

The effects of Nordic school meals on concentration and school performance in 8- to 11-year-old children in the OPUS School Meal Study: a cluster-randomised, controlled, cross-over trial

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Abstract

It is widely assumed that nutrition can improve school performance in children; however, evidence remains limited and inconclusive. In the present study, we investigated whether serving healthy school meals influenced concentration and school performance of 8- to 11-year-old Danish children. The OPUS (Optimal well-being, development and health for Danish children through a healthy New Nordic Diet) School Meal Study was a cluster-randomised, controlled, cross-over trial comparing a healthy school meal programme with the usual packed lunch from home (control) each for 3 months (NCT 01457794). The d2 test of attention, the Learning Rating Scale (LRS) and standard tests on reading and mathematics proficiency were administered at baseline and at the end of each study period. Intervention effects were evaluated using hierarchical mixed models. The school meal intervention did not influence concentration performance (CP; primary outcome, n 693) or processing speed; however, the decrease in error percentage was 0.18 points smaller ($P < 0.001$) in the intervention period than in the control period (medians: baseline 2.03%; intervention 1.46%; control 1.37%). In contrast, the intervention increased reading speed (0.7 sentence, $P = 0.009$) and the number of correct sentences (1.8 sentences, $P < 0.001$), which corresponded to 11 and 25%, respectively, of the effect of one school year. The percentage of correct sentences also improved ($P < 0.001$), indicating that the number correct improved relatively more than reading speed. There was no effect on overall math performance or outcomes from the LRS. In conclusion, school meals did not affect CP, but improved reading performance, which is a complex cognitive activity that involves inference, and increased errors related to impulsivity and inattention. These findings are worth examining in future trials.

Key words: School meals: Nutrition: Cognition: School performance

It is widely considered that a nutritionally balanced diet is beneficial for learning and school performance in children. The influence of diet is plausible, since a poor diet may result in deficiency of nutrients that could play a role in cognitive development⁽¹⁾. In low-income countries where malnutrition is prevalent, school feeding programmes have consistently shown positive short-term effects on the achievement in academic tests⁽²⁾. The relatively high brain metabolism in children also means that children are more vulnerable to fasting compared with adults. In line with this, breakfast skipping has been shown to impair cognitive function and has also been associated with attention problems and lower school grades,

especially in younger children⁽³⁾. Moreover, carbohydrate quality and glycaemic response of foods may influence short-term cognitive performance⁽⁴⁾. The dietary composition has also been hypothesised to influence cognition and school performance through effects on neurological factors involved in learning and memory. Components of a 'Western diet', i.e. a diet high in salt, saturated fat and refined carbohydrates, are linked with reduced cognitive performance, and positive effects are demonstrated of diets rich in n -3 PUFA and micro-nutrients^(5,6). Furthermore, dietary quality has been positively associated with literacy in cross-sectional studies^(7,8), and two recent studies^(9,10) have found that a 12-week intervention

Abbreviations: EI, energy intake; LRS, Learning Rating Scale; OPUS, Optimal well-being, development and health for Danish children through a healthy New Nordic Diet.

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with healthier options in the school cafeteria has positive effects on post-lunch learning-related behaviour. However, evidence of long-term effects of diet on cognition, learning and academic performance in school-aged children is limited^(11,12).

As in many Western populations, the diet of Danish children leaves room for improvement⁽¹³⁾. Danish 8- to 10-year-olds get 40–44% of their daily energy requirement covered during the school day; however, their lunch and snack meals generally contain too much sugar, fat and salt, and too little fish, vegetables, fruit and fibre⁽¹⁴⁾. Moreover, about 12% do not eat any lunch, and the overall dietary habits are less healthy among children whose parents have a lower education level than those whose parents have a higher education level⁽¹⁵⁾. Nutritional interventions in the school setting have the potential to reach children from all socio-economic backgrounds and to influence the nutritional quality of their overall diet. To our knowledge, there is no randomised controlled trial to investigate the effects of introducing a nutritionally balanced, full school meal programme on concentration and school performance in a high-income country. The present study examined the effects of a 3-month school meal intervention on concentration performance (CP; primary outcome) as well as secondary outcomes related to attention, learning and school performance in third and fourth grade children from nine Danish schools. The effect of intervention on other primary outcomes, such as a continuous metabolic syndrome score, is reported in Damsgaard *et al.*⁽¹⁶⁾.

Experimental methods

Study design and subjects

The 'Optimal well-being, development and health for Danish children through a healthy New Nordic Diet' (OPUS) School Meal Study was a cluster-randomised, controlled trial with a cross-over design comparing the habitual packed lunch from home with school meals based on the New Nordic Diet. The New Nordic Diet was largely based on foods grown in the Nordic region and was developed as a healthy, palatable and sustainable diet, which followed the overall guidelines: (1) more energy from plant foods and fewer from meat; (2) more foods from the sea and lakes; (3) more foods from the wild countryside⁽¹⁷⁾. More specifically, the New Nordic Diet is characterised by a relatively high content of berries, cabbage, root vegetables, legumes, fresh herbs, potatoes, whole grains, nuts, fish, seaweed and game⁽¹⁸⁾. Furthermore, the New Nordic Diet is composed in accordance with the Nordic Nutrition Recommendations and the Danish food-based guidelines⁽¹⁸⁾. The control and intervention periods each lasted for approximately 3 months, excluding school holidays. A comprehensive description of the study design and recruitment of schools and participants has been provided previously⁽¹⁹⁾. In order for the study participants to be old enough to participate without their parents being present and to minimise the influence of puberty, only third and fourth grade children were included in the study. To avoid peer contamination of diets and to incorporate the intervention into the regular school schedule, randomisation

was performed in clusters of year group at each school, i.e. either third or fourth grade pupils had the intervention period in the first study period, whereas the other year group had the intervention in the second study period. A school was eligible for the study if it was located in the eastern part of Denmark, had suitable kitchen facilities and had ≥ 4 third or fourth grade classes. Recruitment of participants took place from May to October 2011 and data collection from August 2011 to June 2012. All 1021 children from all of the forty-six classes at third and fourth grade levels at nine schools were invited to participate. The present study aimed to include a variety of children representative of Danish school children, e.g. including children with attention deficit hyperactivity disorder. Hence, exclusion criteria for individual children were only the presence of diseases or conditions that might obstruct the measurements or put the children at risk when eating the intervention meals, or participation in other scientific studies that involved radiation or blood sampling. The present study was conducted according to the guidelines laid down by the Declaration of Helsinki, and all procedures involving human subjects were approved by the Committees on Biomedical Research Ethics for the Capital Region of Denmark (H-I-2010-124). Written informed consent was obtained from the custody holders of all 834 subjects (82% of invited)⁽¹⁹⁾. The study protocol is registered at www.clinicaltrials.gov (NCT 01457794).

Intervention

The dietary intervention consisted of an *ad libitum* lunch meal, a midmorning snack and an afternoon snack served on each school day free of charge. The developed recipes for the school lunch and snack meals were planned to provide around 3.3–3.7 MJ/d, which is equivalent to 40–44% of usual average energy intake (EI) of Danish children of similar ages according to the Danish national dietary survey⁽¹⁴⁾. The planned average energy content was approximately 800 kJ for the midmorning meal, 1700 kJ for the lunch meal and 1000 kJ for the afternoon meal, all with a planned macronutrient distribution in line with the Nordic Nutrition Recommendations, i.e. 25–35% energy from fat, 50–60% energy from carbohydrates and 10–20% energy from protein⁽²⁰⁾. A 3-week menu was developed for each of the four seasons. Each week included a soup day, a fish day, a meat day, a vegetarian day and a buffet day on Fridays; the buffet consisted of pre-made leftovers from the first four weekdays. The lunch meal was predominantly a hot meal with raw vegetables and whole-grain rye bread on the side. A fruit-based dessert was served twice a week. Water was served with the lunch; however, children with milk subscriptions continued to have their milk as usual. The snack meal in the midmorning break consisted of rye bread and raw vegetables or skyr (a high-protein, low-fat yogurt product) with muesli, and the afternoon snack consisted of a bun or bread bar, some raw fruit or vegetable, and nuts or dried berries.

The intervention meals were prepared locally at each school by trained kitchen staff hired for the study. To improve the acceptance of new foods, children were engaged in activities in small teams, who participated in cooking, tasting,

presenting and serving the food to their peers. During the intervention period, the lunch meal was served in a common dining area at seven schools and in the classroom at two schools, and the lunch break was increased from 15 to 20–25 min. Kitchen staff and teachers encouraged the children to taste all parts of the meal and keep a reasonable plate distribution. Children who did not participate in the study were offered the school meals and participation in engaging activities at equal terms.

The control diet was the children's habitual lunch and snacks brought from home; hence, we did not interfere with the dietary intake during school hours in the control period. In Denmark, school children's lunch typically consists of open rye bread sandwiches most often with a meat topping, some fruit (often apple, banana or orange/clementine) and/or vegetables (often cucumber, carrot or tomato) and on average contributes with 24% of EI according to the Danish national dietary survey⁽¹⁴⁾. The control lunch meal was consumed as usual in the classrooms. Besides the lunch meal, some children consumed a snack meal in the midmorning and most children consumed a snack meal in the afternoon. These snack meals often contain fruit and cake and on average contribute with about 4 and 16% of the daily EI, respectively⁽¹⁴⁾.

Randomisation

Cluster randomisation was performed before the children were invited for participation. The unit of randomisation was year group, and cluster randomisation was used to ensure that all third grade classes at a particular school received the intervention and control periods in the same order, and the fourth grade classes at the same school received the intervention and control periods in the opposite order. Since schools had to be visited sequentially, schools were first randomly assigned to two blocks with five and four schools, respectively. Within each of the two blocks, schools were allocated to the order of treatment and control for third and fourth grades by simple randomisation. The randomisation list was performed by a statistician not involved in data collection or analysis using the statistical software package R (R Foundation for Statistical Computing)⁽²¹⁾. The allocation order was not blinded to investigators, schools or participants.

Data collection

Background interview. Before the start of the study, information about parental education was collected during a personal interview with the parent(s) and the child. Household education was based on the parent in the household with the highest education level, distributed on six categories: (1) lower secondary education or less (≤ 10 years); (2) upper secondary education or equivalent; (3) vocational education; (4) short academic education; (5) Bachelor's degree or equivalent; (6) Master's degree or higher (≥ 17 years) based on the standard classifications of education defined by Statistics Denmark⁽²²⁾. Pubertal stage was self-evaluated by the child based on breast development in girls and pubic

hair in boys (Tanner stages)⁽²³⁾. Based on the definitions used by Statistics Denmark⁽²⁴⁾, children were categorised as immigrant/descendant if all grandparents and ≥ 1 parent were born outside Denmark.

Anthropometry. At baseline and at the end of each study period (months 3 and 6), weight and height were measured on a weekday after an overnight fast. Body weight was measured to the nearest 0.1 kg on a digital scale (Tanita BWB 800 S) in an underwear or in light clothing. Height was measured to the nearest 0.1 cm with the child holding the head in Frankfurt horizontal plane using a portable stadiometer (Tanita; CMS Weighing Equipment Limited). Height was measured three times and the mean height was used. BMI was calculated as kg/m^2 . Weight status was categorised as underweight, normal weight, overweight and obesity based on age- and sex-specific cut-offs defined to pass through a BMI of 18.5, 25 and 30 kg/m^2 at the age of 18 years, according to Cole *et al.*^(25,26). Clinical tests (blood sample, blood pressure and dual-energy X-ray absorptiometry scan) were performed on the same day when anthropometric measurements were taken, but were reported separately.

Dietary intake. At baseline and at the end of the each study period (months 3 and 6), the food and beverage intakes of children were assessed for a 7-d period using a validated Web-based Dietary Assessment Software for Children^(27,28). Dietary intake assessments took place the week before the anthropometric measurements. Parent(s) and child received instructions during the background interview, and parents were encouraged to help their child. Portion sizes were estimated by children during the reporting using digital images of various portion sizes developed for the purpose⁽²⁷⁾. Food and nutrient intakes were calculated using data from the Danish Food Composition Databank^(27,29). Dietary intake was estimated for each child as an average over the recorded days. BMR was calculated based on height, weight, sex and age⁽³⁰⁾. Based on mean reported EI and estimated BMR and using a physical activity level of 1.55, cut-offs for under- and over-reporting were set at $\text{EI:BMR} \leq 1.05$ and $\text{EI:BMR} > 2.29$, respectively⁽³¹⁾. Data on dietary intake were only included in the present paper when the dietary intake assessment had been completed at least 4 d and intake was not under- or over-reported.

Physical activity. Physical activity was measured during the same week when dietary intake was also measured by an ActiGraph™ accelerometer (GT3X+ or GT3X from ActiGraph) worn at the waist at all hours of the day and night, for a 7-d period. Analyses of the physical activity data are described in detail by Hjorth *et al.*⁽³²⁾. In the present paper, we included the baseline data on total physical activity for all children who had valid data from at least one weekday and one weekend day. Total physical activity (counts/min) was expressed as total vertical counts from wear-time, divided by measured wear-time.

Outcome measures

At baseline and at the end of the each study period (months 3 and 6), four tests related to concentration and school



performance were administered. At each occasion, the tests were administered on three separate weekdays during the same week when dietary intake and physical activity were also assessed. According to the timetable of each class, all tests were administered on the same weekday and time of day at each occasion. The usual teachers of the class carried out tests in mathematics and reading proficiency during a math and a Danish lesson, respectively. The teachers received written and verbal instructions on how to instruct the pupils and to administer the tests. Project staff administered the d2 test of attention and the Learning Rating Scale (LRS) in the class during school hours (usually in a Danish lesson). All the tests were corrected by project staff.

d2 Test of attention. The d2 test is considered to involve mental concentration, visual perception, visual scanning ability and perceptual speed. It has been shown to have good reliability and validity in assessing the ability to concentrate and pay attention independently of intelligence⁽³³⁾. The d2 test is a simple paper-and-pencil crossing-out task executed under substantial time pressure (6 min)⁽³⁴⁾. The test consists of one page with fourteen lines, each containing forty-seven test items. The test items were the characters 'd' and 'p' with 0–4 dashes arranged either individually or in pairs above and/or below each character. The children were instructed in accordance with standard instruction; to mark as many target characters ('d' with a total of two dashes above and/or below) per line as possible. For every 20 s, the children were instructed to move on to the next line, regardless of how far they had come on the previous line. The outcome parameters from the d2 test were determined based on the number of processed characters as well as the number and type of errors: CP was defined as the number of correctly marked target characters minus errors of commission (incorrectly marked distractor characters). CP was chosen as a primary outcome, because it is assumed to play a considerable role in the learning process, since it is an indicator for overall concentration that encompasses both speed and accuracy of performance. Processing speed was defined as the total number of characters processed. The percentage of errors of omission (unmarked d's with two dashes divided by processing speed) was used as an indicator of inattention and the percentage of errors of commission (incorrectly marked distractor characters divided by processing speed) was used as an indicator of impulsivity in accordance with Wassenberg *et al.*⁽³⁵⁾. Total error percentage (the sum of inattention and impulsivity) was interpreted as an indicator of accuracy.

The Learning Rating Scale. The LRS is a Danish tool developed to measure whether intrinsic learning processes are facilitated in the classroom⁽³⁶⁾. The LRS measures teacher–student relationship, the teacher's expectations towards the students and the social context, i.e. aspects that are expected to be of crucial importance for the learning process. The LRS consists of four 10 cm visual analogue scales, with a smiley face icon at each end that illustrates a negative response on the left and a positive response on the right. Children were instructed to place a mark on the line between the smileys. The negative response on the Learning gain scale was: 'I don't learn a lot in school' and the positive: 'I learn a lot in school'; the Social scale: 'I don't get along well in school'

to 'I get along well in school'; the Method match scale: 'I don't like the way teacher teaches' to 'I like the way teacher teaches'; the Expectation scale: 'Not much is expected of me in school' to 'Much is expected of me in school'. The score was evaluated as the measured distance from the negative smiley (0–10 cm), where a higher score indicates a more positive response. An overall learning alliance score was derived as the sum of the four subscales. In the present study, the LRS was used as an indicator of students' attitudes towards their educational experience.

Sentence reading test. Reading performance was assessed using 'The Sentence Reading Test 2', which is a Danish standard test (Hogrefe Psykologisk Forlag A/S) with good reliability and validity⁽³⁷⁾. The test is designed to be used in second to fifth grade and consists of twenty-seven drawings of a situation, each accompanied by four sentences⁽³⁷⁾. The sentences were formulated as statements, and the child must evaluate each sentence for whether or not the statement matches with the situation in the drawing. Test performance draws on the working memory of the child and reflects the reading comprehension of the child, which includes accurate and fluent decoding of words, vocabulary knowledge, and thinking and reasoning skills. The sentences gradually become longer and more complicated, and as complexity increases, thoughtful analysis of content becomes more essential to comprehension in order to solve the task, e.g. the ability to make inferences. Children were given 8 min to evaluate as many sentences as possible. The outcome parameters from the test are based on the number of correct answers and the number of wrong answers. The number of correct answers relates to the reading proficiency of the child. The number of correct, wrong and skipped sentences were summarised into the total number of sentences read, which reflects the reading speed of the child. Furthermore, the percentage of correct answers out of the total number of answers reflects the ratio between the number of correct answers and speed.

Math tests. Mathematics proficiency was assessed using Danish standard tests. The tests are diagnostic tests designed to measure math skills relative to the grade level. There was a separate version of the test for third and fourth grades (MG3 and MG4), which included fifty and sixty-nine problems, respectively^(38,39). Children were given one lesson (45 min including instructions) to solve as many problems as possible in chronological order and were instructed to skip problems that they could not solve. The outcome parameter from math tests was the number of correctly solved problems.

Sample size

The overall power calculation for the study was based on the metabolic syndrome score. Since no prior information about the year group-level intra-cluster correlation was available and the between-child variation was anticipated to be the main source of variation, the sample size calculation was carried out as if randomisation took place at the child level⁽⁴⁰⁾. A detectable difference of 0.11 SD was judged attainable and relevant for the metabolic outcomes, and nine

schools were considered logistically manageable. Thus, assuming nine schools with four classes and a between-child correlation coefficient of 0.5, a sample size of 673 children was required to detect a difference of 0.11 SD ($\alpha = 0.05$, $\beta = 0.80$)⁽¹⁹⁾. The SD for CP at baseline was 22.9, which translates to a detectable difference of $0.11 \times 22.9 = 2.52$ characters between the intervention and the control diets.

Statistical analyses

Data are presented as means and standard deviations for symmetrically distributed variables and as median and inter-quartile range for skewed variables. Correlation analyses were performed using Pearson's correlation coefficient. Student's *t* test or a rank-sum test was used to evaluate group differences in continuous and ordinal variables. The χ^2 test was used to evaluate group differences in categorical variables.

The effects of the intervention were evaluated at the individual level using hierarchical mixed models in order to account for clustering at the level of schools, year group (within each school), classes and individual children. Linear mixed models were used for the continuous outcomes (LRS and CP and processing speed from the d2 test) and logistic mixed-effects models for percentages and discrete outcomes with an upper limit (error percentages from d2 test, sentence reading test, math tests). The dependent variable was the respective outcome at month 3 and/or month 6. A simple analysis included diet (intervention or control), baseline value, visit (baseline, month 3 and month 6) and the order of the intervention and control periods. We also performed an adjusted analysis, additionally including sex, year group, household education, immigrant/descendant, baseline month of test, and baseline age, BMI and total physical activity as covariates. Furthermore, we performed a secondary subgroup analysis of the effect of the intervention separately for the third and fourth grade math tests, as the tests were not identical with regard to the content and number of tasks.

The underlying assumptions for the models were investigated by visual inspection of residual and normal probability plots. Log-transformations were applied for outcomes from the LRS due to substantial deviations from model assumptions. Estimates and CI were back-transformed when presented in tables. OR were translated to the original scale when presented in text⁽⁴¹⁾. For normally distributed outcomes, the effect size was converted to SD by dividing the effect size on the original scale with the baseline SD, in order to compare the results with the effect of one year schooling, which is estimated to be 0.4 SD⁽⁴²⁾.

The analyses were based on children who had data on at least one of the cognitive outcomes at baseline and month 3 and/or month 6, as well as data on all covariates. This means that the same children were included in the simple model and the adjusted model for each outcome. However, the sample size varies depending on the outcome, since some of the children were absent on some of the cognitive testing days (Fig. 1). Data pre-processing and statistical analyses were carried out using STATA 12.0 (StataCorp LP), except for the logistic mixed-effects models, which were analysed using R⁽²¹⁾. $P < 0.05$ was considered statistically significant.

Results

Consent to participate was obtained for a total of 834 children (82% of the invited and equivalent in the two clusters). Participating children were from all the forty-six classes at the third and fourth grade levels at the nine schools. A total of sixty-nine children (8.3%) withdrew during the study mainly because they changed school or class ($n = 29$), disliked or found the measurements too time-consuming ($n = 17$), or disliked the intervention school meals ($n = 13$) (Fig. 1). The proportion of children who withdrew from the study was not different between the two clusters (intervention–control 10.2% *v.* control–intervention 6.5% of the participants, $P = 0.054$). A total of 739 children (72% of invited) had data available on at least one of the outcomes at baseline and at the end of one or both study periods, as well as on relevant covariates. Baseline characteristics for the 739 children are presented in Table 1. Slightly more fourth grade than third grade children were allocated to receiving the intervention in the second study period ($P = 0.027$); however, the mean age did not differ between clusters ($P = 0.061$). There was also no difference between the clusters with regard to sex distribution, puberty, weight status, physical activity, household education level or the proportion of immigrants/descendants (data not shown). The overall age range was 8.4–11.6 years. The mean duration of the intervention period was 55 (range 48–61) school days and 59 (range 53–65) school days in the control period.

Concentration and school performance at baseline

The d2 test and LRS were performed on the same weekday and school lesson at all the three assessments, except for one class (nineteen children), where the tests were administered in the second lesson of the day (usually between 09.00 and 10.00 hours) at baseline and at month 6, but in the lesson just after lunch (usually between 12.00 and 14.00 hours) at month 3. Baseline performance in the d2 test, LRS, sentence reading test and math tests is summarised in Table 2. Most outcomes were normally distributed; however, the LRS scores and the percentage of correct sentences in reading were highly skewed towards the maximum value, and the percentages of errors in the d2 test were skewed towards the minimum value. In the math test, there was a marked ceiling effect, since many children finished the entire math test in the allocated period of 45 min. This was especially apparent in the MG3 test, where 70% of the children finished the entire test, whereas only 22% finished the MG4 test. There was no difference in baseline test performance between children allocated to receive the intervention in the first and second study periods. CP was positively correlated with the processing speed in the d2 test ($r = 0.89$, $P < 0.001$), the number achieved and the percentage of correct sentences in the sentence reading test ($r = 0.34$ and $r = 0.13$, both $P < 0.001$), and the number of correctly solved problems in the math test ($r = 0.39$, $P < 0.001$), whereas error percentage in the d2 test was negatively correlated with CP ($r = -0.39$, $P < 0.001$). The LRS overall learning alliance score was not correlated with any of the test outcomes, except for

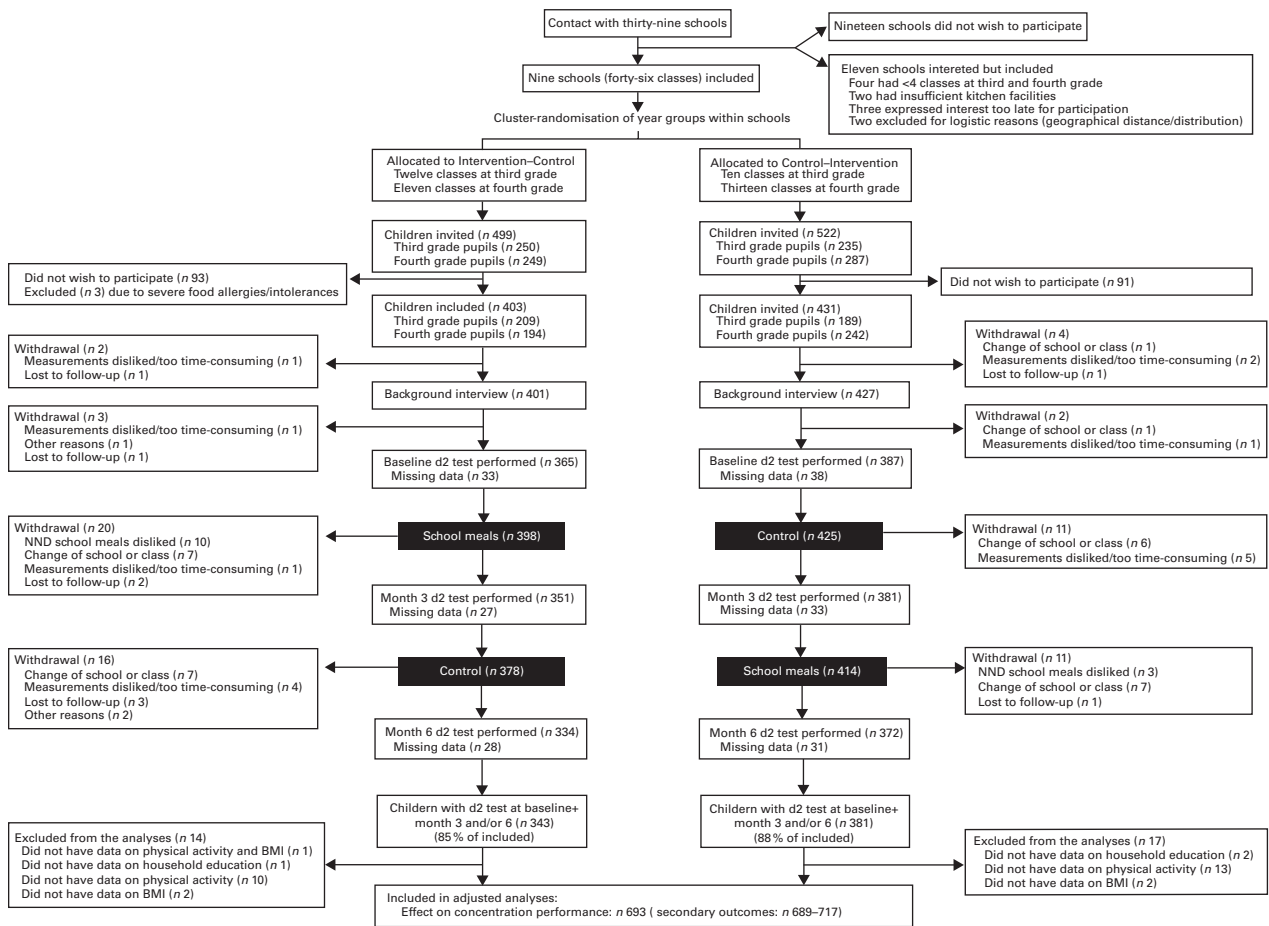


Fig. 1. Flow chart of participants included in the analysis of concentration performance. NND, New Nordic Diet.

a weak negative correlation with processing speed ($r = 0.09$, $P = 0.023$).

From baseline to months 3 and 6, performances improved for most outcome measures, except for most LRS subscale scores and the total percentage of errors in the d2 test, which only decreased from baseline to month 3 (online supplementary Table S1). Fourth grade students generally had higher scores on all tests than third grade students; however, the error percentages in the d2 test did not differ between the third and fourth grades and the LRS scores were higher in third grade (online supplementary Table S2). The number of correctly solved problems in math was slightly lower in the third grade than that in the fourth grade test (31.1 (SD 10.1) *v.* 32.7 (SD 12.2), $P = 0.047$). Yet, due to the higher number of math problems in the fourth grade test, the proportion of correctly solved problems was markedly higher in third grade (62.1 (SD 20.2) and 47.5 (SD 17.7)%, $P < 0.001$) (online supplementary Table S1).

The effect of the school meal intervention on overall diet

Dietary intake data of children showed that their average daily dietary intake was more in line with the recommended nutrient intakes during the school lunch period compared with the control period (Table 3). More specifically, the

average intake of vegetables, fish, potatoes, fibre, protein, Fe, folate, iodine and vitamin D was higher during the intervention period, whereas the average intake of bread, whole grain and fat (predominantly saturated fat) was lower during the intervention period than during the control period (Table 3). Moreover, the proportion of children who met the Danish dietary guidelines for fish was higher in the intervention period than the control period, whereas no difference on the proportion with recommended intake of whole grain or fruit and vegetables was seen (Table 3).

Effects of the school meal intervention on concentration and school performance

The intervention did not influence the primary outcome, CP, or processing speed in the adjusted model; however, the error percentage in the d2 test was 0.18% points higher in the intervention period than the control period (Table 2). Concerning the type of error, the percentage of both the errors of omission (inattention) and the errors of commission (impulsivity) was higher in the intervention period than the control period, with an effect size of 0.14% points and 0.04% points, respectively.

In contrast, all the three outcomes from the reading test were improved by the school meal intervention (Table 2).

Table 1. Demographics and baseline characteristics of the study population

(Mean values and standard deviations; number of participants and percentages)

	Mean	SD	n	%
Male:female ratio			739	51:49
Age (years)	10.0	0.6	739	
Third:fourth grade ratio			739	49:51
Weight status*				
Underweight			72	9.7
Normal weight			570	77.1
Overweight or obese			97	13.1
Girls BMI (kg/m ²)	17.0	2.4	359	
Boys BMI (kg/m ²)	17.3	2.5	380	
Girls entered puberty†			161	46.0
Boys entered puberty†			84	22.9
Total physical activity (counts/min)	490.0	131.2	739	
Immigrant/descendant‡			86	11.6
Household education level§				
Lower secondary education or less			40	5.4
Upper secondary education or equivalent			24	3.3
Vocational education			238	32.2
Short academic education			70	9.5
Bachelor's degree or equivalent			211	28.6
Master's degree or higher			156	21.1

* Based on age- and sex-specific cut-offs defined to pass through BMI at 18.5, 25 and 30 kg/m² at the age of 18 years^(30,31).† Puberty entered was determined based on Tanner stages⁽²²⁾ and defined as Tanner stage ≥ 2 . Girls *n* 350; boys *n* 367.‡ Immigrant/descendant was defined as participants whose grandparents and ≥ 1 parent were born outside Denmark.

§ Households were categorised according to the parent/guardian with the highest education level.

The effect size corresponded to 0.7 sentences or 0.04 SD for reading speed and 1.8 sentences or 0.1 SD for the number of correct sentences. For the percentage of correct sentences, the effect corresponded to 1.5% points more in the intervention period compared with the control period. The overall performance in math was not influenced by the school meal intervention; however, secondary subgroup analyses showed that the intervention decreased performance in the third grade (OR 0.93 (interquartile range 0.88–0.98) approximately 0.6 problems less, $P=0.011$), but increased performance in the fourth grade (1.05 (interquartile range 1.01–1.10) approximately 0.7 problems more, $P=0.020$) (online supplementary Table S3). There was no effect of the school meal intervention on any of the LRS scores. The overall conclusions remained the same for all outcomes with and without adjustment for potential confounders. The order of treatment generally did not significantly influence on the results, except for the number of correct sentences in reading ($P=0.007$), where the effect was only present in children who received the intervention after the control period. The effect size in those children corresponded to 6.2 sentences more in the intervention period than the control period (OR 1.30 (interquartile range 1.13–1.50)). The intervention effect was not influenced by the exclusion of fourteen children diagnosed with attention deficit hyperactivity disorder or attention deficit disorder (data not shown).

Discussion

The present study showed that the introduction of a healthy school meal programme for a 3-month period did not affect CP in 8- to 11-year-old Danish children. However, the school meal intervention improved reading performance, but also increased percentage of errors in the d2 test, which is related to inattention and impulsivity.

To our knowledge, the OPUS School Meal Study is the first randomised, controlled trial to study the effects of serving nutritious school meals in generally well-nourished children. However, a comparable 2-year school meal intervention was performed in 1947–9 in low-income Canadian families⁽⁴³⁾. In contrast to our findings, no effects were identified on intelligence quotient-test scores, school marks, reading or math test performance. Yet, the validity of these results was compromised by methodological issues such as 20% non-random group allocation, a 30% dropout and use of various tests over the course of the study. Contrary to this, improvements in standardised tests of school performance have been detected in studies that investigated the effect of healthier options in school cafeterias^(44–46). Interestingly, in one study, the effect size has been found to be more prominent in English than in mathematics⁽⁴⁶⁾, which is in line with our findings for reading performance and not math proficiency. In contrast, the opposite was observed in another study, where math achievement improved, whereas there was only a trend for improvement in reading achievement⁽⁴⁵⁾. However, these results were found to be using a quasi-experimental design, and in one study, the intervention included a physical activity component^(44–46). Moreover, none of these studies assessed whether the healthy options in school cafeterias actually improved the dietary intake of the children. The present study only focused on diet and physical activity was not influenced by the intervention⁽³²⁾. We served the school meals to all children free of charge, which improved their overall diet and increased their intake of fish and several nutrients, such as iodine, Fe, folate and vitamin D, which have been associated with cognitive performance in children^(12,47).

The observed effect of the intervention on reading performance was small relative to the effect of factors such as genetics, sex, health, social position and quality of school⁽⁴⁸⁾. Yet, a modest effect size is not surprising, since the effect of nutrition is expected to be subtle in a generally well-nourished population⁽⁴⁹⁾. Relative to the estimated effect of one year schooling, i.e. 0.4 SD⁽⁴²⁾, the difference between intervention and control for reading speed and proficiency corresponded to 10.9 and 24.9% of the effect of one school year⁽⁴²⁾, which seems relevant, especially considering that this was obtained after only 3 months of school meals. Hence, the intervention increased number correct relatively more than reading speed, as confirmed by the effect on percentage correct. The interaction with the order of dietary intake periods was significant for number of correct, but not number read or percentage correct and could thus have been a chance finding. The consistent effect for reading supports the credibility of the result. Contrary to this, the percentage of errors in the d2 test was influenced by the intervention, whereas CP and processing speed were not.



Table 2. Concentration and school performance at baseline, after the control and intervention periods, and evaluated as differences between intervention and control* (Medians and interquartile ranges (IQR)†; mean values and standard deviations)

	Crude values												
	Baseline			Control			Intervention			Difference between intervention and control‡			
	Median	IQR	<i>n</i>	Median	IQR	<i>n</i>	Median	IQR	<i>n</i>	Estimate	95 % CI	<i>P</i>	<i>n</i>
d2 Test of attention													
Concentration performance			693			637			643	-0.16	-1.29, 0.98	0.79	693
Mean	130.6			159.0			159.2						
SD	22.9			27.0			28.4						
Processing speed			693			637			643	1.84	-0.83, 4.51	0.18	693
Mean	331.4			397.3			400.3						
SD	57.7			65.8			68.8						
Total error %	2.03	1.05-3.27	693	1.37	0.69-2.42	637	1.46	0.78-2.54	643	1.10	1.06, 1.15	< 0.001	693
Omission error %	1.60	0.81-2.87	693	1.27	0.63-2.24	637	1.35	0.67-2.47	643	1.09	1.04, 1.14	< 0.001	693
Commission error %	0.27	0.0-0.58	693	0.0	0.0-0.30	637	0.0	0.0-0.29	643	1.22	1.06, 1.40	0.004	693
Learning Rating Scale													
Overall, learning alliance§	37.0	33.5-39.3	689	37.2	32.7-39.4	636	36.8	32.0-39.3	637	-0.14	-0.44, 0.16	0.37	689
Learning gain scale§	9.6	8.2-10	689	9.7	8.2-10.0	636	9.6	8.0-10.0	637	-0.05	-0.14, 0.04	0.27	689
Social scale§	9.9	9.1-10	689	9.9	8.9-10.0	636	9.9	8.7-10.0	637	-0.03	-0.11, 0.06	0.55	689
Method match scale§	9.7	8.3-10	689	9.7	8.0-10.0	636	9.6	8.0-10.0	637	0.005	-0.10, 0.11	0.93	689
Expectation scale§	9.7	8.1-10	689	9.8	8.0-10.0	636	9.8	8.0-10.0	637	-0.04	-0.15, 0.07	0.44	689
Sentence reading test													
Reading speed			717			661			666	1.03	1.01, 1.06	0.009	717
Mean	55.9			67.8			68.5						
SD	16.2			16.8			17.7						
No. correct			717			661			666	1.08	1.05, 1.10	< 0.001	717
Mean	51.2			61.9			63.5						
SD	17.7			19.2			20.0						
% correct (of read)	96.9	93.1-98.6	717	97.6	94.0-98.9	661	97.5	94.6-98.9	666	1.34	1.26, 1.43	< 0.001	717
Math test													
No. correct			698			648			655	1.003	0.97, 1.04	0.85	698
Mean	31.9			40.1			40.5						
SD	11.2			10.5			10.8						

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* The table includes children with data on relevant covariates and at baseline and month 3 and/or 6 on ≥ 1 of the outcomes (*n* 739).

† Median and IQR values are non-normally distributed data.

‡ The difference between intervention and control was estimated using linear mixed models (concentration performance, processing speed and Learning Rating Scale outcomes) or logistic mixed-effects models (all other outcomes), with the respective estimates presented as β and 95 % CI or OR and 95 % CI. The model included visit, order of intervention and control period, the respective baseline value, grade, sex, immigrant/descendant, baseline age, household education, month of baseline test, baseline BMI and baseline physical activity, and random effects (school, year group within school, class and individual). Analyses of outcomes from the d2 test of attention and Learning Rating Scale were also adjusted for weekday and lesson of test at all the three assessments.

§ Dependent variable was log-transformed to perform regression analysis.

Table 3. Dietary intake at control and intervention periods, and evaluated as differences between the intervention and control* (Medians, percentages, 25th and 75th percentiles)

	Control				Intervention				Difference between intervention and control		
	%	Median	Percentiles		%	Median	Percentiles		Estimate†	95% CI	P
			25	75			25	75			
Vegetables (g/d)		119.1	76.1	160.3		134.7	96.9	172.3	13.6	7.6, 19.7	<0.001
Fruit (g/d)		121.8	72.1	179.8		111.1	68.6	176.7	-4.2	-11.6, 3.2	0.27
Fruit and vegetable intake ≥ 300 g/d (%)	32.7				34.9				1.0	-4.1, 6.1‡	0.70
Meat (g/d)		93.2	65.3	125.4		90.9	65.5	127.5	-1.2	-5.8, 3.5	0.63
Poultry (g/d)		16.9	4.2	36.2		16.9	3.9	33.8	0.9	-1.2, 3.1	0.39
Fish consumers (%)§	73.1				91.2				18.5	13.8, 23.2‡	<0.001
Fish and fish products (g/d)		19.8	7.6	36.0		27.3	16.7	47.6	9.8	7.1, 12.5	<0.001
Fish intake ≥ 350 g/week (%)	11.1				18.0				6.8	2.9, 10.7‡	<0.001
Potatoes and potato products (g/d)		37.5	17.9	65.5		82.1	48.2	122.4	44.2	39.2, 49.3	<0.001
Bread and cereal products (g/d)		196.3	162.9	237.0		171.3	137.8	211.1	-26.0	-30.4, -21.6	<0.001
Whole grain (g/d)		49.1	33.0	69.8		42.6	27.8	62.4	-6.2	-8.5, -3.9	<0.001
Whole-grain intake ≥ 75 g/d (%)	19.6				16.5				-3.1	-6.8, 0.7‡	0.11
Fibre (g/d)		17.0	13.9	20.4		17.8	14.8	21.5	0.8	0.3, 1.2	0.001
Energy (kJ/d)		7676	6767	8607		7757	6869	8887	12.6	-116.0, 141.2	0.85
Energy from carbohydrates (%)		51.7	50.0	54.9		52.1	48.9	55.3	0.3	-0.2, 0.7	0.25
Energy from added sugar (%)		11.0	8.3	14.6		11.2	8.3	14.8	-0.1	-0.5, 0.3	0.65
Energy from protein (%)		15.2	13.7	16.8		16.0	14.4	17.4	0.8	0.6, 1.1	<0.001
Energy from fat (%)		32.9	30.4	35.5		31.8	29.2	34.4	-1.1	-1.5, -0.7	<0.001
Energy from SFA (%)		13.4	11.9	14.7		12.8	11.4	14.2	-0.6	-0.8, 0.1	<0.001
Energy from MUFA (%)		12.2	10.9	13.5		11.8	10.6	13.1	-0.4	-0.6, -0.2	<0.001
Energy from PUFA (%)		4.7	4.3	5.4		4.7	4.2	5.3	-0.004	-0.1, 0.1	0.93
Fe (mg/d)		8.5	7.4	10.0		9.2	7.9	10.9	0.5	0.3, 0.7	<0.001
Folate (µg/d)		231.6	195.8	278.3		247.8	208.6	301.4	14.2	7.0, 21.4	<0.001
Iodine (µg/d)		174.4	140.9	221.3		206.2	161.4	258.9	23.0	15.2, 30.7	<0.001
Vitamin D (µg/d)		1.9	1.4	2.9		2.4	1.6	5.7	0.9	0.6, 1.1	<0.001

* The table includes children with data on dietary intake from baseline and month 3 and/or 6. Baseline *n* 594; control *n* 532; intervention *n* 510, unless otherwise noted.

† The difference between intervention and control diet was estimated using mixed models with random effects (school, year group within school, class and individual) that included visit, order of intervention and control periods, baseline values, sex, baseline age, grade, household education, immigrant/descendant, month of baseline dietary assessment, baseline BMI and baseline physical activity. *n* 594 unless otherwise noted.

‡ Estimate and 95% CI is presented as percentage points, calculated from OR.

§ The percentage eating fish (% yes) was determined as the proportion of children who had an intake > 0 g/d during the 7-d dietary assessment.

|| Intake in g/d, only for children who had a fish intake above 0 g/d. Baseline *n* 425; control *n* 323; intervention *n* 362. Dependent variable was log-transformed and estimates are back-transformed in table.

The lack of effect on CP might be due to insufficient sample size, since the power calculation was based on the other primary outcome in the study and subsequent conversion of the effect size for that outcome. However, the estimated effect on CP is very close to zero and would not have been of practical relevance. The increase in error percentage indicated that the children were relatively more prone to make errors related to inattention and impulsivity in the intervention period compared with the control period. As opposed to processing speed and CP, the proportions of errors of omission and errors of commission (inattention and impulsivity) were not correlated with age and did not differ between the third and fourth grades. A previous study has also found this for inattention, whereas impulsivity has been found to be higher in fourth grade⁽³⁵⁾. This might indicate that these aspects of attention were already fully developed at the beginning of third grade. In this perspective, it is puzzling to find an effect of diet intervention on these outcomes. The opposite effect of the intervention on the third and fourth grade math tests was also surprising. This might be related to differences in reliability and validity of the two math tests,

i.e. different complexity and number of tasks. This is supported by the different degree of ceiling effect, which was more pronounced in third grade than in fourth grade. Moreover, the math tests were administered differently from the original test instructions, which prescribed no time limit in order to allow all children to finish the test⁽³⁷⁾. Besides, the subgroup analysis was not planned, and there was no effect on overall math performance. It is, therefore, not feasible to draw a conclusion on the effect of school meals on math performance in the present study. The lack of effect on the LRS indicated that students' attitude towards their educational experience was not influenced by the school meal intervention. However, it is possible that the pronounced skewedness reduced the variability of the data and the power to detect differences.

As planned, the dietary intake during school hours, defined as midmorning snack, lunch and afternoon snack, contributed with 44% of total EI at baseline (R Andersen, A Biloft-Jensen, T Christensen, EW Andersen, M Ege, AV Thorsen, VK Knudsen, CT Damsgaard, LB Sørensen, RA Petersen, KF Michaelsen and I Tetens, unpublished results). During the control period, the

overall intake of fish, fruit, vegetables, whole grain, vitamin D and Fe is lower, and the intake of saturated fat and added sugar is higher than recommended^(20,50). As the intervention improved the intake of most of these dietary parameters, the school meal intervention succeeded to improve the quality of their overall dietary intake. Hence, these results confirmed the previously reported findings for dietary intake in the entire study population⁽⁵¹⁾. The intervention meals differed from the habitual meals during the school day in several ways. A major difference was that a hot lunch meal was served in the intervention period as opposed to a lunch pack brought from home, typically with rye bread sandwiches in the control period. Moreover, there were no confectionaries or processed foods in the intervention meals, whereas this was not restricted during the control period where the children consumed their habitual diet. The whole-diet approach to obtain a healthier diet has high applicability and relevance to public health. Yet, this kind of intervention also means that participants cannot be blinded to the intervention and control meals. Hence, it is possible that expectations contributed to the observed effects. Moreover, we cannot distinguish between dietary and environmental elements of the intervention, such as the lunch setting and participation in the school kitchen, which may have increased the children's self-efficacy and confidence in the intervention period. However, these circumstances could be expected to occur if a similar school food programme was introduced and are therefore considered to be part of the intervention effect.

Since the OPUS School Meal Study was performed in a 'real-life' setting, compromises had to be made to fit the study into the everyday life at school; for example, we used a cluster randomisation by year group at each school, although individual randomisation would have been optimal. Yet, adjustment for a number of potential confounders did not influence the results. Moreover, participants who received intervention in the first study period did not seem to differ from participants who received the intervention in the second study period. The 'real-life' setting also meant that the intervention meals were served *ad libitum* and that we did not strictly control what and how much children consumed of the food that was served. This is similar to the circumstances in the control period, but without data on dietary intake during school hours, this limits our ability to determine in what ways the intervention and control meals differed from each other. The local anchoring and collaboration with each school most probably contributed to the high participation (82%), which resulted in a reasonable sample size with an equal representation of girls and boys, and third and fourth grade students. The internal validity of the study was strengthened by the low dropout rate (8.3%). Although dropouts had lower household education level, reasons were mainly unrelated to the study and did not differ with regard to age, sex, immigrant/descendant or anthropometry, which reduce the likelihood of bias⁽¹⁹⁾. Another strong point was that we predominantly succeeded to administer each test at the same weekday and lesson at each occasion. Although we did not observe while teachers administered the tests, we thoroughly instructed teachers; teachers were familiar with this type of test and the same

teacher usually administered the test to the class at each occasion. Overall, it was positive that test conditions resembled participants' everyday school environment. However, we cannot rule out biased outcome assessment, since the persons administering the tests were not blinded. Nevertheless, project staff was blinded to the study period when correcting the tests. We obtained a fairly representative sample with respect to parental education level and the proportion of immigrants/descendants in the Danish population^(52,53). Likewise, dietary intake in the control period was similar to the Danish National Surveys⁽⁵⁴⁾. Overall, this indicates that the results have a high degree of generalisability to Danish children of similar ages and possibly to other high-income countries. Yet, we cannot extrapolate the findings to interventions of longer duration.

The OPUS School Meal Study is the first randomised, controlled trial investigating the effects of serving healthy school meals on concentration and school performance in a generally well-nourished population. The study applied a rigorous design and found consistent improvement in reading performance, which is a complicated cognitive activity, a fundamental skill for participation in society and a prerequisite for learning. This finding has perspectives for educational attainment, which has long-term implications for occupation, income and social status and, in turn, influences a range of health determinants, such as work environment and health behaviour^(55,56). However, the intervention also seemed to increase the number of errors related to inattention and impulsivity. These noteworthy findings call for further investigation, including the role of specific cognitive, behavioural and motivational aspects that may influence school performance. Yet, the scarcity of evidence should not hold back the promotion of nutritionally balanced meals during school hours as part of a healthy diet.

Supplementary material

To view supplementary material for this article, please visit <http://dx.doi.org/10.1017/S0007114515000033>

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