

List of papers

- Paper I. Sørensen LB, Dyssegaard CB, Damsgaard CT, Petersen RA, Dalskov S, Hjorth MF, Andersen R, Tetens I, Ritz C, Astrup A, Lauritzen L, Michaelsen KF and Egelund N. The effects of healthy school meals on concentration and school performance in 8 to 11 year old children in the OPUS School Meal Study: a cluster randomized controlled cross-over trial (*Submitted to Br J Nutr*).
- Paper II. Sørensen LB, Damsgaard CT, Dalskov S, Petersen RA, Egelund N, Dyssegaard CB, Stark KD, Andersen R, Tetens I, Astrup A, Michaelsen KF and Lauritzen L. Are diet induced changes in iron and n-3 fatty acid status associated with cognitive performance in 8-11 year-old Danish children? Secondary analyses of a cluster-randomised trial (*ready for submission*).
- Paper III. Sørensen LB, Damsgaard CT, Petersen RA, Dalskov S, Hjorth MF, Dyssegaard CB, Egelund N, Tetens I, Astrup A, Lauritzen L and Michaelsen KF. Differences in the effects of school meals on children's cognitive performance according to gender, household education, and baseline reading skills (*ready for submission*).

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English summary

Background

It is widely assumed that nutrition can affect school performance in children, yet evidence remains limited and inconclusive. In high-income countries the role of dietary quality, iron and n-3 long chain polyunsaturated fatty acids (n-3 LCPUFA) are nutritional issues that may be of relevance to cognitive functions. Few studies have investigated the effect of school meals on cognition and academic performance in high-income countries. Most previous school meal studies investigated the effects of healthier options in school cafeteria and did not consider effects on dietary intake or biomarkers of iron and n-3 LCPUFA-status. Furthermore, methodological issues in earlier studies question the validity of the results.

Methods

In the OPUS School Meal Study we investigated the effect of serving healthy school meals on attention and academic performance in 8-11-year-old children. The study was a cluster-randomized controlled cross-over trial implemented in third and fourth grade at nine Danish schools. The three-month intervention consisted of a healthy school meal program based on the New Nordic Diet, which was compared with the usual packed lunch from home (control). Information on pubertal stage, ethnic background and parental education was obtained in a background interview. At baseline and at the end of each study period, several measurements were performed including weight, height and blood sampling as well as a 7-day assessment of both physical activity and dietary intake. Moreover, we assessed student performance in d2-test of attention and Danish standard tests in reading and mathematics at baseline and at the end of each study period. Hemoglobin concentration, serum ferritin concentration and whole blood fatty acid composition were employed as biomarkers of iron and n-3 LCPUFA-status. Intervention effects were evaluated using hierarchical mixed models and multivariate principal component analysis (PCA).

Results

There was no effect of the school meal intervention on children's concentration performance, processing speed or math performance. However, reading performance was improved. For the number of correct sentences the effect size corresponded to 25% of the expected improvement during a school year. The effect on reading performance coincided with a 0.18%-point higher error percentage in the attention test, which might indicate increased inattention and impulsivity. The concurrence of increased error% with improved reading performance was confirmed in PCA analysis.

Interestingly, the effect of the intervention differed in subgroups, suggesting that the effects of the school meal intervention primarily occurred in boys, children with normal/good reading proficiency and children from well-educated families. The concurrence of increased error percentage and reading performance was also consistent in the subgroup analyses, which supports the interpretation of those outcomes as reflecting a joint effect. A hypothesis derived from this is that a focus on the overall meaning of a sentence is linked to less emphasis on details.

The school meal intervention improved the overall quality of dietary intake and increased n-3 LCPUFA-status, but there was no effect on iron status. The increased n-3 LCPUFA-status supported that the intake of fish and/or n-3 LCPUFA was involved in the effect of the intervention on cognitive outcomes, although causality could not be determined. However, the intervention effect on dietary intake and n-3 LCPUFA-

status did not differ between boys and girls, children with poor versus normal/good reading proficiency or children with low versus high household education level.

Conclusion

The OPUS School Meal Study bring important evidence to a highly relevant and largely undescribed research area and showed that the school meal intervention did indeed have an impact on outcomes related to school performance in a high-income country. Nevertheless, there is uncertainty regarding the effects, since we identified a beneficial effect on reading ability, but also a potential adverse effect on attention, which merits further investigation. The role of fish and/or n-3 LCPUFA intake was substantiated for the overall intervention effect. Differences in the physiological and/or behavioural reaction to the dietary and environmental aspects of the school meal intervention may be possible explanations to the differential effects in subgroups. Hence, the role of specific nutritional components and nutrition versus environment requires further clarification in future studies.

Dansk sammendrag

Baggrund

Det er en udbredt opfattelse, at kost har betydning for, hvordan børn klarer sig i skolen. Imidlertid er der utilstrækkelig videnskabelig evidens for denne opfattelse. I høj-indkomst lande som Danmark er kostens kvalitet, samt indtaget af jern og n-3 langkædede polyumættede fedtsyrer (n-3 LCPUFA) fra fed fisk de mest relevante ernæringsrelaterede forhold i relation til kognitive funktioner. Få studier har undersøgt effekten af skolemads på børns kognition og indlæring i høj-indkomst lande. De fleste tidligere skolemadsstudier har undersøgt effekten af at øge udbuddet af sund mad i skolekantine og undersøgte ikke effekten af dette på børnenes kostindtag eller på biomarkører for jern- og n-3 LCPUFA-status. Desuden sætter metodiske svagheder ved disse studier spørgsmålstegn ved resultaternes validitet.

Metode

I OPUS Skolemadsprojekt undersøgte vi effekten af at servere sunde skolemåltider i forhold til opmærksomhed og faglige færdigheder i skolen blandt 8-11 årige børn. Studiet var et cluster-randomiseret overkrydsningsforsøg, som blev implementeret i tredje og fjerde klassetrin på ni danske skoler. Den tre måneder lange intervention bestod af et sundt skolemadsprogram baseret på Ny Nordisk Hverdagsmad, og blev sammenlignet med børnenes sædvanlige madpakke hjemmefra (kontrolperioden). Information om pubertetsstadiet, etnisk baggrund og forældrenes uddannelse blev indsamlet i et baggrundsinterview. Ved baseline og i slutningen af hver studieperiode blev der foretaget en række målinger, herunder vægt, højde og blodprøve, samt en vurdering af fysisk aktivitet og kostindtag over syv dage. Herudover vurderede vi elevernes præstation i d2 opmærksomheds- og koncentrationstest, samt i danske standardtests af færdigheder i læsning og matematik både ved baseline og i slutningen af de to studieperioder. Blodets indhold af hæmoglobin og ferritin, samt blodets fedtsyresammensætning blev benyttet som biomarkører for jern- og n-3 LCPUFA-status. Statistisk vurdering af interventionens effekt blev foretaget ved brug af hierarkiske mixed modeller, samt multivariat principal component analysis (PCA).

Resultater

Interventionen havde ikke nogen effekt på børnenes koncentrationsevne, arbejdstempo eller matematikfærdigheder. Derimod blev læsefærdigheder forbedret af skolemadsinterventionen. For antal rigtige sætninger i læsetesten svarede effekten til 25% af den forventede forbedring i løbet af et skoleår. Samtidig med effekten på læsning øgedes elevernes fejlprocent i opmærksomhedstesten med 0.18%-point, hvilket indikerede øget uopmærksomhed og impulsivitet. Sammenfaldet mellem øget fejlprocent og forbedrede læsefærdigheder blev bekræftet i PCA-analysen.

Interessant nok, havde interventionen forskellig effekt i subgrupper, og det tydede på at skolemaden primært havde en effekt på drenge, børn med normale/gode læsefærdigheder ved baseline, og børn med veluddannede forældre. Sammenfaldet mellem øget fejlprocent og forbedrede læsefærdigheder var også konsistent i subgruppeanalyserne, hvilket understøtter fortolkningen af, at disse udfald afspejler en fælles effekt. En hypotese udledt heraf er at øget fokus på den overordnede mening i en sætning hænger sammen med, at der lægges mindre vægt på detaljer.

Skolemadsinterventionen forbedrede kostens kvalitet og øgede n-3 LCPUFA-status, men der var ingen effekt på jernstatus. Øgningen af n-3 LCPUFA-status underbyggede, at indtaget af fisk og/eller n-3 LCPUFA havde betydning for interventionens effekt på de kognitive udfald, selvom sammenhængens kausalitet ikke

kunne bestemmes. Interventionens effekt på kostindtaget og n-3 LCPUFA-status var imidlertid ikke forskellig blandt piger versus drenge, børn med dårlige versus normale/gode læsefærdigheder, eller børn med lavt versus højt uddannelsesniveau i husstanden.

Konklusion

OPUS Skolemadsprojekt tilførte vigtig evidens til dette høj-relevante og relativt ubeskrevne forskningsområde og viste, at skolemadsinterventionen rent faktisk havde en effekt på udfald relateret til børns præstation i skolen i et høj-indkomst land. Ikke desto mindre var der usikkerhed omkring effekterne, eftersom vi fandt en positiv effekt på læsefærdigheder, men også en potentielt negativ effekt på opmærksomhed, hvilket bør udforskes nærmere. Betydningen af fisk og/eller n-3 LCPUFA-indtag blev underbygget i forhold til den overordnede effekt af interventionen. En mulig forklaring på den forskellige effekt i subgrupperne, er forskelle i deres fysiske og/eller adfærdsmæssige reaktion på ændringer i kost og miljø i forbindelse med skolemadsinterventionen. I fremtidige studier er der på den baggrund behov for yderligere belysning af effekten af specifikke ernæringskomponenter, samt betydningen af ernæring versus socialt miljø.

1. Introduction

Children's performance in school has long term effects on health determinants and educational attainment, which is required for the growth of nations in a competitive, knowledge-based, globalized world (1,2). Good nutrition has an important role in child development and learning. Malnutrition is associated with less energy and interest for learning, increased risk of multiple micronutrient deficiencies, alterations in brain growth and structure and impaired cognitive development (3,4). Empirical evidence shows that good health and nutrition are prerequisites for effective learning. Dietary aspects such as breastfeeding appear to be beneficial for cognition in children (5). Most studies that have investigated the association between diet and cognitive development have focused on isolated micronutrients, especially n-3 polyunsaturated fatty acids (PUFA), vitamin B12, folic acid, iodine, iron and zinc. Observational studies suggest that these nutrients influence cognitive development, whereas the evidence from trials remains inconsistent (5).

In Denmark and other high-income countries, undernourishment and micronutrient deficiencies are rare. Nonetheless, Danish children's lunch and snack meals during the school day generally contain too much sugar and fat, and too little fish, vegetables, fruit, and wholegrain (6,7). In addition, about 12% do not eat any lunch and there are socioeconomic inequalities in children's dietary habits (8). The low fish intake means that the sufficiency of n-3 long-chain PUFA for cognitive development may be a relevant issue in this high-income setting. The role of iron also remains important, since iron deficiency (ID) is one of the most common micronutrient deficiencies in high-income countries (9). The European Food Safety Authority (EFSA) recently concluded that both the intake of iron, alpha-linolenic acid (ALA, 18:3n-3) and docosahexaenoic acid (DHA, 22:6n-3) are low in European infants and young children (10). However, people eat a combination of foods, not isolated nutrients; hence it is highly relevant to focus on the meal pattern, the quality of the diet and the interactive effects of nutrients. Dietary quality early in life has been positively associated with cognition later in life (11,12) and better diet quality in school aged children has been associated with improved literacy (13,14).

Nutritional interventions in the school setting have the potential to reach children from all socioeconomic backgrounds and to influence the nutritional quality of their overall diet. In low-income countries school feeding programs increase energy intake, micronutrient status, school enrolment, and attendance, and there is reasonable evidence for a positive effect on short-term cognitive functions and school performance (15). In high-income countries, the effect of school meals has only been investigated in a few studies and it remains uncertain whether diet has an effect on cognitive functions, behaviour and academic performance in school.

The present PhD thesis is based on data from the OPUS School Meal Study, in which the effects of serving healthy school meals were investigated among Danish schoolchildren in third and fourth grade. The thesis reports findings on student performance in tests of attention, reading and math. Besides this, the thesis examines whether the effect of the school meal intervention was different depending on the child's gender, baseline reading proficiency and socioeconomic background. In relation to the effect of the intervention, the potential role of iron, n-3 LCPUFA and dietary intake was examined.

1.1 Objectives of the PhD thesis

The overall aim of this thesis was to assess the effects of providing school meals for three months on cognitive function and academic performance. Specific objectives included:

- To investigate the overall intervention effects on attention, reading and math performance (Paper I)
- To examine whether an intervention effect on attention, reading and math performance was modified by the child's gender or baseline reading attainment, or by parental education level (Paper III)
- To explore the potential role of dietary intake as well as iron and n-3 LCPUFA-status in relation to effects on cognition and academic performance (Paper II and III)