkin BM (1996) Trends in breakfast consumption of US adults between 1965–1991. *J Am Diet Assoc* **96**, 464–470.
6. Street C & Kenway P (1999) *Food for thought: breakfast clubs and their challenges*. London: New Policy Institute.
7. Dye L, Lluch A & Blundell JE (2000) Macronutrients and mental performance. *Nutrition* **16**, 1021–1034.
8. Hoyland A, Lawton CL & Dye L (2008) Acute effects of macronutrient manipulations on cognitive test performance in healthy young adults: a systematic research review. *Neurosci Biobehav Rev* **32**, 72–85.
9. Dye L & Blundell JE (2002) Functional foods: psychological and behavioural functions. *Br J Nutr* **88**, Suppl. 2, 187–211.
10. Sokoloff L (1976) Circulation and energy metabolism. In *Basic Neurochemistry*, pp. 388–413 [GJ Siegel, RW Albers and BW Agranoff, editors]. Boston: Little Brown.
11. Kennedy D & Sokoloff L (1957) An adaptation of the nitrous oxide method to the study of the cerebral circulation in children; normal values for cerebral blood flow and cerebral metabolic rate in childhood. *J Clin Invest* **36**, 1130–1137.
12. Chugani HT (1994) Development: of regional brain glucose metabolism in relation to behaviour and plasticity. In *Human Behavior and the Developing Brain*, pp. 153–175 [G Dawson and KW Fischer, editors]. New York: Guildford Press.
13. Chugani HT (1998) A critical period of brain development: studies of cerebral glucose utilization with PET. *Prev Med* **27**, 184–188.
14. Connors CK & Blouin AG (1983) Nutritional effects on behaviour of children. *J Psychiatr Res* **17**, 198–201.
15. Grantham-McGregor S (2005) Can the provision of breakfast benefit school performance? *Food Nutr Bull* **26**, Suppl. 2, 144–158.
16. Taras H (2005) Nutrition and student performance at school. *J Sch Health* **75**, 199–213.
17. Pollitt E & Mathews R (1998) Breakfast and cognition: an integrative summary. *Am J Clin Nutr* **67**, Suppl., 804–813.
18. Ells LJ, Hillier FC, Shucksmith J, *et al*. (2008) A systematic review of the effect of dietary exposure that could be achieved through normal dietary intake on learning and performance of school-aged children of relevance to UK schools. *Br J Nutr* **100**, 927–936.
19. Kristjansson EA, Robinson V & Petticrew M, *et al.* (2007) School feeding for improving the physical and psychosocial health of disadvantaged elementary school children. *The Cochrane Database of Systematic Reviews 2007*, issue 1, CD004676. http://www.mrw.interscience.wiley.com/cochrane/clsysrev/articles/CD004676/frame.html
20. Lichtenstein AH, Yetley EA & Lau J (2008) Application of systematic review methodology to the field of nutrition. *J Nutr* **138**, 2297–2306.
21. Dickie NH & Bender AE (1982) Breakfast and performance in schoolchildren. *Br J Nutr* **48**, 483–496.

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22. Mahoney CR, Taylor HA, Kanarek RB, *et al*. (2005) Effect of breakfast composition on cognitive processes in elementary school children. *Physiol Behav* **85**, 635–645.
23. Pollitt E, Jacoby E & Cueto S (1996) School breakfast and cognition among nutritionally at-risk children on the Peruvian Andes. *Nutr Rev* **54**, 22–26.
24. Worobey J & Worobey HS (1999) The impact of a two-year school breakfast program for preschool-aged children on their nutrient intake and pre-academic performance. *Child Stud J* **29**, 113–131.
25. Chandler AM, Walker SP, Connolly K, *et al*. (1995) School breakfast improves verbal fluency in undernourished Jamaican children. *J Nutr* **125**, 894–900.
26. Pollitt E, Cueto S & Jacoby ER (1998) Fasting and cognition in well- and undernourished schoolchildren: a review of three experimental studies. *Am J Clin Nutr* **67**, Suppl., 779–784.
27. Simeon DT & Grantham-McGregor S (1989) Effects of missing breakfast on cognitive functions of schoolchildren of differing nutritional status. *Am J Clin Nutr* **49**, 646–653.
28. Simeon D & Grantham-McGregor S (1987) Cognitive function, undernutrition and missed breakfast. *Lancet* **ii**, 737–738.
29. Simeon DT (1998) School feeding in Jamaica: a review of its evaluation. *Am J Clin Nutr* **67**, Suppl., 790–794.
30. Jadad AR, Moore RA, Carroll D, *et al*. (1996) Assessing the quality of reports of randomised clinical trials: is blinding necessary? *Control Clin Trials* **17**, 1–12.
31. Thomas J, Sutcliffe K, Harden A, *et al.* (2003) *Children and Healthy Eating: A Systematic Review of Barriers and Facilitators*. London: EPPI Centre, Social Science Research Unit, Institute of Education, University of London.
32. Jackson C, Cheater F & Reid I (2008) A systematic review of decision support needs of parents making child health decisions. *Health Expect* **11**, 232–251.
33. Wesnes KA, Pincock C, Richardson D, *et al*. (2003) Breakfast reduced declines in attention and memory over the morning in schoolchildren. *Appetite* **41**, 329–331.
34. Busch CR, Taylor HA, Kanarek RB, *et al*. (2002) The effects of a confectionery snack on attention in young boys. *Physiol Behav* **77**, 333–340.
35. Pollitt E, Leibel RL & Greenfield D (1981) Brief fasting, stress and cognition in children. *Am J Clin Nutr* **34**, 1526–1533.
36. Vaisman N, Voet H, Akivis A, *et al*. (1996) Effect of breakfast timing on the cognitive functions of elementary school students. *Arch Pediatr Adolesc Med* **150**, 1089–1092.
37. Cromer BA, Tarnowski KJ, Stein AM, *et al*. (1990) The school breakfast program and cognition in adolescents. *J Dev Beh Pediatr* **11**, 295–300.
38. Pollitt E, Lewis NL, Garza C, *et al*. (1982–3) Fasting and cognitive function. *J Psychiatr Res* **17**, 169–174.
39. Ingwersen J, Defeyter MA, Kennedy DO, *et al*. (2007) A low glycaemic index breakfast cereal preferentially prevents children's cognitive performance from declining throughout the morning. *Appetite* **49**, 240–244.
40. Atkinson FS, Foster-Powell K & Brand-Miller JC (2008) International tables of glycemic index and glycemic load values: 2008. *Diabetes Care* **31**, 2281–2283.
41. Benton D, Maconie A & Williams C (2007) The influence of the glycaemic load of breakfast on the behaviour of children in school. *Physiol Behav* **92**, 717–724.
42. López I, de Andraca I, Perales CG, *et al*. (1993) Breakfast omission and cognitive performance of normal, wasted and stunted schoolchildren. *Eur J Clin Nutr* **47**, 533–542.
43. Richter LM, Rose C & Griesel RD (1997) Cognitive and behavioural effects of a school breakfast. *S Afr Med J* **87**, Suppl. 1, 93–100.
44. Vera Noriega JA, Dominguez Ibanez SE, Pena Ramos MO, *et al*. (2000) Evaluation of the effects of a school breakfast program on attention and memory. *Arch Latinoam Nutr* **50**, 35–41.
45. Shemilt I, Harvey I, Shepstone L, *et al*. (2004) A national evaluation of school breakfast clubs: evidence from a cluster randomized controlled trial and an observational analysis. *Child Care Health Dev* **30**, 413–427.
46. Cueto S & Chinen M (2008) Educational impact of a school breakfast programme in rural Peru. *Int J Educ Dev* **28**, 132–148.
47. Herrero Lozano R & Fillat Ballesteros JCF (2006) A study on breakfast and school performance in a group of adolescents. *Nutr Hosp* **21**, 346–352.
48. Baxter SD, Hardin JW, Royer JA, *et al*. (2008) Children's recalls from five dietary-reporting validation studies. Intrusions in correctly reported and misreported options in school breakfast reports. *Appetite* **51**, 489–500.
49. Livesey G, Taylor R, Hulshof T, *et al*. (2008) Glycemic response and health – a systematic review and meta-analysis: the database, study characteristics, and macronutrient intakes. *Am J Clin Nutr* **87**, Suppl. 1, 223–236.
50. Meikle A, Riby LM & Stollery B (2004) The impact of glucose ingestion and gluco-regulatory control on cognitive performance: a comparison of younger and middle aged adults. *Hum Psychopharmacol* **19**, 523–535.
51. Messier C, Gagnon M & Knott V (1997) Effect of glucose and peripheral glucose regulation on memory in the elderly. *Neurobiol Aging* **18**, 297–304.
52. Nabb S & Benton D (2006) The influence on cognition of the interaction between the macro-nutrient content of breakfast and glucose tolerance. *Physiol Behav* **87**, 16–23.
53. Benton D, Owens DS & Parker PY (1994) Blood glucose influences memory and attention in young adults. *Neuropsychologia* **32**, 595–607.
54. Foster J, Lidder P & Sunram S (1998) Glucose and memory: fractionation of enhancement effects? *Psychopharmacology* **137**, 259–270.
55. Kennedy D & Scholey A (2000) Glucose administration, heart rate and cognitive performance: effects of increasing mental effort. *Psychopharmacology* **149**, 63–71.
56. Sünram-Lea S, Foster J, Durlach P, *et al*. (2002) The effect of retrograde and anterograde glucose administration on memory performance in healthy young adults. *Behav Brain Res* **134**, 505–516.
57. Bellisle F (2001) Glucose and mental performance. *Br J Nutr* **86**, 117–118.
58. Gibson EL (2007) Carbohydrates and mental function: feeding or impeding the brain? *Nutr Bull* **32**, Suppl. 1, 71–83.
59. Hasselmo ME & Giocomo LM (2006) Cholinergic modulation of cortical function. *J Mol Neurosci* **30**, 133–135.
60. Park CR (2001) Cognitive effects of insulin in the central nervous system. *Neurosci Biobehav Rev* **25**, 311–323.
61. Schmitt JAJ, Jorissen BL, Dye L, *et al*. (2005) Memory function in women with premenstrual complaints and the effect of serotonergic stimulation by acute administration of an α-lactalbumin protein. *J Psychopharmacol* **19**, 375–384.
62. Fairclough SH & Houston K (2004) A metabolic measure of mental effort. *Biol Psychol* **66**, 177–190.
63. Beardsall K, Yuen K, Williams R, *et al*. (2006) Applied physiology of glucose control. *Curr Paediatr* **16**, 434–438.
64. Rampersaud GC, Pereira MA, Girard BL, *et al*. (2005) Breakfast habits, nutritional status, body weight, and academic performance in children and adolescents. *J Am Diet Assoc* **105**, 743–760.

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65. Ma G, Hu X, Gao S, *et al*. (1999) Effect of energy intake at breakfast on school performance. *Wei Sheng Yan Jiu* **28**, 286–288.
66. Marquez Acosta M, Sutil de Naranjo R, Rivas de Yepez CE, *et al*. (2001) Influence of breakfast on cognitive functions of children from an urban area in Valencia, Venezuela. *Arch Latinoam Nutr* **51**, 57–63.
67. Michaud C, Musse N, Nicolas JP, *et al*. (1991) Effects of breakfast-size on short-term memory, concentration, mood and blood glucose. *J Adolesc Health* **12**, 53–57.
68. Morrell G & Atkinson DR (1977) Effects of breakfast program on school performance and attendance of elementary school children. *Education* **98**, 111–116.
69. Morris N & Sarll P (2001) Drinking glucose improves listening span in students who miss breakfast. *Educ Res* **43**, 201–207.
70. Widenhorn-Müller K, Hille K, Klenk J, *et al*. (2008) Influence of having breakfast on cognitive performance and mood in 13- to 20-year-old high school students: results of a crossover trial. *Pediatrics* **122**, 279–284.
71. Wyon DP, Abrahamsson L, Jartelius M, *et al*. (1997) An experimental study on the effects of energy intake at breakfast on the test performance of 10-year-old children in school. *Int J Food Sci Nutr* **48**, 5–12.
72. Cueto S, Jacoby E & Pollitt E (1998) Breakfast prevents delays of attention and memory functions among nutritionally at-risk boys. *J Appl Dev Psychol* **19**, 219–234.
73. Grantham-McGregor SM, Chang S & Walker SP (1998) Evaluation of school feeding programs: some Jamaican examples. *Am J Clin Nutr* **67**, Suppl., 785–789.
74. Chandler AK, Walker SP, Connolly K, *et al*. (1995) School breakfast improves verbal fluency in undernourished Jamaican children. *J Nutr* **125**, 894–900.
75. Muthayya S, Thomas T, Srinivasan K, *et al*. (2007) Consumption of a mid-morning snack improves memory but not attention in school children. *Physiol Behav* **90**, 142–150.
76. Noriega JAN (2000) Method and theory in school breakfast program evaluation. *Estudios de Psicologia* **5**, 33–48.
77. Kleinman RE, Hall S, Green H, *et al*. (2002) Diet, breakfast and academic performance in children. *Ann Nutr Metab* **46**, Suppl. 1, 24–30.
78. Lieberman HM, Hunt IF, Coulson AH, *et al*. (1976) Evaluation of a ghetto school breakfast program. *J Am Diet Assoc* **69**, 132–138.
79. Meyers AF, Sampson AE, Weitzman M, *et al*. (1989) School Breakfast Program and school performance. *Am J Dis Child* **143**, 1234–1239.
80. Murphy JM, Pagano M, Nachmani J, *et al*. (1998) The relationship of school breakfast to psychosocial and academic functioning: cross-sectional and longitudinal observations in an inner-city school sample. *Arch Pediatr Adolesc Med* **152**, 899–907.
81. Wahlstrom KL & Begalle M (1999) More than test scores – results of the Universal School breakfast pilot in Minnesota. *Topics Clin Nutr* **15**, 7–29.
82. Lien L (2007) Is breakfast consumption related to mental distress and academic performance in adolescents? *Public Health Nutr* **10**, 422–428.
83. Lopez-Sobaler AM, Ortega RM, Quintas ME, *et al*. (2003) Relationship between habitual breakfast and intellectual performance (logical reasoning) in well-nourished schoolchildren of Madrid (Spain). *Eur J Clin Nutr* **57**, Suppl. 1, 49–53.
84. Morales IF, Villas MVA, Vega CJM, *et al*. (2008) Relation between the breakfast quality and the academic performance in adolescents of Guadalajara (Castilla-La Mancha). *Nutr Hosp* **23**, 383–387.

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Appendix: Quality assessment tool

Quality assessment sheet: Breakfast and performance in children review

A. Overview of study	1, 2, 3, 4, 12, 17, 18
B. Data collection	5, 6, 7, 8
C. Manipulation	9, 10, 11
D. Outcomes and analysis	13, 14, 15, 16

Paper: Rater:

Score 0 if criterion not satisfied. Score 1 if criterion satisfied. Score:

No.	Criterion	Score	Comments
1	Clear aims and objectives stated		
2	Clear description of setting/environment, e.g. location, laboratory/classroom		
3	Clear description of sample, e.g. age (mean, SD, range), sex, *n*		
4	Clear description of study design		
5	Clear description of data collection		
6	Provision of recruitment data and strategy		
7	Provision of attrition data		
8	Provision of compliance data, i.e. performance testing and breakfast intake		
9	Clear description of manipulation, e.g. serving size, composition, kJ		
10	Appropriateness of manipulation, e.g. serving size, food style/quality		
11	Evidence of fasting before testing		
12	Sufficiency of matching, sample selection, blinding, counterbalancing or placebo comparison N.B. within limitations of study design		
13	Valid and reliable outcomes, e.g. appropriateness of cognitive test		
14	Clear description of data analysis		
15	Appropriateness of data analysis		
16	Clear description of findings		
17	Strengths of study and suggestions for future work		
18	Limitations of study		

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