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Systematic Review

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

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The aim of the present review was to perform a systematic in-depth review of the best evidence from controlled trial studies that have investigated the effects of nutrition, diet and dietary change on learning, education and performance in school-aged children (4–18 years) from the UK and other developed countries. The twenty-nine studies identified for the review examined the effects of breakfast consumption, sugar intake, fish oil and vitamin supplementation and 'good diets'. In summary, the studies included in the present review suggest there is insufficient evidence to identify any effect of nutrition, diet and dietary change on learning, education or performance of school-aged children from the developed world. However, there is emerging evidence for the effects of certain fatty acids which appear to be a function of dose and time. Further research is required in settings of relevance to the UK and must be of high quality, representative of all populations, undertaken for longer durations and use universal validated measures of educational attainment. However, challenges in terms of interpreting the results of such studies within the context of factors such as family and community context, poverty, disease and the rate of individual maturation and neurodevelopment will remain. Whilst the importance of diet in educational attainment remains under investigation, the evidence for promotion of lower-fat, -salt and -sugar diets, high in fruits, vegetables and complex carbohydrates, as well as promotion of physical activity remains unequivocal in terms of health outcomes for all schoolchildren.

Schoolchildren: Diet: Learning: Behaviour

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The UK Government and those involved in education are committed to improving learning and raising standards in schools, as well as meeting the needs of individual pupils. There is widespread belief that nutrition and diet may have a part to play in this process; however, there is a degree of uncertainty as to what interventions or supplements work. Much of the available evidence is confusing and contradictory. In essence, parents and those charged with supporting and delivering education are seeking clear guidance for both individuals and groups of children, so as to be able to identify which interventions and supplements may work and which are less likely to.

The UK Government is committed to promoting healthier schools and lifestyles among schoolchildren, for example, through improving the quality of school meals and introducing nutrient-based standards for school meals. Changes to school food provision have been introduced in Scotland(1), England(2) and are soon to be introduced in Wales(3). The rationale for these improvements was based on evidence relating to poor nutrient and food intake among some school-aged children taken from the National Diet and Nutrition Survey: young people aged 4–18 years(4) and from data collected as part of new research on school meals(5). Whilst the commitment to improve school meals was primarily made on health

Abbreviations: AA, arachidonic acid; ADHD, attention deficit hyperactivity disorder; EPPI, Evidence for Policy and Practice Information; GLA, γ-linolenic acid; IQ, intelligence quotient; RCT, randomised controlled trial; SIGN, Scottish Intercollegiate Guidance Network.

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grounds, there was considerable interest in how good nutrition may also impact on behaviour, learning and performance among school-aged children. However, the evidence base to support clear associations in this area was confused and lacked cohesion, and the panel was therefore unable to make a clear evidence-based statement at the time. As part of the development of school meal standards in England, the school meals review panel requested an assessment into the links between good nutrition and educational performance.

The aim of the present study was to perform a systematic in-depth review of published evidence from controlled trials that have investigated the effects of nutrition, diet and dietary change on the learning, education and performance of school-aged children from the developed world.

Methodology

Search strategy

A comprehensive search strategy was developed to explore the aim of the present review (the complete list of the search terms is shown in Appendix 1). A computerised systematic literature search was then carried out on the 21 and 22 December 2005. As the topic area lies at the interface between health sciences, education and social sciences, the following electronic databases were explored: MEDLINE; CINAHL; PsychINFO; British Educational Index (BEI); Education Research Information Center (ERIC); Australian ERIC; Social Science Citation index (SSCI); Applied Social Sciences Index and Abstracts (ASSIA); International Bibliography of the Social Sciences; Sociological Abstracts; SPECTRE; and The British Library's electronic table of contents of current journals, and conference proceedings (ZETOC).

All databases were searched from the date of their inception and, where possible, limits were applied to fit the inclusion criteria (listed below). Every citation was stored using the Evidence for Policy and Practice Information (EPPI) Centre software (EPPI-Reviewer; EPPI Centre, London, UK), where they were combined, de-duplicated and then screened to meet the following inclusion and exclusion criteria.

All included studies had to be:

(1) primary studies reporting empirical research from controlled trials (research criterion);
(2) studies that have been peer-reviewed (i.e. appear in an edited journal) (peer-review criterion);
(3) studies that include an exposure or intervention focusing on nutrition, diet or dietary change, and at least one of the following outcomes – educational performance, behaviour and motivation in humans (topic criterion);
(4) studies that include a nutritional and dietary exposure that can be achieved through normal dietary intake (no more than twice the daily recommended dietary reference value[6]), (dosage criterion);
(5) studies focusing on school-aged children aged 4–18 years (age criterion);
(6) studies written in English (language criterion);
(7) studies undertaken in developed countries (as defined by the World Bank as countries of 'high human development', i.e. a human development index score of $>0{\cdot}8$; http://web.worldbank.org) (population criterion);
(8) studies of a duration >5 d (except for high carbohydrate studies where any time frame >2 h is acceptable) (duration criterion);
(9) studies reporting exposures or interventions based in any type of setting – for example, mainstream, special schools, pupil referral units and community centres (setting criterion).

A summary of the methodology is shown in Fig. 1.

Quantitative and qualitative data were extracted from each of the studies selected for in-depth review by two independent researchers, with any discrepancies resolved after consultation with the review group to maintain consistency. Data extraction took place using a specially designed data extraction tool developed using the EPPI reviewer software and templates (details available at http://eppi.ioe.ac.uk/cms/).

Quality assurance

Quality-assurance measures were operational at several levels for the present review.

Level 1. To oversee the quality of the review process and final report production, an external steering group was formed with expertise within the fields of education, social sciences, nutrition, paediatric medicine and biochemistry.

Level 2. To ensure the efficacy of the search strategy, a list of publications deemed 'highly relevant' within this area of interest were selected after consultation with the steering group[7–18]. These publications were cross-referenced against the citations captured from the combined searches to ensure all were identified. Of these twelve 'highly relevant studies', eight were included in the present review. Two studies[7,12] were excluded because the dosage of supplements used was greater that 2 × dietary reference value for some vitamins and minerals, one study[10] was excluded because it was a cross-sectional study, and one study[15] was excluded because it was not conducted in a developed country as defined by the World Bank.

Level 3. To assess the quality of the papers selected for in-depth review, two quality-assurance protocols were utilised. The first protocol was based on the Scottish Intercollegiate Guidance Network (SIGN; www.sign.ac.uk) quality-assurance assessment for the randomised controlled trial (RCT). This accounted for critical quality issues such as randomisation, blinding, concealment and intention-to-treat analysis, upon which a numerical scoring system was applied. The second protocol was based on the quality-assurance template produced by EPPI reviewer, which weighted the evidence into low, medium and high categories.

Results and discussion

Breakfast

By far the largest number of included publications (fifteen: eight from the USA, three from the UK, one each from France, Chile, Israel and Sweden) examined the effect of breakfast. Eleven of these studies focused on children within the 4–12-year age bracket, whilst the remaining four included a teenage population. Generally the size of the study populations was small (predominantly <100 participants) and of short duration (<1 week; these studies were included due to

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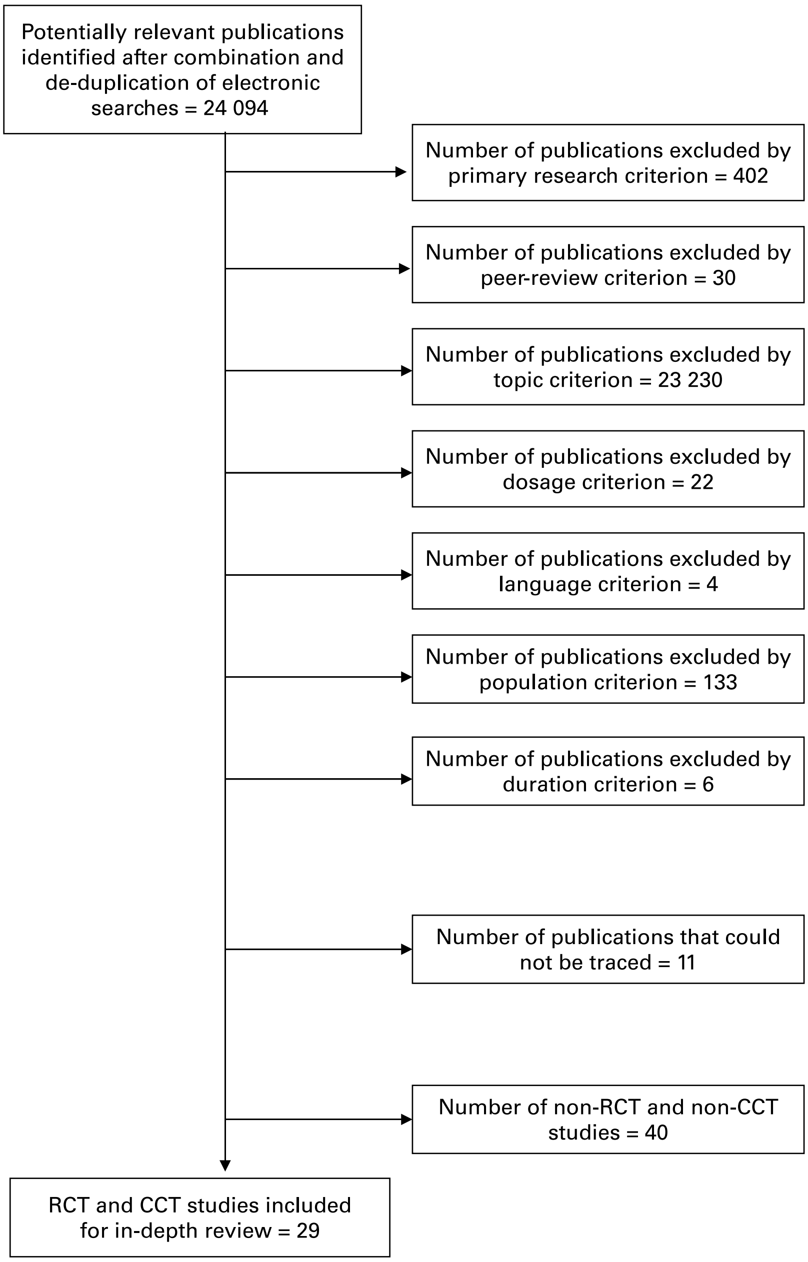

Fig. 1. Methodology summary flow diagram. RCT, randomised control trials; CCT, case–control trials.

the high carbohydrate content of the breakfast intervention). All studies examined predominantly healthy, mixed sex populations from mainstream education. Most participants (where recorded) were white Caucasian, with the exception of those participating in three studies[11,19,20], who were predominantly black, mixed race and Hispanic, respectively. Ten studies reported socio-economic status (using a variety of scales and indicators); of these, half recruited children from low-income families and half recruited children from middle- to high-income families.

The type of breakfast interventions investigated fell into five categories: (1) the impact of the provision of breakfast clubs[11,19,21,22]; (2) breakfast consumption *v.* fasting[9,13,23–26]; (3) low- *v.* high-protein breakfast consumption[20]; (4) low- *v.* high-energy breakfast consumption[8,18]; (5) habitual breakfast consumption *v.* a standardised breakfast consumption[27,28]. Of the studies investigating breakfast clubs, three identified a small but positive impact of breakfast club participation on a selection of educational outcomes, whilst the remaining study found no effect. Four of the six studies investigating breakfast consumption *v.* fasting identified some improvements ($P=0{\cdot}05$) in problem solving, attention and epidsodic memory after cereal consumption and complex visual display after consuming breakfast, although the remaining two studies were unable to identify any significant differences. The study investigating the protein content of breakfast was unable to demonstrate any significant differences between consumption of high- or low-protein breakfasts. When energy content was examined, one study demonstrated a disadvantage ($P=0{\cdot}05$) of a low-energy breakfast in terms of mood, physical endurance and creative thinking; however, the other study found no significant differences between the two breakfast conditions. When habitutal breakfast conditions were compared against a standardised breakfast provision, both studies demonstrated some improvements to cognitive function after consumption of the standard breakfast. However, although one study[27] demonstrated an increase in memory scale results after consumption of the standard breakfast, this was accompanied by a negative reduction in concentration.

The diverse range of different breakfast interventions and research designs makes it very difficult to draw together the findings presented. The majority of studies (ten out of fifteen), however, were able to demonstrate that the provision of breakfast may have some small benefit to a limited selection of short-term behavioural and cognitive functions. However, this very generalisable overview must be considered within the context of the numerous shortcomings of many of these studies: (1) only three studies considered the impact of habitual diet, which particularly given the very short duration of many of these studies may have had a substantial effect; (2) in general, many of the studies failed to adjust for, or even acknowledge, many of the factors, which like habitual diet, may impact significantly upon the findings presented; (3) there are a huge number of behavioural and cognitive indices that are important in measuring educational attainment – however, most studies selected a limited range of subjective and objective methodologies, many lacking appropriate validation, with very little consistency in methodology between studies; (4) breakfast clubs often have a social dimension to them, for example, some parents may use them primarily because they provide childcare, so it is difficult to dissociate the different benefits; (5) as mentioned previously, many of the studies were of short duration, making it extremely difficult to control for different rates of emotional and neurological maturation, as well as being unable to quantify sustainability and longer-term benefits. Given these shortcomings, it was unsurprising that many of the studies gained very low quality-assurance scores, with eight achieving a SIGN grading of under ten (out of a possible twenty-seven) and an EPPI weighting of low.

Sugars

Six of the included studies[17,29–33] (five from the USA and one from Canada) investigated the effect of sugar intake on learning and behavourial outcomes in school-aged children. All studies were carried out between 1985 and 1994, and examined a population of pre-teens (3–12 years) with the exception of one study[32] that included teenagers. Every study examined the effect of sucrose against aspartame or aspartame and saccharin in an RCT cross-over design. The period of exposure to the sugar or sweetener substitutes was short in most cases (1–2 d) with the exception of two studies[17,31] which examined each exposure over 1 week.

Only one study examined the effects of sugar in an entirely healthy population of children. The remaining studies were investigated in a population of chidren with symptoms of attention deficit hyperactivity disorder (ADHD), either on their own (two studies) or alongside control healthy children (three studies). The two small studies (population n 16 in each) carried out in an all-male 'ADHD' population found no significant difference between the sugar and aspartame exposure on any of the objective or subjective outcomes measured. Of the remaining studies, two identified small statisticially ($P=0{\cdot}05$) (but often not clinically) significant adverse effects on behavioural outcomes in the sucrose group, whilst another could only identify a disadvantage in the 'ADHD' subgroup. The only long-term diet that combined the sugar or sweeteners into habitual diet rather than a drink was unable to identify any difference between the sucrose and sweetener in primary-aged children. This was, incidentally, the only study also to examine any blood biochemistry. However, a small but significant improvement was seen in a small number of the subjective behaviour scores for the infants, although this finding was inconsistent with a significant decrease in the score for one of the objective performance measures in the same group.

Whilst all but one study gained reasonable quality-assurance scores (for both EPPI and SIGN), only two studies calculated power. As with the breakfast studies, very little attention was paid to important factors, particularly physical activity and habitual diet, both of which could significantly impact upon the metabolic responses to sugar consumption. Given the small number of studies included and diversity of the populations examined, it becomes difficult to derive any conclusive outcome from these studies. However, the data presented do suggest that short-term exposure to sucrose has no dramatic detrimental effects on educational and behavioural outcomes in school-aged children, when compared with commonly consumed artificial sweeteners.

Fish oil supplementation

A total of five included studies[14,34–37] examined the effect of fish oil supplementation on learning and behavioural outcomes. All studies were carried out during the last 5 years and used a placebo-controlled RCT design in a population aged between 5 and 13 years, with symptoms of neurodevelopmental disorders (dyspraxia and ADHD). The study population sizes were small, ranging from forty to 117 particpants, all of which included both boys and girls although boys predominated, probably due to the prevalence of male ADHD diagnoses. Studies were carried out for periods between 2 and 4 months and took place in the USA (two studies), UK (two studies) and Japan (one study). The two UK and one of the USA studies used fish oil, the other USA study used an algae-derived oil, and these were taken as capsules, whilst the Japanese study incorporated the test fish oil into pre-prepared food and drink. The fatty acid composition selected for each study differed, with four out of the five studies using a mixture rich in DHA, whilst a recent study[14] used a composition rich in EPA, which also contained γ-linolenic acid (GLA).

Whilst all studies gained medium to high quality ratings, the outcome assessment measures and results varied considerably. Only two of the studies measured blood biochemistry alongside objective testing and subjective parental and teacher observations. However, despite concurrent increases in blood concentrations of the long-chain n-3 fatty acid DHA in the treatment groups, one study[34] found no significant differences in the behavioural and educational outcomes between the treatment (345 mg DHA/d) and control groups. One study[36] using a dose of 480 mg DHA, 80 mg EPA, 96 mg GLA and 40 mg arachidonic acid (AA) per d detected a small improvement in just two out of sixteen subjective parental and teacher observations after secondary intention-to-treat analysis, although blood fatty acid concentrations were shown to correlate significantly with further parent- ($P=0{\cdot}05$) and teacher-rated ($P=0{\cdot}03$) behaviours. Of the remaining three studies, one[35] showed a small statistically significant ($P=0{\cdot}05$) improvement in three out of fourteen subjective parental behaviour scores in the fish oil plus other fatty acids (186 mg EPA, 480 mg DHA, 96 mg GLA and 42 mg AA per d) supplemented group. One study[37] found no significant difference between treatment (DHA 3·6 g/week or 514 mg/d) and placebo groups, apart from a small significant improvement in continuous performance ($P=0{\cdot}001$) and visual short-term memory ($P=0{\cdot}02$) in the control group only, over 2 months. However, they later reported[38] a significant ($P=0{\cdot}001$) reduction in aggression in the DHA treatment group. A recent study[14] was the only study to report consistent significant ($P=0{\cdot}05$) improvements in both objective and subjective behavourial and educational outcomes assessed in the EPA-rich treatment group (558 mg EPA, 174 mg DHA, 60 mg GLA per d).

There remain too many inconsistencies between the studies included in the present review to reliably inform any conclusion, raising several areas of concern, including: (1) most studies were carried out in children with varying degrees of neurodevelopmental disorders, which may raise questions over the applicability of these data to mainstream children without any developmental complications; (2) the trials were carried out in different populations, likely to have differences in baseline n-3 long-chain fatty acid status; (3) there was a lack of biochemical data – whilst the extraction of blood samples from child populations raises many ethical implications, further metabolic and neurophysiological analyses are required in order to place these findings into any mechanistic context and identify differences in baseline status between different populations; (4) the dosage used in these studies are inconsistent and unlikely to be achieved through dietary means in the UK; (5) whilst the fish oils consumed in the aforementioned studies appeared to be well tolerated, there is currently no national UK dietary reference value and it is essential that optimal dose, duration and fatty acid compositions be established.

Since the date of the search for studies for the present review, several new RCT studies have been reported at scientific meetings and have been published. At the International Society for the Study of Fatty Acids and Lipids (ISSFAL) 7th Congress in July 2006 two research groups reported on the effects of EPA + DHA supplementation in primary schoolchildren (6–10 years). One study[39] in South Australian and Indonesian children found no consistent effects on cognition in well- and marginally nourished children in a total of 780 children over 12 months at a dose of 88 mg DHA/d and 22 mg EPA/d. The other study[40] in 355 South African children over 6 months at a dose of 274 mg n-3 long-chain-PUFA/d found not only improved verbal learning, memory and spelling ability of subjects, but also lessening of the number of days they were absent from school. The third study, now published[41], reported the effects of an EPA (558 mg), DHA (174 mg) and GLA (60 mg) daily supplement in 132 Australian children aged 7–12 years with ADHD over 15 weeks. They found no significant treatment effects on the Conners Teacher Rating Scales but significant effects (between $P=0{\cdot}05$ and $P=0{\cdot}01$ on the various scores) on the Conners Parent Rating Scales. Another recently published RCT[42] was a follow-up study at 4 years of age of breast-fed infants and infants supplemented with and without DHA and AA formula. DHA- and AA-supplemented infants had similar visual acuity and intelligence quotient (IQ) to that of breast-fed infants whilst children who were fed formula containing no DHA and AA had significantly poor visual acuity and verbal IQ at 4 years of age.

Vitamin and mineral supplementation

Two relatively recent studies[16,43] examined the effect of low-dose multivitamin and mineral supplementation on measures of IQ, assessed by the established Wechsler Intelligence Scale for Children revised (WISC-R) test. Both studies took place over several months, were well conducted and gained high quality-assurance assessments. The larger and more recent of the two studies[43] utilised an RCT design in a USA population comprised of predominantly Hispanic working-class pre-teens (6–12 years). The authors reported a moderate, but statistically significant, average increase in the non-verbal IQ ($P=0{\cdot}038$) of children from the active supplement group. However, further matched pairing analyses indicated that this may have been accounted for by a substanital net IQ increase from just a small sub-sample of these children. Analysis of blood biochemistry and/or habitiual diet would have assisted the interpretation of these findings. The other smaller, slightly older, case–control study[16], carried out in a British population of teenagers (13–14 years), reported no significant effect of supplementation on verbal and non-verbal IQ, although this study may have been under-powered. Interestingly, however, blood biochemistry of the participants demonstrated a significant association between plasma ascorbic acid and non-verbal IQ of boys ($P<0{\cdot}001$) and whole-blood glutathione peroxidase activity and non-verbal and verbal IQ of both sexes ($P=0{\cdot}05$). This highlights the importance of examining baseline nutritional status before the functional significance of vitamin and mineral supplementation can be determined.

Although well conducted, these two studies alone provide insufficient evidence as to the effects of low-dose vitamin and mineral supplementation on the IQ score of schoolchildren from the developed world. As both of these studies indicate that particular subgroups of children may be more ‘at risk’, it is imperative that future studies determine baseline and habitual nutritional status. As there may also be potential sex and age differences, it remains important to assess mixed sex populations powered to represent different age groups.

Other

One study[44] examined the effect of a supplemented diet of ‘good food’ *v.* no supplementation in a very small group of deprived Mexican schoolchildren during their first year of elementary school. Whilst significant improvements were observed in the examination results and behaviour of those children who had received the supplemented diet, this study lacked detail, quality and rigour, making it difficult to draw any reliable conclusions.

Comparison of UK and non-UK data

Only six RCT or case–control trial studies were included from the UK (three breakfast studies[9,22,25], two fish oil studies[14,35] and one multivitamin study[16]), all of which were carried out during this decade, with the exception of one study[9]. As there were not sufficient UK studies, the search strategy was expanded to include other countries categorised as 'highly developed' according to the World Bank criterion. It is, however, important to acknowledge the potential dietary, economic, social, educational and cultural differences that may exist between countries. Indeed, the different measures of educational attainment between the countries made it difficult to draw parallels across the datasets. The present review highlighted the requirement for further high-quality, longer-term research to examine the effect of diet on the educational attainment of UK schoolchildren.

Quality-assurance issues

In general the quality scores for the studies investigating sugar, fish oils and multivitamin and mineral supplementation were higher than those investigating breakfast. It is, however, important to recognise the difficulties of delivering a complex intervention such as breakfast within the rigorous framework of an RCT. There were, however, several quality-assurance issues arising generally across the studies included in the present review.

(1) *Factors that could affect the external validity of the studies included in this systematic review.*

Whilst nearly all studies took account of age and sex, ten studies accounted for body weight, six recorded ethnicity and seven adjusted for disease status (although the majority of these studies were in children with ADHD-like behaviours). Only five studies considered habitual nutritional and socio-economic status (four of these also accounted for parental education) whilst just two studies considered family status. As discussed previously, habitual dietary intake may have a significant effect, particularly in the studies of short duration, where the body is physiologically adapted to override any short-term stresses. Although logistically difficult to measure in some circumstances, family status may also impact upon measures of educational attainment, through a complex interplay of socio-cultural modifying effects. Whilst not within the scope of the present review, family status may also be linked to other early life factors such as low birth weight, weaning, breast-feeding, nutrition *in utero* and incidence of illness, which have also been shown to be implicated in later educational attainment[4,45].

Only one study accounted for smoking status, whilst no studies reported alcohol intake, illegal drug misuse or physical activity levels. Whilst it is unlikely in very young children that smoking, alcohol and drug misuse are prevalent, it would be prudent to control for these measures, particularly in older children, given the potential influence on educational and behavioural measures[4]. Physical activity levels have also been shown to positively impact upon cognitive performance in school-aged children[46–48] and must consequently be considered as having a potentially important effect in all age groups. Similarly, no studies adjusted for locality and context, although it is accepted that these factors are highly complex and may be very difficult to control for particularly within 'free-living' situations. However, if studies are carried out under tightly controlled conditions such as a research laboratory, it raises questions over the potential impact of stresses that may be encountered within this artificial environment and the applicability of the findings to 'real-life' situations.

(2) *Maturation and development.*

Although the majority of studies focused on the pre-teen population, only two studies[8,24] formally assessed pubertal development. The mean age at entry to puberty in UK females is 11·2 years[49], with the current definitions of normality for entry into puberty being aged 8 years or more in females and 9 years or more in males. Therefore a significant number of studies would have included pre-pubertal and pubertal children. It is now acknowledged that brain and cognitive development progresses through puberty[50] and studies assessing cognitive function should, if possible, take account of this (particularly in short-term studies).

(3) *Measurement of educational outcomes.*

There was little consistency in methodological assessments of educational attainment (including behaviour). The included papers gave rise to a vast array of different objective and subjective measures of behavioural and educational outcomes, often lacking in appropriate validation. This variety of assessment tools may have, at least in part, been accountable to international differences; however, it may also reflect the vast range of indices that make up an educational achievement, i.e. the complex interaction of mood, motivation, knowledge, application and capability, to name but a few.

(4) *Power, concealment, compliance, randomisation and blinding.*

Statistical power was calculated in just five of the twenty-nine included studies. In addition to this, the degree to which concealment and compliance was reported varied dramatically, which made interpretation and comparisons between studies difficult.

Future research

The current evidence base examining the effect of diet and dietary change on educational attainment (including behaviour) remains inconclusive; it is therefore imperative that future research is undertaken. More research is required within the UK to investigate the effects of supplementation (for example, vitamins and fish oils), specific nutrients (for example, sugar) and complex meals (for example, consumption and nutritional composition of breakfasts and school meals). However, the limitation of existing studies should inform future research, in order to improve the quality and depth of evidence:

(1) Additional longer-term or -duration studies are required to assess long-term impact, sustainability and overcome the possibility of short-term mechanistic adaptations and differences in the rate of pubertal maturation and neurological development.
(2) More studies are required within older (teenage) young individuals.
(3) Biochemical monitoring is important, not only to establish baseline levels of nutrients under investigation, but also to assess compliance and support the understanding of mechanisms. However, withdrawal of blood samples from children requires careful ethical consideration and other alternatives such as finger-prick blood, hair and cheek-cell analyses should be considered where possible.
(4) Studies should be statistically powered and provide clear details regarding randomisation, blinding, concealment and compliance, where an RCT structure can be easily applied (for example, for supplementation studies). In free-living situations (for example, breakfast), that may not easily fit into the rigid confines of the RCT, extremely well-designed cohort studies should be considered as a possible alternative.
(5) Studies should measure and adjust for all potential counfounders, where feasibly possible.
(6) Authors should acknowlege any limitations of their research and use this to place their findings into context.
(7) There should be a broad range of investigations that include children in care, with special needs and from different ethnic minority and socio-economic groups, in order to address populations that may have different needs to the 'mainstream'.
(8) Authors should base research on existing mechanistic evidence and where possible use this to place their findings into context.
(9) We suggest that some consideration be given to the development and use of universal validated measures of educational attainment which would assist comparisons between studies and allow for appropriate meta analyses. However, although this problem is acknowledged by experts in the field, we understand that it will be difficult to achieve a consensus.

Conclusions

The effect of nutrition, diet and dietary change on learning, education and performance is clearly an important question with significant policy implications. However, the current evidence base remains limited and inconclusive. Many studies included within the present review lacked quality in research methodology and reporting (particularly those investigating breakfast consumption) and failed to account for potentially important factors, such as habitual dietary intake, physical activity levels, locality and family context. Two-thirds of the included studies were carried out in primary-aged children and over a half took place over a short duration (<1 month). There was insufficient quantity and consistency to draw any firm conclusions from the studies examining sugar intake, fish oil or vitamin and mineral supplementation. Whilst the majority of included studies examined breakfast interventions, the quality of much of this research remains questionable, which, in conjunction with the diversity of interventions and inconsistency in research design and methodology, made it impossible to reach any definitive conclusions. However, although the current evidence base remains limited there does appear to be emerging evidence for effects of certain fatty acids, for example, EPA and DHA, as a function of dose and time. Furthermore, although not within the scope of the present review, this would be consistent with a wealth of animal, as well as other human studies, showing effects of *n*-3 fatty acids on brain structure and function, behaviour, learning and performance.

The current evidence base would greatly benefit from further research, particularly based in the UK. However, it is essential that future studies reach a high quality standard, are representative of all populations (including minority groups), are undertaken for longer duration and use universal validated measures of educational attainment. Although the importance of this area warrants further research, this will continue to present many challenges given that the effects of nutrition on educational attainment are intrinsically interwoven with multifaceted factors such as family and community context, poverty, disease and individual rates of maturation and neurodevelopment. Whilst the importance of diet in educational attainment remains under investigation, the evidence for promotion of physical activity and a diet low in fat, salt and sugar but high in fruits, vegetables and complex carbohydrates remains unequivocal in terms of health outcomes for all schoolchildren.

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Appendix 1

Search terms

Search terms were developed for Ovid Medline and adapted for the remaining databases.

exp obesity
exp weight gain
exp weight loss
obes$.tw
adipos$.tw
weight gain.tw
weight loss.tw
overweight.tw
over weight.tw
overeat$.tw
over eat$.tw
weight change.tw
body mass$.tw
body composition$.tw
body fat$.tw
bodyfat$.tw
body size.tw
(fat adj3 mass).mp
anthropometry.tw
skinfold measurement$.tw
weight change$.tw
skinfold thickness$.tw
DEXA.tw
bioimpedance.tw
bio-impedance.tw
waist circumference.tw
hip circumference.tw
waist hip ratio.tw
(waist adj2 hip).tw
exp biology
exp genetics
mechanism.tw
function.tw
gene$.tw
leptin.tw
molecul$.tw
cell$.tw
metabol$.tw
ob.tw
environment.tw
hormon$.tw
musc$.tw
adipos$.tw
transport$.tw
glu$.tw
insulin.tw
islet.tw
fatty acids.tw
sterol.tw
inheritance.tw
heritable.tw
geneotyp$.tw
phenotyp$.tw
chromosom$.tw
aetiology.tw
etiology.tw
cause.tw
causal.tw
origin.tw
effect.tw
source.tw
knockout.tw
knock out.tw
chylomicron$.tw
LDL.tw
HDL.tw
knock in.tw
knockin.tw
transgenic.tw
ppar.tw
SREBP1.tw
ChREBP.tw
NPY.tw
MCH.tw
MC4.tw
receptor.tw
POMC.tw
thyroid.tw
CART.tw
androgen.tw
oestrogen.tw
testosterone.tw
growth hormone.tw
IGF.tw
skeletal muscle.tw
tissue.tw
fat oxidation.tw
carbohydrate.tw
protein.tw
epigenetics.tw
foetal.tw
early life.tw
nutrient-gene.tw
db mouse.tw
fa rat.tw
high fat diet.tw
high protein diet.tw
high carbohydrate diet.tw
sucrose.tw
fructose.tw
sympathetic.tw
adrenal.tw
develop$.tw
cortisol.tw
subcutaneous.tw
intra abdominal.tw
intraabdominal.tw
adiposity rebound.tw
adolescent.tw
energy expenditure.tw
resting metabol$.tw
basal metabol$.tw
storage.tw
lipogenesis.tw
lipolysis.tw
lipoprotein.tw
insulin receptor.tw
insulin sensitivity.tw
thermogenesis.tw
breast feeding.tw
breastfeeding.tw
weaning.tw
birth weight.tw
genotyp$.tw
pregnan$.tw
bmi.tw
fat$.tw