European Journal of Clinical Nutrition (2016) 70, 1155–1161

www.nature.com/ejcn

ORIGINAL ARTICLE

Differences in the effects of school meals on children's cognitive performance according to gender, household education and baseline reading skills

LB Sørensen[1], CT Damsgaard[1], RA Petersen[1], S-M Dalskov[1], MF Hjorth[1], CB Dyssegaard[2], N Egelund[2], I Tetens[3], A Astrup[1], L Lauritzen[1] and KF Michaelsen[1]

BACKGROUND/OBJECTIVES: We previously found that the OPUS School Meal Study improved reading and increased errors related to inattention and impulsivity. This study explored whether the cognitive effects differed according to gender, household education and reading proficiency at baseline.

SUBJECTS/METHODS: This is a cluster-randomised cross-over trial comparing Nordic school meals with packed lunch from home (control) for 3 months each among 834 children aged 8 to 11 years. At baseline and at the end of each dietary period, we assessed children's performance in reading, mathematics and the d2-test of attention. Interactions were evaluated using mixed models. Analyses included 739 children.

RESULTS: At baseline, boys and children from households without academic education were poorer readers and had a higher d2-error%. Effects on dietary intake were similar in subgroups. However, the effect of the intervention on test outcomes was stronger in boys, in children from households with academic education and in children with normal/good baseline reading proficiency. Overall, this resulted in increased socioeconomic inequality in reading performance and reduced inequality in impulsivity. Contrary to this, the gender difference decreased in reading and increased in impulsivity. Finally, the gap between poor and normal/good readers was increased in reading and decreased for d2-error%.

CONCLUSIONS: The effects of healthy school meals on reading, impulsivity and inattention were modified by gender, household education and baseline reading proficiency. The differential effects might be related to environmental aspects of the intervention and deserves to be investigated further in future school meal trials.

European Journal of Clinical Nutrition (2016) **70,** 1155–1161; doi:10.1038/ejcn.2016.99; published online 15 June 2016

INTRODUCTION

A main argument for school meal programmes is that nutritious food in school will affect all children regardless of background and thereby reduce some of the socioeconomic disparities in diet and health. Hence, when examining the effect of dietary interventions in the school setting, it is important to be aware of any heterogeneous effects. Even though differential effects of a school meal programme are highly relevant in a public health context, few studies have investigated such research questions.

Cognitive effects of dietary interventions are particularly important in the school setting, as school performance has extensive implications for occupation, income and social status, which in turn influences a range of health determinants, such as work environment and health behaviour.[1] Food and taste preferences are strongly influenced by social factors, and low socioeconomic status is associated with unhealthy eating patterns.[2,3] This may serve as a barrier for changing dietary habits, and interventions targeted at obesity prevention have been shown to be more effective in children from higher socioeconomic background.[4,5] On the other hand, because of the lower starting point, the potential for improvement is particularly high in children from less advantaged families. Nevertheless, only a few nutrition intervention studies in the school setting have investigated the effects on socioeconomic inequality in cognitive outcomes.[6,7]

Even before the onset of puberty, gender differences exist in several cognitive domains—for example, boys tend to be better at spatial skills, whereas girls tend to be better at verbal fluency and aspects of memory performance.[8] Gender differences in school performance are also well known. Social expectations, gender roles and biological differences in intellectual development mean that boys and girls have different characteristics with regard to school readiness and the ability to adapt to learning activities.[9] Hence, girls and boys may also respond differently to the introduction of a comprehensive school meal intervention, which involves changes to both their diet and eating environment. Obesity prevention interventions have been shown to be more effective in girls than in boys.[4,5] Similarly, a previous school meal study has identified stronger effects on educational outcomes in girls.[6]

Interestingly, a school trial found that supplementation with docosahexaenoic acid (20:6n-3) only improved reading performance among children who initially underperformed in reading.[10] Poor literacy often coincides with poor performance in other areas, and therefore it is especially important to focus on enhancing the performance of children who underperform in reading.

[1]Department of Nutrition, Exercise and Sports, Faculty of Science, University of Copenhagen, Frederiksberg C, Denmark; [2]Department of Education, Faculty of Arts, Aarhus University, Copenhagen, Denmark and [3]Division of Nutrition, The National Food Institute, Technical University of Denmark, Søborg, Denmark. Correspondence: Dr LB Sørensen, Department of Nutrition, Exercise and Sports, Faculty of Science, University of Copenhagen, Rolighedsvej 26, Frederiksberg C 1958 Denmark.
E-mail: louise.bergmann@gmail.com
Received 1 September 2015; revised 18 April 2016; accepted 20 April 2016; published online 15 June 2016

In the Optimal well-being, development and health for Danish children through a healthy New Nordic Diet (OPUS) School Meal Study, we showed that 3 months of school meal intervention increased 8- to 11-year-old children's intake of fish, potatoes and vegetables, slightly increased the energy percentage (E%) from protein and lowered the fat E%.[11,12] The effect on fish intake was confirmed by an increase in whole-blood n-3 LCPUFA status.[13] Moreover, we have shown that the intervention improved children's reading performance, but at the same time increased the d2-error%, which is related to inattention and impulsivity.[14] The objective of this study was to explore whether the effects of the school meal intervention on attention and school performance were modified by gender, baseline reading proficiency and household education. Similarly, we evaluated effect modifications for the intervention effects on dietary intake and n-3 LCPUFA status. Finally, we examined whether the intervention influenced any inequalities in baseline test performance.

SUBJECTS AND METHODS

The design and methods of the OPUS School Meal Study have been described previously.[12] The study was a cluster-randomised cross-over trial comparing school meals based on the New Nordic Diet principle with the traditional packed lunch (control) for 3 months each in Danish third- and fourth-grade children. The overall purpose was to evaluate effects on early disease risk markers, cognition and school performance, body composition and dietary intake. The primary outcomes were concentration performance and the metabolic syndrome score, and the sample size calculation was based on a clinically relevant change of 0.11 s.d. in the metabolic syndrome score, resulting in a sample size of 673 children ($\alpha = 0.05$, $\beta = 0.80$).[12] The study took place at nine Danish schools that had $\geqslant 4$ classes at the third- and fourth-grade level and suitable kitchen facilities. Classes were randomly allocated to receive the intervention in the first or the second study period in clusters of year group within each school. Year groups were randomised within two blocks of five and four schools. A total of 834 children (82% of invited) were enrolled in the study (May–October 2011). The only exclusion criteria were (1) diseases or conditions that might obstruct the measurements or put the child at risk when eating the intervention meals, or (2) participation in other scientific studies that involved radiation or blood sampling. Written informed consent was obtained from the custody holders, and all procedures were in accordance with the ethical standards of the Committees on Biomedical Research Ethics of the Capital Region of Denmark (H-I-2010-124). The trial was registered at www.clinicaltrials.gov.

Intervention

The intervention school meals were prepared at each school and consisted of an *ad libitum* lunch, a midmorning snack and an afternoon snack served on each school day. Recipes were in line with the Nordic recommendations,[15] covered 40–44% of the daily energy requirement of an 11-year-old boy and were in line with the guidelines of the New Nordic Diet.[16] Each week the lunch meal scheme was soup, fish, meat, vegetarian and a buffet on Fridays, which was based on food from the first four days. The lunch break during the intervention period was 20–25 min, and lunch was served in a common dining area at seven of the nine schools and in the classroom at two schools. In small teams, the children participated in cooking, tasting, presenting and serving the lunch meal two to three times during the intervention period. In the control period, children had their usual lunch during the standard 15- min break in the classroom, typically a lunch pack with open rye-bread sandwiches brought from home.

Data collection

Data collection took place from August 2011 to June 2012. The household education level was based on the parent with the highest education in the household and categorised as follows: (1) non-academic education including lower secondary education or less, upper secondary education or equivalent and vocational education, or (2) academic education including short academic education, Bachelor's degree or equivalent and Master's degree or higher. Household income before tax was obtained in 12 categories and recoded into three categories ($<$67 113 EUR, 67 113–93 958 EUR and $\geqslant$93 958 EUR). Immigrant/descendant was defined as children whose grandparents and $\geqslant 1$ parent were born outside Denmark. Commencement of puberty was defined as Tanner stage $\geqslant 2$, based on breast development in girls and pubic hair in boys at baseline.[17]

Other measurements were performed three times during the study: at baseline, and at the end of each study period (visits 1, 2 and 3). Physical activity was assessed using the Actigraph accelerometer (GT3X+ or GT3X) that the child wore at the waist for 7 days.[18] Total physical activity was expressed as total vertical counts divided by measured wear-time (counts per min (c.p.m.)). Dietary intake was assessed using a consecutive 7-day dietary record using a validated Web-based Dietary Assessment Software for Children.[19–22] Data on dietary intake were only included if $1.05 <$ energy intake/basal metabolic rate < 2.29.[23] Under-reporting of dietary intake was defined as energy intake/basal metabolic rate $\leqslant 1.05$. A venous blood sample was drawn, and we measured weight (Tanita BWB 800 S, Arlington Heights, IL, USA) and length (Tanita; CMS Weighing Equipment LTD, London, United Kingdom) according to standard procedures as described previously.[24] Age- and sex-specific International Obesity Task Force cutoffs were used to categorise the children as underweight, normal weight, overweight or obese.[25,26] Whole-blood fatty acid composition was analysed by high-throughput GC at the Department of Kinesiology (University of Waterloo, Waterloo, ON, Canada).[27] Docosahexaenoic acid (w/w%) was used as a marker of n-3 LCPUFA status.

Performance was assessed by the d2-test of attention and Danish standard tests in reading and math, as described previously.[14] For each class, each test was administered on the same weekday and the same time of day (lesson) at each visit. The d2-test of attention consists of 14 rows, each containing 47 test items: 'd' or 'p' with 0–4 dashes above and/or below each character.[29,28] Project staff instructed the children to mark as many target characters (a 'd' with a total of two dashes) as possible within 20 s for each line. The d2-test outcomes were concentration performance (primary outcome), number of correctly marked target characters minus incorrectly marked distractor characters (errors of commission), processing speed (total number of characters processed), inattention (percentage of errors of omission), impulsivity (the percentage of errors of commission) and the total error percentage (the sum of inattention and impulsivity; d2-error%).[30] The teachers of the class administered the reading and the math tests. The math test was specific for third and fourth grade, and included 50 and 69 problems, respectively,[31,32] of which as many as possible should be solved in 45 min. The outcome was the number of correct answers. The reading test consisted of 27 drawings, each accompanied by four statements. Children had 8 min to evaluate the relevance in relation to the drawing of as many sentences as possible.[31,32] The outcomes in reading were the total number of sentences read (reading speed), number of correct sentences and the percentage of correct answers out of the total number of sentences read (%correct). A standardised score for reading proficiency was generated using the standardised residuals from a linear regression of the number correct at baseline, adjusted for age, grade and the week the test was performed. Poor baseline reading proficiency was defined as a score below − 1 s.d.

Statistical methods/analyses

Data are shown as mean ± s.d., median (interquartile range) or odds ratios (95% confidence intervals). Baseline differences between groups were analysed using two-sided *t*-test or a rank-sum test. Potential interactions between the intervention effect (intervention or control) and the variables such as gender, household education (academic or non-academic education) and baseline reading proficiency (poor or normal/good) were evaluated using linear mixed models (for concentration performance and processing speed) or logistic mixed-effects models (for discrete outcomes with an upper limit; i.e., all the other outcomes). The model included visit, order of intervention and control, baseline value, gender, baseline age, year group, household education (six categories), immigrant/descendant (yes or no), baseline total physical activity (c.p.m.), baseline body mass index (BMI) (kg/m^2) and month of baseline test. School, year group within each school, class and individual were included as random effects to account for non-independence and repeated measurements. Odds ratios were translated to the original scale.[33] Model assumptions were assessed by visual inspection of residual and normal probability plots. Homogeneity of variance was tested using Levene's test. Data preprocessing, descriptive analyses and linear mixed models were performed using STATA 12.0 (StataCorp LP, College Station, TX, USA), whereas R[34] was used for logistic mixed-effects models using the extension package lme4. $P < 0.05$ was considered statistically significant.

RESULTS

A total of 739 children (89% of the recruited) had data available on all covariates and on at least one of the outcomes at baseline and at least one more time point and were therefore included in the analyses. The participant flow is presented in Figure 1, and baseline characteristics are presented in total and for boys and girls in Table 1.

Baseline test performance and characteristics in subgroups

At baseline, male gender was associated with better math performance, higher d2-error% and slower speed and fewer correct sentences in reading (Supplementary Information and Supplementary Table 1).

Compared with children from lower educational background, children from households with an academic education performed better at baseline in reading and math, had higher concentration performance, faster processing speed and a lower percentage of errors in the d2-test (Supplementary Table 2). These children from higher education background were also less likely to be immigrants/descendants (6.9 vs 18.5%, $P<0.001$), to have entered puberty (29.5 vs 41.3%, $P=0.001$), to be overweight (9.9 vs 17.9%, $P=0.001$) and to be under-reporters of dietary intake (6.1 vs 12.0%, $P=0.006$).

Poor reading proficiency was associated with poorer performance in math, lower concentration performance, slower processing speed and a tendency to make more errors in the d2-test (Supplementary Table 3). A higher proportion of children were categorised as poor readers in fourth grade than in third grade (53 vs 42%, $P=0.021$), but at the same time poor readers tended to be slightly younger than children with adequate reading proficiency (9.9 ± 0.6 vs 10.0 ± 0.6, $P=0.051$). The proportion of poor readers tended to be higher in boys than in girls (20 vs 15%, $P=0.094$), but it was similar in households with and without an academic education (17 vs 20%, $P=0.267$).

Modifications of intervention effects on test outcomes

The intervention effect on dietary intake, n-3 LCPUFA-status, concentration performance, processing speed and math performance did not differ between subgroups (data not shown).

However, we identified heterogeneous effects of the intervention for errors in the d2-test and outcomes from the reading test (see Supplementary Table 2). The intervention effect on impulsivity was only present in boys, and the effect on speed and number correct in the reading test was also more pronounced in boys (effects on gender inequality is illustrated in Supplementary Figure 1). Furthermore, the intervention effect on impulsivity and number and percentage correct in reading was only present in children from households with an academic education (effects on socioeconomic inequality is illustrated in Supplementary Figure 2). Although the interaction term was insignificant, a similar result was seen for inattention and the total d2-error%. The intervention increased total d2-error% in both reading proficiency subgroups, but the increase was larger in children with normal/good baseline reading proficiency than in children with poor baseline reading proficiency. There were similar tendencies for inattention and impulsivity, although the interaction was insignificant. Furthermore, the intervention increased the percentage correct in reading in children who were normal/good readers at baseline, but not in children with a poor baseline reading proficiency (effects on inequality in reading proficiency is illustrated in Supplementary Figure 3).

DISCUSSION

The present study showed that the previously identified intervention effects on reading performance and d2-errors were stronger in boys, in children from families with higher education level and in children with normal/good reading proficiency at baseline. The effects on reading outcomes suggest that the school meal intervention

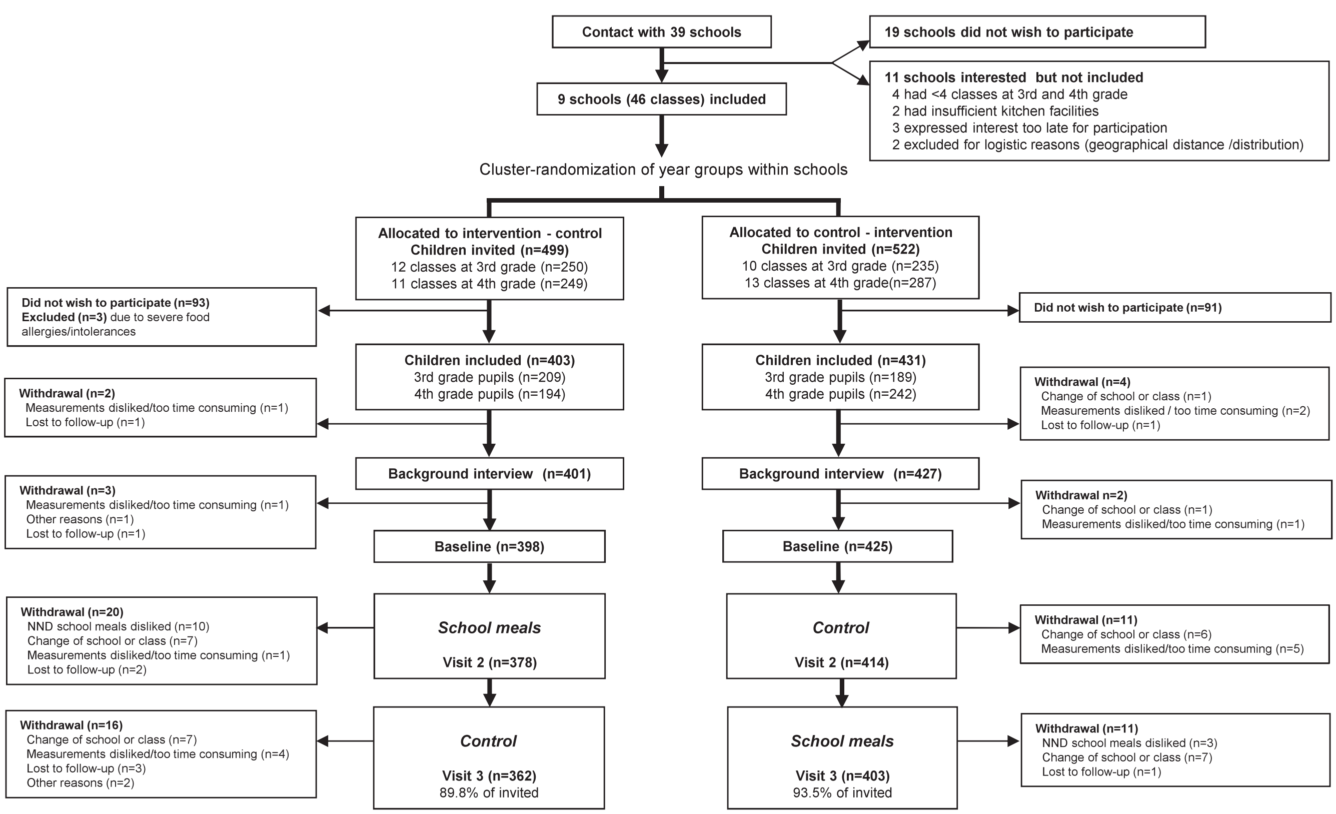

Figure 1. Flow chart for the OPUS School Meal Study.

Table 1. Demographics and baseline characteristics of the total study population and by order of assigned diets

	Total (n = *739)*	*Girls* (n = *359)*	*Boys* (n = *380)*
Male : female ratio (%)	51:49		
Age (years)	10.0 ± 0.6	10.0 ± 0.6	9.9 ± 0.6[a]
Third : fourth grade ratio (%)	49:51	49:51	49:51
*Baseline reading proficiency (% (*n*))*[b]			
Poor reading proficiency	17.9 (129)	15.5 (54)	20.3 (75)
Normal/good reading proficiency	82.1 (590)	84.5 (295)	79.7 (295)
Household education level (% (n))[c]			
Academic education	59.1 (437)	57.7 (207)	60.5 (230)
Non-academic education	40.9 (302)	42.3 (152)	39.5 (150)
*Household income (% (*n*))*[d]			
< 67 113 EUR	29.6 (209)	28.6 (99)	30.6 (110)
67 113–93 958 EUR	30.2 (213)	32.7 (113)	27.8 (100)
⩾93 958 EUR	40.2 (284)	38.7 (134)	41.7 (150)
Immigrant/descendant (% (*n*) yes)[e]	11.6 (86)	10.9 (39)	12.3 (47)
Entered puberty (% (*n*) yes)[f]	34.2 (245)	46.0 (161)	22.9 (84)[a]
Total physical activity (counts per min)	490.0 ± 131.2	454.7 ± 116.6	523.4 ± 135.5[a]
*Weight status (% (*n*))*[g]			
Underweight	9.7 (72)	11.7 (42)	7.9 (30)
Normal weight	77.1 (570)	75.8 (272)	78.4 (298)
Overweight or obese	13.1 (97)	12.5 (45)	13.7 (52)
BMI (kg/m^2)	17.0 ± 2.4	17.0 ± 2.4	17.3 ± 2.5

Abbreviations: BMI, body mass index; DKR, Danish Krone; EUR, Euro. Data are shown as mean plus/minus s.d. or as % and frequencies and numbers. [a]Significantly different from girls, $P < 0.01$, in *t*-test or rank-sum test as appropriate. [b]Baseline reading proficiency was calculated as a standardised score for the number of correct answers in reading adjusted for age, year group and the time of the school year the test was performed. Poor reading proficiency was defined as s.d. < −1, and normal/good reading proficiency was defined as s.d. ⩾ −1 (total $n = 719$; girls $n = 349$; boys $n = 370$). [c]Households were categorised according to the parent/guardian with the highest education level. [d]Household income before tax was converted to EUR from DKR (< 499.999, 500.000–699.999 and ⩾700.000 kr). [e]Immigrant/descendant was defined as participants whose grandparents and ⩾1 parent were born outside Denmark. [f]Puberty entered was determined based on Tanner[17] and defined as Tanner stage ⩾2 (total $n = 717$; girls $n = 350$; boys $n = 367$). [g]Based on the International Obesity Task Force BMI cutoffs.[25,26]

Table 2. Difference in cognitive performance between intervention and control in subgroups of gender, household education and baseline reading proficiency[a]

	Gender			*Household education level*			*Baseline reading proficiency*		
	Girls OR (95% CI)	*Boys OR (95% CI)*	$P_{interaction}$	*Non-academic education OR (95% CI)*	*Academic education OR (95% CI)*	$P_{interaction}$	*Poor OR (95% CI)*	*Normal/good OR (95% CI)*	$P_{interaction}$
d2-test of attention									
Total error%	1.09 (1.02; 1.16)	1.12 (1.06; 1.18)	0.49	1.05 (0.98; 1.12)	1.14 (1.08; 1.20)	0.066	1.08 (1.03; 1.13)	1.25 (1.13; 1.39)	0.012[b]
Inattention	1.10 (1.02; 1.17)	1.08 (1.02; 1.14)	0.73[c]	1.06 (0.99; 1.14)	1.10 (1.04; 1.17)	0.40	1.07 (1.02; 1.12)	1.20 (1.08; 1.34)	0.056[b]
Impulsivity	0.96 (0.76; 1.20)	1.43 (1.20; 1.70)	0.007[d]	0.96 (0.78; 1.19)	1.46 (1.22; 1.75)	0.002	1.18 (1.01; 1.38)	1.63 (1.17; 2.27)	0.074[b]
Sentence reading test									
Reading speed	1.01 (0.98; 1.04)	1.05 (1.02; 1.09)	0.079	1.01 (0.97; 1.05)	1.05 (1.02; 1.08)	0.102	1.05 (0.999; 1.11)	1.03 (1.0002; 1.05)	0.40
No. correct	1.05 (1.02; 1.09)	1.10 (1.07; 1.14)	0.046	1.01 (0.97; 1.05)	1.13 (1.10; 1.16)	< 0.001	1.05 (0.99; 1.10)	1.09 (1.06; 1.11)	0.22
Percentage correct	1.32 (1.20; 1.45)	1.36 (1.26; 1.48)	0.62	0.97 (0.89; 1.06)	1.77 (1.62; 1.92)	< 0.001	0.93 (0.82; 1.05)	1.52 (1.42; 1.63)	< 0.001[e]

Abbreviations: BMI, body mass index; CI, confidence interval; OR, odds ratio. [a]The differences between intervention and control analysed by logistic mixed-effects models. The model included diet (intervention or control), visit, order of intervention and control period, baseline values, gender, baseline age, grade, household education, immigrant/descendant, month of baseline test, baseline BMI and baseline physical activity, and random effects (school, year group within school, class and individual), unless otherwise noted. Analyses of gender and education interactions included 693 children for outcomes from d2-test of attention and 717 for outcomes from the reading test, unless otherwise noted. [b]Analyses of interactions with reading proficiency included 678 children for outcomes from the d2-test of attention. [c]The model did not include the random effect of year group within school because of failure to converge. [d]The model did not include baseline BMI, physical activity or the random effect of year group within school because of failure to converge. [e]The model did not include baseline physical activity or the random effects of year group within school because of failure to converge.

reduced the gender difference in reading, but increased the socio-economic inequality in reading, as well as the difference between poor and normal/good readers. Contrary to this, the heterogeneous effects on impulsivity and/or inattention increased the gender difference but reduced the gap between household education groups and between poor and normal/good readers. Such effects on inequalities are important findings, yet few school meal studies have investigated effect modifications on cognitive outcomes.

The increased socioeconomic inequality in reading performance is in accordance with results of the 'Feed Me Better' study, in which nutritionally improved school canteen menus coincided with beneficial effects on reading, math and science achievement that mainly occurred in children who were non-eligible for free school meals and those from less deprived backgrounds.[6] A potential explanation to the socioeconomic inequality might be factors that are not influenced by diet—for example, that the intervention stressed children more when it was very different from their home environment. Contrary to our results, a 2-year multicomponent intervention, which included modifications to already existing school menus, improved math and tended to improve reading in low-income children.[35] The authors did not test the interaction statistically, and the effect was not reported for the remaining children. However, this might suggest that it takes longer for effects to occur in less advantaged children or that the effect in these children was influenced by concomitant environmental changes in the multicomponent intervention. Contrary to reading, social inequality in impulsivity was reduced by the intervention. We have not found other studies that investigated impulsivity, but a school breakfast intervention investigated hyperactivity (and episodic memory) and found no effects on socioeconomic inequality, even though breakfast habits improved more in deprived schools and households.[7] Academic versus non-academic education level may be a quite crude proxy measure of socioeconomic status, but it was chosen rather than to rank education levels by their duration. The definition of socioeconomic status and the choice of cutoff makes it complex to compare between studies and could explain some of the inconsistencies between their effects on socioeconomic inequality. Many studies use income or information related to low income (e.g. free school meal entitlement) to investigate socioeconomic inequality of an intervention. However, the optimal definition depends on the local context, and parental education is a better predictor of Danish children's dietary habits than income and occupation.[3] Some studies also use ethnicity as a socioeconomic marker of inequality, but the percentage of immigrants/descendants is relatively low in Denmark and represents a very diverse group. Overall, effects on social inequality in dietary effects on cognitive outcomes are poorly investigated and results are inconsistent.

Interestingly, we found that impulsivity only increased in boys and thereby increased the gender gap. To our knowledge, no prior school meal study has investigated effect modification by gender on outcomes related to attention. It could be hypothesised that boys are more vulnerable to the environmental changes and the stress that might have been induced during the intervention. Contrary to the results for education, a greater effect on number correct in reading in boys is in opposition to the 'Feed Me Better' study, in which the beneficial effect on reading, math and science was larger among girls, although only significantly so for math.[6] The effect modifications for d2-error% generally coincided with the effect modifications for reading performance, which could suggest that an increase in d2-error% was associated with better reading comprehension. As previously hypothesised, less focus on details, such as the number of dashes around a letter, could somehow be linked to more focus on the overall meaning of a sentence.[13]

The improvement in reading accuracy (i.e. percentage correct) that only occurred in children with good reading proficiency was in accordance with findings in the 'Feed Me Better' study.[6] The absence of an intervention effect in children with poor baseline reading proficiency in the present study was contrary to the results in a docosahexaenoic acid supplementation study that found more pronounced effects in poor readers.[10] However, that study only included children with relatively low reading proficiency, and the dosage of n-3 fatty acids was much higher than the increase in fish intake in the present study. One could speculate that a beneficial effect of n-3 fatty acids in poor readers might not be evident when the dosage is relatively low.

Prior food interventions in school settings have concluded that their intervention decreased socioeconomic inequalities in dietary intake,[7,36] whereas others found that social inequality persisted.[37] In this study, we did not find any indication that dietary compliance differed between groups. Thus, the differential cognitive effects of the intervention in subgroups could be related to the environmental aspects of the intervention, for example, participation in the school kitchen, which may have had an impact on social relations and self-efficacy. On the other hand, differential under- and over-reporting of dietary intake is a potential bias to the dietary data, and we did find a higher degree of under-reporting among children from lower educational background. Moreover, the interpretation of dietary intake is limited, as we do not know whether the subgroups differed in compliance at school (which could have acute cognitive effects), but compensated in their intake at home. Furthermore, as n-3 LCPUFA status and dietary intake were assessed at the end of the study periods, it is possible that compliance in the beginning of the intervention period differed between subgroups. In practise, this would influence the duration of the intervention period. Hence, the differing effects in subgroups might be related to children's ability to adapt to the intervention meals. In the OPUS School Meal Study, we aimed to minimise the duration of such adaptation by including educational material about Nordic foods and by having pupils participate in the school kitchen and present the lunch menu to their peers. Perhaps, differential adaptation in subgroups would be more homogeneous if the intervention consisted of fewer foods that were unfamiliar at home or by gradual introduction of the healthy food scheme. However, this might be difficult in practise, as familiarity of foods differs between children. Furthermore, a gradual introduction would require a longer intervention period. Another possibility is that children differed in their physiological and/or behavioural reaction to the changed dietary intake and/or the environmental aspects of the intervention. Depending on the underlying mechanisms, such differences could either disappear or be reinforced if the intervention lasted for a longer period.

It has been proposed that a comprehensive intervention including nutrition education, capacity building, policy changes and skill building is more likely to promote social equity in healthy eating.[38] The OPUS School Meal Study was designed to optimise the likelihood of a beneficial dietary change in all children. Meals were served for free to all children in the included classes, and cooking skills were improved by school kitchen participation. We also provided educational material, but it was optional for the teachers to use it. Hence, obligatory use and more focus on healthy diet in educational material might help eliminate inequalities in the uptake of the school meals. On the other hand, interventions based on education may be more likely to widen inequality in dietary intake, whereas those based on environmental change are more likely to narrow it.[39] Another strategy could be to focus on a subgroup with poor dietary habits such as the less privileged children. However, such a targeted intervention implicates a risk of social stigma and ethical challenges in the school setting.

The external validity of the results was improved by performing the study as part of everyday life in regular schools and a study population that was fairly representative for the Danish population in terms of education level and the proportion of immigrants/descendants.[40,41] Dropouts had lower household education level, but did not differ with regard to age, gender, immigrant/descendant or anthropometry, and their reasons for withdrawal were generally unrelated to the study.[12] Hence, the results have high generalisability to Danish children of similar ages and

possibly to other high-income countries. Compromises were made to accommodate the school setting and consider logistic and practical matters—for example, it would have been optimal to perform individual randomisation and administer the tests in a more standardised way and in a controlled environment. On the other hand, test conditions resembled the everyday school environment of the participants and were consistent over time. Although teachers were not observed during test administration, they were generally familiar with the tests and had received thorough instruction. Moreover, the design most likely contributed to the high participation (82%) and the low dropout rate (8.3%). The proportion of poor readers (18%) at baseline was in line with the proportion observed in the Programme for International Student Assessment[42] and in a UK study population of 7- to 9-year-old children.[10] The identified gender differences in cognition and the suboptimal performance of children from households with lower education level and children with poor reading skills were consistent with the literature.[9,43–47] However, we cannot rule out bias in the outcome assessment, as the persons who administered the tests were not blinded.

In conclusion, our findings suggest that the effects of the school meal intervention on reading, inattention and impulsivity were modified by gender, household education and baseline reading proficiency. The heterogeneous effects resulted in both decreases and increases of the observed baseline inequalities. Generally, this increased the socioeconomic inequality in reading performance, increased the gender difference in impulsivity and increased the gap in reading performance between poor and normal/good readers. However, this also resulted in decreased socioeconomic inequality in impulsivity, decreased gender difference in reading and decreased difference in d2-error% between poor and normal/good readers. The risk of increased inequality in test performance deserves to be recognised and taken into account when dietary interventions take place in the school setting. Introducing dietary and environmental changes in a school setting is a complex matter, and potential differential effects in subgroups deserve attention in future studies.

CONFLICT OF INTEREST

AA has received royalties from sale of New Nordic Diet cookbooks from FDB/Coop. All other authors have no conflicts of interest.

ACKNOWLEDGEMENTS

We thank all of the schools, teachers, children and their families for their interest and participation in the study and the biotechnicians, interns, students and scientific staff for their great contribution. We also owe a special thanks to Bente Maribo for administering the d2-test of attention and for the extensive work on correcting tests. The OPUS project 'Optimal well-being, development and health for Danish children through a healthy New Nordic Diet' was supported by a grant from the Nordea Foundation (Grant No. 02-2010-0389). Danæg A/S, Naturmælk, Lantmännen A/S, Skærtoft Mølle A/S, Kartoffelpartnerskabet, AkzoNobel Danmark, Gloria Mundi and Rose Poultry A/S provided foods in kind for the study. Sources of funding and donation had no role in design, analysis or writing of this article.

AUTHOR CONTRIBUTIONS

AA and KFM conceived the work. LBS, CTD, RAP, SMD, MFH, CBD, NE, IT and KFM designed the work that led to submission and acquired data. LBS, LL and KFM played an important role in interpreting the results. LBS drafted the manuscript. All authors revised the manuscript and approved the final version.

REFERENCES

1 Almquist YB. School performance as a precursor of adult health: exploring associations to disease-specific hospital care and their possible explanations. *Scand J Public Health* 2013; **41**: 81–91.
2 Johansson L, Thelle DS, Solvoll K, Bjørneboe GE, Drevon CA. Healthy dietary habits in relation to social determinants and lifestyle factors. *Br J Nutr* 1999; **81**: 211–220.
3 Groth M, Christensen LM, Knudsen VK, Fagt S, Ege M, Matthiessen J, Sociale forskelle: børns kostvaner, fysiske aktivitet og overvægt & voksnes kostvaner [Danish] (Social differences in children´s dietary habits, physical activity and overweight and adult´s dietary habits). DTU Fødevareinstituttet, Danmarks Tekniske Universitet, 2013. Available at: http://maaltidspartnerskabet.dk/wp-content/uploads/Sociale-forskelle-i-kost-fysisk-aktivitet-og-overv%C3%A6gt.pdf (accessed 6 June 2016).
4 Müller MJ, Danielzik S, Pust S. School- and family-based interventions to prevent overweight in children. *Proc Nutr Soc* 2005; **64**: 249–254.
5 Plachta-Danielzik S, Pust S, Asbeck I, Czerwinski-Mast M, Langnäse K, Fischer C *et al.* Four-year follow-up of school-based intervention on overweight children: the KOPS study. *Obesity (Silver Spring MD)* 2007; **15**: 3159–3169.
6 Belot M, James J. Healthy school meals and educational outcomes. *J Health Econ* 2011; **30**: 489–504.
7 Moore GF, Murphy S, Chaplin K, Lyons RA, Atkinson M, Moore L. Impacts of the Primary School Free Breakfast Initiative on socio-economic inequalities in breakfast consumption among 9–11-year-old schoolchildren in Wales. *Public Health Nutr* 2014; **17**: 1280–1289.
8 Herlitz A, Reuterskiöld L, Lovén J, Thilers PP, Rehnman J. Cognitive sex differences are not magnified as a function of age, sex hormones, or puberty development during early adolescence. *Dev Neuropsychol* 2013; **38**: 167–179.
9 Buzhigeeva MI. Gender characteristics of children in the primary stage of instruction. *Russ Educ Soc* 2004; **46**: 76–88.
10 Richardson AJ, Burton JR, Sewell RP, Spreckelsen TF, Montgomery P. Docosahexaenoic acid for reading, cognition and behavior in children aged 7–9 years: a randomized, controlled trial (the DOLAB Study). *PLoS One* 2012; **7**: e43909.
11 Andersen R, Biltoft-Jensen A, Christensen T, Andersen EW, Ege M, Thorsen AV *et al.* Dietary effects of introducing school meals based on the New Nordic Diet—a randomized controlled trial in Danish children. The OPUS School Meal Study (in press). *Br J Nutr* 2014; **111**: 1967–1976.
12 Damsgaard CT, Dalskov S-M, Petersen RA, Sørensen LB, Mølgaard C, Biltoft-Jensen A *et al.* Design of the OPUS School Meal Study: a randomised controlled trial assessing the impact of serving school meals based on the New Nordic Diet. *Scand J Public Health* 2012; **40**: 693–703.
13 Sørensen LB, Damsgaard CT, Dalskov S-M, Petersen RA, Egelund N, Dyssegaard CB *et al.* Diet induced changes in iron and n-3 fatty acid status and associations with cognitive performance in 8–11 year-old Danish children. Secondary analyses of the Optimal well-being, development and health for Danish children through a healthy New Nordic Diet School Meal Study. *Br J Nutr* **114**: 1623–1637.
14 Sørensen LB, Dyssegaard CB, Damsgaard CT, Petersen RA, Dalskov S-M, Hjorth MF *et al.* 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. *Br J Nutr* 2015; **113**: 1280–1291.
15 Nordic Council of Ministers. *Nordic Nutrition Recommendations 2004: NNR: Integrating Nutrition and Physical Activity*, 4th edn. Nordic Council of Ministers: Copenhagen, Denmark, 2004.
16 Mithril C, Dragsted LO, Meyer C, Blauert E, Holt MK, Astrup A. Guidelines for the New Nordic Diet. *Public Health Nutr* 2012; **15**: 1941–1947.
17 Morris NM, Udry JR. Validation of a self-administered instrument to assess stage of adolescent development. *J Youth Adolesc* 1980; **9**: 271–280.
18 Hjorth MF, Chaput J-P, Michaelsen K, Astrup A, Tetens I, Sjödin A. Seasonal variation in objectively measured physical activity, sedentary time, cardio-respiratory fitness and sleep duration among 8–11 year-old Danish children: a repeated-measures study. *BMC Public Health* 2013; **13**: 808.
19 Biltoft-Jensen A, Trolle E, Christensen T, Islam N, Andersen LF, Egenfeldt-Nielsen S *et al.* WebDASC: a web-based dietary assessment software for 8–11-year-old Danish children. *J Hum Nutr Diet Off J Br Diet Assoc* 2012; **27**(Suppl 1): 43–53.
20 Biltoft-Jensen A, Bysted A, Trolle E, Christensen T, Knuthsen P, Damsgaard CT *et al.* Evaluation of Web-based Dietary Assessment Software for children: comparing reported fruit, juice and vegetable intakes with plasma carotenoid concentration and school lunch observations. *Br J Nutr* 2013; **110**: 186–195.
21 Biltoft-Jensen A, Hjorth MF, Trolle E, Christensen T, Brockhoff PB, Andersen LF *et al.* Comparison of estimated energy intake using Web-based Dietary Assessment Software with accelerometer-determined energy expenditure in children. *Food Nutr Res* 2013; **57**: 21434.
22 Biltoft-Jensen A, Damsgaard CT, Andersen R, Ygil KH, Andersen EW, Ege M *et al.* Accuracy of self-reported intake of signature foods in a school meal intervention study: comparison between control and intervention period. *Br J Nutr* 2015; **114**: 635–644.

23 Black AE. Critical evaluation of energy intake using the Goldberg cut-off for energy intake:basal metabolic rate. A practical guide to its calculation, use and limitations. *Int J Obes Relat Metab Disord* 2000; **24**: 1119–1130.
24 Damsgaard CT, Dalskov S-M, Laursen RP, Ritz C, Hjorth MF, Lauritzen L *et al.* Provision of healthy school meals does not affect the metabolic syndrome score in 8–11-year-old children, but reduces cardiometabolic risk markers despite increasing waist circumference. *Br J Nutr* 2014; **112**: 1826–1836.
25 Cole TJ, Flegal KM, Nicholls D, Jackson AA. Body mass index cut offs to define thinness in children and adolescents: international survey. *BMJ* 2007; **335**: 194.
26 Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Establishing a standard definition for child overweight and obesity worldwide: international survey. *BMJ* 2000; **320**: 1240–1243.
27 Metherel AH, Aristizabal Henao JJ, Stark KD. EPA and DHA levels in whole blood decrease more rapidly when stored at − 20 °C as compared with room temperature, 4 and − 75 °C. *Lipids* 2013; **48**: 1079–1091.
28 Bates ME, Lemay EP Jr. The d2 test of attention: construct validity and extensions in scoring techniques. *J Int Neuropsychol Soc* 2004; **10**: 392–400.
29 Brickenkamp R, Zillmer E. *The d2 Test of Attention*. Hogrefe & Huber: Seattle, WA, USA, 1998.
30 Wassenberg R, Hendriksen JGM, Hurks PPM, Feron FJM, Keulers EHH, Vles JSH *et al.* Development of inattention, impulsivity, and processing speed as measured by the d2 Test: results of a large cross-sectional study in children aged 7–13. *Child Neuropsychol* 2008; **14**: 195–210.
31 Hansen KF. *MG/FG 3 : matematik grundlæggende, færdigheder grundlæggende : vejledning [in Danish] (MG3/FG3 Mathematics Basic: Manual)*, 2nd edn. Hogrefe Psykologisk Forlag: Virum, Denmark, 2007.
32 Hansen KF. *MG/FG 4 : matematik grundlæggende, færdigheder grundlæggende : vejledning [in Danish] (MG4/FG4 Mathematics Basic: Manual)*, 2nd edn. Hogrefe Psykologisk Forlag: Virum, Denmark, 2007.
33 Laursen RP, Dalskov S-M, Damsgaard CT, Ritz C. Back-transformation of treatment differences—an approximate method. *Eur J Clin Nutr* 2014; **68**: 277–280.
34 R Core Team. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing: Vienna, Austria, 2012. Available at: http://www.R-project.org/ (accessed 2 September 2015).
35 Hollar D, Messiah SE, Lopez-Mitnik G, Hollar TL, Almon M, Agatston AS. Effect of a two-year obesity prevention intervention on percentile changes in body mass index and academic performance in low-income elementary school children. *Am J Public Health* 2010; **100**: 646–653.
36 Hughes RJ, Edwards KL, Clarke GP, Evans CEL, Cade JE, Ransley JK. Childhood consumption of fruit and vegetables across England: a study of 2306 6–7-year-olds in 2007. *Br J Nutr* 2012; **108**: 733–742.
37 Rush E, Reed P, McLennan S, Coppinger T, Simmons D, Graham D. A school-based obesity control programme: Project Energize. Two-year outcomes. *Br J Nutr* 2012; **107**: 581–587.
38 Friel S, Hattersley L, Ford L, O'Rourke K. Addressing inequities in healthy eating. *Health Promot Int* 2015; **30**: ii77–ii88.
39 Moore GF, Littlecott HJ, Turley R, Waters E, Murphy S. Socioeconomic gradients in the effects of universal school-based health behaviour interventions: a systematic review of intervention studies. *BMC Public Health* 2015; **15**: 907.
40 Statistics Denmark. *StatBank Denmark: Income, Consumption and Prices. INDKF7: Level of Education of the Family by Region, Unit, Family Type, Level of Education and Type of Income*, 2013. Available at: http://www.statistikbanken.dk/statbank5a/SelectVarVal/Define.asp?MainTable = INDKF7&TabStrip = Select&PLanguage = 1&FF = 2 (last accessed 5 September 2013).
41 Statistics Denmark. *Indvandrere i Danmark 2012 [Danish] (Immigrants in Denmark 2012)*. Danmarks statistik: Copenhagen, Denmark, 2012. Available at: http://www.dst.dk/pukora/epub/upload/16601/indv.pdf (accessed 6 June 2016).
42 OECD. *PISA 2009 Results: What Students Know and Can Do—Student Performance in Reading, Mathematics and Science (Volumen 1)*. OECD: Paris, France, 2010. Available at: http://dx.doi.org/10.1787/9789264091450-en (last accessed 13 December 2013).
43 Considine G, Zappala G. The influence of social and economic disadvantage in the academic performance of school students in Australia. *J Sociol* 2002; **38**: 129–148.
44 OECD. *PISA 2009 Results: Overcoming Social Background—Equity in Learning Opportunities and Outcomes (Volume II)*. OECD: Paris, 2010.
45 Mullis IVS. *Pirls 2011 International Results in Reading*. TIMSS & PIRLS International Study Center: Chestnut Hill, MA, USA, 2012.
46 Stoet G, Geary DC. Sex differences in mathematics and reading achievement are inversely related: within- and across-nation assessment of 10 years of PISA Data. *PLoS One* 2013; **8**: e57988.
47 OECD. *PISA 2012 Results: What Students Know and Can Do—Student Performance in Mathematics, Reading and Science (Volume 1)*, 2013. Available at: 2013http://dx.doi.org/10.1787/9789264207585-en (last accessed 27 January 2014).

Supplementary Information accompanies this paper on European Journal of Clinical Nutrition website (http://www.nature.com/ejcn)