Author(s): Sehrish, Naveed; Venäläinen, Taisa; Eloranta, Aino-Maija; Erkkilä, Arja T.; Jalkanen, Henna; Lindi, Virpi; Lakka, Timo A.; Haapala, Eero A.

Title: Associations of dietary carbohydrate and fatty acid intakes with cognition among children

Year: 2020

Version: Accepted version (Final draft)

Please cite the original version:

Sehrish, N., Venäläinen, T., Eloranta, A.-M., Erkkilä, A. T., Jalkanen, H., Lindi, V., Lakka, T. A., & Haapala, E. A. (2020). Associations of dietary carbohydrate and fatty acid intakes with cognition among children. Public Health Nutrition, 23(9), 1657-1663. https://doi.org/10.1017/s1368980019003860

Associations of dietary carbohydrate and fatty acid intakes with cognition among children

Sehrish Naveed[1], Taisa Venäläinen[1,2], Aino-Maija Eloranta[1], Arja T. Erkkilä[3], Henna Jalkanen[1], Virpi Lindi[1], Timo A. Lakka[1,4,5], Eero A. Haapala[1,6]

[1]Physiology, Institute of Biomedicine, School of Medicine, University of Eastern Finland, Kuopio Finland;
[2]Clinical Nutrition, Institute of Public Health and Clinical Nutrition, University of Eastern Finland, Kuopio Campus, Finland;
[3]Public Health, Institute of Public Health and Clinical Nutrition, University of Eastern Finland, Kuopio Campus, Finland;
[4]Department of Clinical Physiology and Nuclear Medicine, Kuopio University Hospital and University of Eastern Finland, Kuopio, Finland;
[5]Kuopio Research Institute of Exercise Medicine, Kuopio, Finland;
[6]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland.

Corresponding author: Sehrish Naveed. M.B.B.S., MPHN. Physiology | Institute of Biomedicine, School of Medicine | University of Eastern Finland. PO Box 1627 | FI-70211 Kuopio, Finland. e-mail: sehrisn@uef.fi | Phone: +358466137254

Running title: Dietary intakes and cognition among children

Keywords: Diet, fatty acid, carbohydrate, children, brain, cognition

Acknowledgement: I acknowledge the work of all authors especially Dr. Haapala and Prof. Timo Lakka for their throughout support in completion of the paper.

Financial support: This study was financially supported by grants from the Jenny and Antti Wihuri Foundation, the Sinikka and Sakari Sohlberg Foundation, the Ministry of Social Affairs and Health of Finland, the Ministry of Education and Culture of Finland, the Finnish Innovation Fund Sitra, the Social Insurance Institution of Finland, the Finnish Cultural Foundation, the Juho Vainio Foundation, the Yrjö Jahnsson Foundation, the Foundation for Pediatric Research, the Paavo Nurmi Foundation, the Paulo Foundation, the Diabetes Research Foundation Kuopio, the Kuopio University Hospital (EVO-funding number 5031343) and the Research Committee of the Kuopio University Hospital Catchment Area (the State Research Funding), Yrjö Jahnsson Foundation.

Authorship: Naveed S, Lakka TA and Haapala EA were responsible for study design; SN drafted the manuscript and analyzed the data. Venäläinen T, Eloranta AM, Arja T, Jalkanen H, Lindi V, and Lakka TA collected the data and contributed the intellectual content and interpretation of the results.

	Lakka TA is the principal investigator of the PANIC Study.
Conflict of interest	The manuscript has been approved by all authors, and there are no conflicts of interest regarding it.
Ethical Standards Disclosure	This study was conducted according to the guidelines laid down in the Declaration of Helsinki and all procedures involving research study participants were approved by the Research Ethics Committee of the Hospital District of Northern Savo, Kuopio. Written informed consent was obtained from the parents of all subjects.

ASSOCIATIONS OF DIETARY CARBOHYDRATE AND FATTY ACID INTAKES WITH COGNITION AMONG CHILDREN

ABSTRACT

Objective: To investigate the cross-sectional associations of dietary carbohydrate and fatty acid intakes with cognition in mid-childhood.

Design: Dietary carbohydrate and fatty acid intakes were assessed using 4-days food records and cognition was evaluated using the Raven's Coloured Progressive Matrices (RCPM) Score. The cross-sectional associations of dietary carbohydrate and fatty acid intakes with cognition were investigated using linear regression analyses adjusted for age, sex, body fat percentage, household income, parental education, and daily energy intake.

Setting: The baseline examinations of the Physical Activity and Nutrition in Children (PANIC) study.

Participants: A population-based sample of 487 children (250 boys, 237 girls) aged 6–8 years living in the city of Kuopio, Finland.

Results: A higher dietary intake of fructose (standardized regression coefficient $\beta = 0.24$, $P < 0.001$), total fibre ($\beta = 0.16$, $P = 0.02$), and soluble fibre ($\beta = 0.15$, $P = 0.02$) were associated with a higher RCPM score in boys. Other dietary carbohydrates and fatty acids including total carbohydrates, glucose, sucrose, starch, insoluble fibre, total fat, SFAs, monounsaturated fatty acids, PUFAs, palmitic acid (C16), stearic acid (C18), linoleic acid (C18:2), alpha-linoleic acid (C18:3), arachidonic acid (C20:4), EPA (C20:5 n-3), and DHA (C22:6 n-6) were not associated with the RCPM score in boys. Dietary carbohydrates or fatty acids were not associated with the RCPM score in girls.

Conclusion: Higher dietary fructose and fibre intakes were associated with better cognition in boys, but not in girls. Dietary fatty acids were not related to cognition in boys or in girls.

Key words: Diet, fatty acid, carbohydrate, children, brain, cognition

INTRODUCTION

Childhood is a period of rapid neural and cognitive development (1,2) that involves the myelination of various brain areas (3,4) and the acquisition of higher order cognitive abilities to regulate goal-directed activity, emotions, and decision-making (5,6). A sufficient quantity and quality of various nutrients, particularly carbohydrates and fatty acids (FAs), are vital for optimal cognitive development in children (7). A modern era has introduced a poor diet quality, including a low intake of fibre and a high intake of refined sugars and saturated fatty acids (SFAs), among children (8). A poor diet quality may impair neural and cognitive development in children (9,10), but such evidence in general population of school-aged children without nutritional deficiencies or learning disabilities is limited (11,12).

Glucose is the most studied carbohydrate in association with cognition, as it is main source of energy for brain cells (13). The results of previous studies indicate that increased blood glucose after breakfast improves attention, memory, and information processing in preadolescent children (14). A higher total dietary fibre intake has been associated with better verbal memory (15) and higher dietary intake of soluble and insoluble fibre have been linked to better selective attention and inhibition (16) in preadolescent children. Furthermore, a recent cross-sectional study found that a lower dietary intake of simple carbohydrates and a higher dietary intake of fibre were associated with better cognition in preadolescent children (17). However, most of the existing studies on the associations of dietary intakes of carbohydrates with cognition have only assessed blood glucose levels after meals (18,19). Moreover, evidence on the associations of dietary intakes of other carbohydrates with cognition, particularly in children, is limited (15,16).

A higher dietary intake of SFAs and trans fatty acids and a lower dietary intake of omega-3 polyunsaturated fatty acids (PUFAs) have been related to poorer cognition in some (20) but not all (21) cross-sectional studies among children. A meta-analytic study exhibited that omega-3 fatty acid supplements improved cognition in infants but not in older children (22). However, recent dietary (23) and supplementary (24) intervention studies suggest that increased intakes of omega-3 and omega-6 PUFAs and especially increased intakes of eicospentaenoic acid (EPA) and docosahexaenoic acid (DHA) are linked to improved cognitive skills in children 8–11 years of age. Nevertheless, there is limited knowledge on the associations of dietary intakes of other FAs than EPA and DHA with cognition.

We investigated the association of dietary intakes of carbohydrates and FAs with cognition in a population sample of school children aged 6–8 years. We hypothesized that higher intakes of fibre and PUFAs and lower intakes of SFAs and refined carbohydrates are related to better cognition in children.

METHODS

Study population and design

The present analyses are based on the baseline data from the Physical Activity and Nutrition in Children (PANIC) Study, that is a controlled physical activity and dietary intervention study in a population sample of children from the city of Kuopio, Finland. We invited 736 children 6–9 years of age who started the first grade in 16 primary schools of Kuopio in 2007–2009 to participate in the study. Altogether 512 children (248 girls, 264 boys), who accounted for 70% of those invited, participated in the baseline examinations in 2007–2009. The participants did not differ in age, sex, or body mass index standard deviation score (BMI-

SDS) from all children who started the first grade in the city of Kuopio in 2007–2009 based on data from the standard school health examinations performed for all Finnish children before the first grade. After excluding children with developmental disabilities and attention deficit hyperactivity disorder, 487 (237 girls, 250 boys) children had complete data used in the analyses.

Assessment of dietary intakes of carbohydrates and fatty acids

We assessed energy and nutrient intakes by food records filled out by the parents on four predefined consecutive days (25). Of the food diaries, 99.5% included two weekdays and two weekend days and 0.5% included three weekdays and one weekend day. A clinical nutritionist instructed the parents to record all food and drinks consumed by their children at home, at school, in afternoon care, and elsewhere outside home using household or other measures, such as tablespoons, decilitres, and centimetres. She reviewed the food records at return and completed the records with the parents using a picture booklet of portion sizes (26), if needed. A clinical nutritionist also asked the catering company about the details of food and drinks, such as menus, cooking fat, and spread on bread, served at schools and in afternoon care. Moreover, she disaggregated all prepared foods and mixed dishes into ingredients according to the recipes used. We calculated total energy and nutrient intakes from the collected food record data by using the Micro Nutrica® dietary analyses software, Version 2.5 (The Social Insurance Institution of Finland), that utilizes Finnish and international data on nutrient concentrations of foods (27).

The current analyses include the daily intakes of energy (kcal), total carbohydrates, glucose, fructose, sucrose, starch, total fibre, soluble fibre, insoluble fibre, total fat, SFAs, monounsaturated fatty acids, PUFAs, palmitic acid (C16), stearic acid (C18), linoleic acid

(C18:2), alpha-linoleic acid (C18:3), arachidonic acid (C20:4), EPA (C20:5 n-3), and DHA (C22:6 n-6).

Assessment of cognition

We assessed non-verbal reasoning by using Raven´s Coloured Progressive Matrices (RCPM) (28) that was administered by one trained researcher. The RCPM includes three sets of 12 items. Each test page includes a large item or a pattern of items and six small items. The children were asked to select the correct small item, which completes the large item or the set of items. The test score was the number of correct answers, ranging from zero to 36.

Assessment of body size and composition

A research nurse measured body weight twice the children being fasted for 12 hours and emptied the bladder and standing in light underwear by a calibrated InBody 720® bioelectrical impedance device (Biospace, Seoul, Korea) to accuracy of 0.1 kg. We used the mean of these two values in the analyses. A research nurse measured stature three times the children being in the Frankfurt plane without shoes by a wall-mounted stadiometer to accuracy of 0.1 cm. We measured body fat percentage and lean body mass with the Lunar® dual-energy X-ray absorptiometry device (GE Medical Systems, Madison, WI, USA) (25,29).

Other assessments

The parents were asked to report their annual household income (30,000 €, 30,001–60,000 €, and 60,001 €) and their highest completed or ongoing educational degrees (vocational school or less, polytechnic, and university) in a questionnaire. We used the educational degree of the more educated parent in the analyses. The parents were also asked to report the medically diagnosed developmental disorders and attention deficit-hyperactivity disorder of their children.

Statistical methods

We analysed the data using the SPSS Statistics for Windows software, Version 21.0 (IBM Corp., Armonk, NY, USA). We used the Student´s t-test and the Chi-Square test to compare basic characteristics between boys and girls and multivariate linear regression analyses adjusted for age, sex, body fat percentage, household income, parental education, total physical activity, and daily energy intake to investigate the associations of the dietary intakes of carbohydrates and FAs with the RCPM score. Because the results of previous studies suggest that the associations of the components of diet quality with cognition are stronger in boys than in girls (11), we conducted the analyses separately for boys and girls. However, we performed the analyses also for all children, because sex did not statistically significantly modify the associations of the measures of diet quality with the RCPM score ($P > 0.05$ for interactions).

RESULTS

Basic characteristics

Boys were taller, had lower body fat percentage, and came from families with higher annual household income than girls (**Table 1**). Boys had a higher daily energy intake and higher intakes of total carbohydrates, sucrose, starch, total fibre, insoluble fibre, and total fat than girls. Boys also had higher intakes of most FAs, except EPA and DHA, than girls (**Table 2**).

Associations of dietary carbohydrate and fatty acid intakes with cognition

In all children, a higher intake of fructose was associated with a higher RCPM score (adjusted $r^2 = 0.049$) after adjustment for age, sex, body fat percentage, household income, parental education, total physical activity, and daily energy intake (**Table 3**). This association was slightly weakened after further adjustment for the consumption of fruit and berries (β=0.11, p=0.100). None of the dietary FAs was associated with the RCPM score in all children.

In boys, higher intakes of fructose (adjusted $r^2 = 0.045$), total fibre (adjusted $r^2 = 0.011$), and soluble fibre (adjusted $r^2 = 0.012$) were related to a higher RCPM score after adjustment for age, body fat percentage, household income, parental education, total physical activity, and daily energy intake (Table 3). Further adjustment for the consumption of fruit juices (β=0.15, p=0.02; adjusted $r^2 = 0.025$) strengthened the association of soluble fibre with the RCPM score. Similarly, further adjustment for the consumption of high-fibre bread (β=0.21, p=0.01; adjusted $r^2 = 0.015$) or fruit juices (β=0.16, p=0.02; adjusted $r^2 = 0.025$) strengthened the association of the intake of total fibre with the RCPM score. However, adjustment for the consumption of fruit and berries (β=0.19, p=0.040) or fruit juices (β=0.23, p=0.006) slightly attenuated the association of the intake fructose with the RCPM score. Similarly, further adjustment for the consumption of fruit and berries (β=0.07, p=0.37) or vegetables (β=0.12, p=0.08) attenuated the association of the intake of total fibre with the RCPM score. Further adjustment for the consumption of fruit and berries (β=0.03, p=0.72), vegetables (β=0.11, p=0.12) or high-fibre bread (β=0.16, p=0.03) attenuated the association of the intake of soluble fibre with the RCPM score. None of the dietary FAs was related to the RCPM score in boys.

In girls, the intakes of carbohydrates or FAs were not associated with the RCPM score after adjustment for age, body fat percentage, household income, parental education, total physical activity, and daily energy intake (Table 3).

DISCUSSION

We found that higher dietary intakes of fructose, total fibre, and soluble fibre were associated with better cognition in boys but not in girls. However, dietary FAs were not related to cognition in boys or in girls.

Our finding on the association between a higher dietary intake of fructose and better cognition in boys is in contrast to previous observations on an inverse association between dietary fructose and cognition in adults (30). One reason for these contrasting findings may be that a higher intake of fructose from refined sugars may impair cognitive performance, whereas a higher intake of fructose from natural sources, such as fruits, vegetables, and grain products, may be neuroprotective and support cognitive functions (31–33). We have previously observed in the present study population of children that the carbohydrates were mainly obtained from low-fibre grain products and the main sources of fibre were high-fibre bread and vegetables (25) and that fruit and fruit juice consumption was directly related to cognition (11). Natural sources of fructose, such as fruits, include also other neuroprotective nutrients, such as B vitamins and antioxidants, which may partly explain these observations (32,33). Accordingly, we found that the consumption of fruit and berries partly explained the positive association between dietary fructose and the RCPM score.

Our observation on the positive associations of dietary total and soluble fibres with cognition in boys is in accordance with few previous findings in children (16) and in older adults (34). We have previously found that a higher consumption of high-fibre grain products was related to better cognition in children (11). A higher intake of fibre may support normal cognitive development, because it has been observed to amplify the effect of neuroprotective brain-derived neurotrophic factor (35). A higher dietary fibre intake has also been associated with a decreased concentration of neuroinflammatory markers, such as interleukin 1 beta and tumour necrosis factor alpha, in the brain (36).

We found positive associations of dietary fructose and fibre with cognition in boys but not in girls. The results of some previous studies suggest that dietary factors have a stronger effect on brain development in boys than in girls (7,37). Isaacs and co-workers observed that a higher use of protein-enriched formula during infancy was associated with a larger volume of caudate nucleus and intelligence quotient in adolescence among boys but not among girls (7). The explanation of these sexually dimorphic findings is not known, but they may relate to differences in the stage and rate of neural maturation between boys and girls (7). However, few studies have reported their data in boys and girls separately. Therefore, further studies on sex differences in the associations of dietary factors with cognition are warranted.

We observed no associations of dietary glucose, sucrose, starch, or insoluble fibres with cognition in children. One explanation may be that different carbohydrates have varying effects on diverse types of cognition. Papanikolaou and co-workers found that a carbohydrate-rich meal with a high glycaemic index was associated with deterioration in verbal memory but not working memory, measured by a digit span test, among adults (38). Another study in children showed that working memory was poorer after consuming a meal with a high glycaemic index than after a meal with a low glycaemic index (18). However, neither of these meals had effects on sustained attention (18).

We found no statistically significant associations of dietary FAs with cognition in children. Our observations are in line with those of some previous studies that the dietary intake or supplementation of FAs had weak if any association with cognitive performance in well-nourished children with no psychological or reading disabilities (12,24,39,40). It is possible that the intake of FAs (25) and the proportion of plasma FAs (41) among children in our study was adequate to support normal development of cognition (6,42).

The other reason for no associations of dietary FAs with cognition in the present study may be that dietary FAs have different impacts on various cognitive domains. The dietary intake of omega-3 FAs has been directly associated with relational memory but not with item memory in children (20). Furthermore, the dietary intake of SFA has been inversely associated with relational and item-memory in children aged 7–9 years (20,43). The reason for these observations may be that PUFAs, such as omega-3 FAs, have a pronounced positive effect on cognitive functions that are regulated in hippocampus, such as relational memory, whereas SFAs have more global negative effects on memory (43).

The strengths of the present study include a relatively large population sample of children and valid methods used to assess dietary factors and cognition. The parents were asked to record all food and drinks consumed by their children at home, at school, in afternoon care, and elsewhere outside home on four predefined and consecutive days, including two weekdays and two weekend days, which provides a better view on overall nutrition than using weekdays only. Moreover, a clinical nutritionist reviewed the food records at return and completed the records with the parents using a picture booklet of portion sizes (26), if needed. Our analyses are based on cross-sectional data, and we therefore cannot provide evidence for a causal link between dietary factors and cognition. We neither had dietary data from infancy or early childhood, which are important phases of cognitive development (6) and could therefore have an effect on our results. Furthermore, it would have been optimal to use multiple cognitive tests to study the associations of dietary factors with different aspects of cognition.

In conclusion, higher dietary intakes of fructose, total fibre, and soluble fibre were associated with better cognition in boys 6–8 years of age. However, dietary fats were not associated with cognition in children. These findings suggest that increasing the consumption of fruit and fruit juices, which are natural sources of fructose, and high-fibre food products, such as grain products, may support normal cognition in boys. Longitudinal studies, and optimally dietary intervention studies, are needed to provide further evidence for the role of dietary carbohydrates and fats in cognition to investigate whether gender modifies the associations of dietary factors with cognition.

REFERENCES

1. Bourre JM. Effects of nutrients (in food) on the structure and function of the nervous system: update on dietary requirements for brain. Part 1: micronutrients. J Nutr Health Aging. France; 2006;10(5):377–85.

2. Lenroot R, Giedd J. Brain development in children and adolescents: Insights from anatomical magnetic resonance imaging. Neurosci Biobehav Rev. 2009;30:718–29.

3. Thatcher RW. Maturation of the human frontal lobes: Physiological evidence for staging. Dev Neuropsychol. 1991;7(3):397–419. Available from: http://www.tandfonline.com/doi/abs/10.1080/87565649109540500

4. Bryan J, Osendarp S, Hughes D, et al. Nutrients for cognitive development in school-aged children. Nutr Rev. United States; 2004;62(8):295–306.

5. Atallah HE, Frank MJ, O'Reilly RC. Hippocampus, cortex, and basal ganglia: Insights from computational models of complementary learning systems. Neurobiol Learn Mem. 2004;82(3):253–67. Available from: http://www.sciencedirect.com/science/article/pii/S1074742704000693

6. Diamond A. Executive Functions. Annu Rev Psychol. 2013;64(1):135–68. Available from: http://www.annualreviews.org/doi/10.1146/annurev-psych-113011-143750

7. Isaacs E, Oates J. Nutrition and cognition: assessing cognitive abilities in children and young people. Eur J Nutr. 2008;47(S3):4–24. Available from: http://www.ncbi.nlm.nih.gov/pubmed/18683026

8. Danaei G, Finucane MM, Lu Y, et al. National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: systematic analysis of health

examination surveys and epidemiological studies with 370 country-years and 2·7 million participants. Lancet. 2011;378(9785):31–40. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21705069

9. Nyaradi A, Li J, Hickling S, et al. The role of nutrition in children's neurocognitive development, from pregnancy through childhood. Front Hum Neurosci. 2013;7:97. Available from: http://www.ncbi.nlm.nih.gov/pubmed/23532379

10. Haapala E, Lintu N, Vaisto J, et al. Associations of physical performance and adiposity with cognition in children. Med Sci Sport Exerc. 2015;47(10):2166–74. Available from: https://www.researchgate.net/profile/Leah_Robinson3/publication/273439198_Associations_of_Physical_Performance_and_Adiposity_with_Cognition_in_Children/links/574f6bfd08aebb988044f4de/Associations-of-Physical-Performance-and-Adiposity-with-Cognition-in-Chi

11. Haapala EA, Viitasalo A, Venäläinen T, et al. Associations of diet quality with cognition in children – the Physical Activity and Nutrition in Children Study. Br J Nutr. 2015;

12. Osendarp SJM, Baghurst KI, Bryan J, et al. Effect of a 12-mo micronutrient intervention on learning and memory in well-nourished and marginally nourished school-aged children: 2 parallel, randomized, placebo-controlled studies in Australia and Indonesia. Am J Clin Nutr. 2007;86(4):1082–93. Available from: http://www.ncbi.nlm.nih.gov/pubmed/17921387

13. Stephen A, Alles M, de Graaf C, et al. The role and requirements of digestible dietary carbohydrates in infants and toddlers. Eur J Clin Nutr. Nature Publishing Group; 2012;66(7):765–79. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22473042

14. Márquez Acosta M, Sutil de Naranjo R, Rivas de Yepez C, et al. Influencia del desayuno sobre la función cognoscitiva de escolares de una zona urbana de Valencia, Venezuela. Arch Latinoam Nutr. 200;51(1):57–63. Available from: http://www.scielo.org.ve/scielo.php?pid=S0004-06222001000100008&script=sci_arttext&tlng=pt

15. Micha R, Rogers PJ, Nelson M. Glycaemic index and glycaemic load of breakfast predict cognitive function and mood in school children: a randomised controlled trial. Br J Nutr. 2011;106(10):1552–61. Available from: http://www.journals.cambridge.org/abstract_S0007114511002303

16. Khan NA, Raine LB, Drollette ES, et al. Dietary fiber is positively associated with cognitive control among prepubertal children. J Nutr. American Society for Nutrition; 2015;145(1):143–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25527669

17. Hassevoort KM, Lin AS, Khan NA, et al. Added sugar and dietary fiber consumption are associated with creativity in preadolescent children. Nutr Neurosci. Taylor & Francis; 2018;1–12. Available from: https://www.tandfonline.com/doi/full/10.1080/1028415X.2018.1558003

18. Benton D, Maconie A, Williams C. The influence of the glycaemic load of breakfast on the behaviour of children in school. Vol. 92, Physiology & behavior. 2007. 717-724 p.

19. Cooper SB, Bandelow S, Nute ML, et al. Breakfast glycaemic index and cognitive function in adolescent school children. Br J Nutr. 2012;107(12):1823–32. Available from: http://www.journals.cambridge.org/abstract_S0007114511005022

20. Baym CL, Khan NA, Monti JM, et al. Dietary lipids are differentially associated with hippocampal-dependent relational memory in prepubescent children. Am J Clin Nutr. American Society for Nutrition; 2014;99(5):1026–32. Available from:

http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3985209/

21. Zhang J, Hebert JR, Muldoon MF. Dietary Fat Intake Is Associated with Psychosocial and Cognitive Functioning of School-Aged Children in the United States. J Nutr. Oxford University Press; 2005;135(8):1967–73. Available from: https://academic.oup.com/jn/article/135/8/1967/4663924

22. Jiao J, Li Q, Chu J, et al. Effect of n-3 PUFA supplementation on cognitive function throughout the life span from infancy to old age: a systematic review and meta-analysis of randomized controlled trials. Am J Clin Nutr. 2014;100(6):1422–36. Available from: http://www.ncbi.nlm.nih.gov/pubmed/25411277

23. Sørensen LB, Damsgaard CT, Dalskov S-M, 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. 2015;114(10):1623–37. Available from: http://www.ncbi.nlm.nih.gov/pubmed/26359192

24. Johnson M, Fransson G, Östlund S, et al. Omega 3/6 fatty acids for reading in children: a randomized, double-blind, placebo-controlled trial in 9-year-old mainstream schoolchildren in Sweden. J Child Psychol Psychiatry. 2017;58(1):83–93. Available from: http://www.ncbi.nlm.nih.gov/pubmed/27545509

25. Eloranta A-M, Lindi V, Schwab U, et al. Dietary factors associated with overweight and body adiposity in Finnish children aged 6–8 years: the PANIC Study. Int J Obes. 2012;36(7):950–5. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22665136

26. Paturi M, Nieminen R, Reinivuo H, et al. Picture book of food portion sizes. Helsinki, Finland; 2006.

27. Rastas M, Seppänen R, Knuts L, et al. Nutrient Composition of Foods. Helsinki, Finland; 1997.

28. Raven J, Raven J, Court J. Coloured Progressive Matrices. Manual for Raven's Progressive Matrices and Vocabulary Scales. London: Oxford Psychologist Press Ltd; 1998.

29. Tompuri TT, Lakka TA, Hakulinen M, et al. Assessment of body composition by dual-energy X-ray absorptiometry, bioimpedance analysis and anthropometrics in children: the Physical Activity and Nutrition in Children study. Clin Physiol Funct Imaging. 2015;35(1):21–33. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24325400

30. Ye X, Gao X, Scott T, et al. Habitual sugar intake and cognitive function among middle-aged and older Puerto Ricans without diabetes. Br J Nutr. 2011;106(09):1423–32. Available from: http://www.journals.cambridge.org/abstract_S0007114511001760

31. Ye X, Gao X, Scott T, et al. Habitual sugar intake and cognitive function among middle-aged and older Puerto Ricans without diabetes. Br J Nutr. 2011;106(09):1423–32. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21736803

32. Tucker KL, Qiao N, Scott T, et al. High homocysteine and low B vitamins predict cognitive decline in aging men: the Veterans Affairs Normative Aging Study. Am J Clin Nutr. 2005;82(3):627–35. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16155277

33. Akbaraly NT, Faure H, Gourlet V, et al. Plasma carotenoid levels and cognitive performance in an elderly population: results of the EVA Study. J Gerontol A Biol Sci Med Sci. United States; 2007;62(3):308–16. Available from: https://www.ncbi.nlm.nih.gov/pubmed/17389729

34. Ortega RM, Requejo AM, Andrés P, et al. Dietary intake and cognitive function in a group of elderly people. Am J Clin Nutr. 1997;66(4):803–9. Available from: http://www.ncbi.nlm.nih.gov/pubmed/9322553

35. Schroeder FA, Lin CL, Crusio WE, et al. Antidepressant-like effects of the histone deacetylase inhibitor, sodium butyrate, in the mouse. Biol Psychiatry. 2007;62(1):55–64. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16945350

36. Sherry CL, Kim SS, Dilger RN, et al. Sickness behavior induced by endotoxin can be mitigated by the dietary soluble fiber, pectin, through up-regulation of IL-4 and Th2 polarization. Brain Behav Immun. 2010;24(4):631–40. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20138982

37. Craft S, Murphy C, Wemstrom J. Glucose effects on complex memory and nonmemory tasks: The influence of age, sex, and glucoregulatory response. Psychobiology. 1994;22(2):95–105. Available from: https://doi.org/10.3758/BF03327086

38. Papanikolaou Y, Palmer H, Binns MA, et al. Better cognitive performance following a low-glycaemic-index compared with a high-glycaemic-index carbohydrate meal in adults with type 2 diabetes. Diabetologia. 2006;49(5):855–62. Available from: http://www.ncbi.nlm.nih.gov/pubmed/16508776

39. Ryan AS, Astwood JD, Gautier S, et al. Effects of long-chain polyunsaturated fatty acid supplementation on neurodevelopment in childhood: a review of human studies. Prostaglandins Leukot Essent Fatty Acids. Elsevier; 2010;82(4–6):305–14. Available from: http://www.ncbi.nlm.nih.gov/pubmed/20188533

40. Muthayya S, Eilander A, Transler C, et al. Effect of fortification with multiple micronutrients and n-3 fatty acids on growth and cognitive performance in Indian schoolchildren: the CHAMPION (Children's Health and Mental Performance

Influenced by Optimal Nutrition) Study. Am J Clin Nutr. 2009;89(6):1766–75. Available from: http://www.ncbi.nlm.nih.gov/pubmed/19369376

41. Venäläinen T, Schwab U, Ågren J, et al. Cross-Sectional Associations of Food Consumption with Plasma Fatty Acid Composition and Estimated Desaturase Activities in Finnish Children. Lipids. 2014;49(5):467–79. Available from: http://www.ncbi.nlm.nih.gov/pubmed/24659110

42. Rask-Nissilä L, Jokinen E, Terho P, et al. Neurological development of 5-year-old children receiving a low-saturated fat, low-cholesterol diet since infancy: A randomized controlled trial. JAMA. 2000;284(8):993–1000. Available from: http://www.ncbi.nlm.nih.gov/pubmed/10944645

43. Kanoski SE, Davidson TL. Western diet consumption and cognitive impairment: Links to hippocampal dysfunction and obesity. Physiol Behav. 2011;103(1):59–68. Available from: http://www.ncbi.nlm.nih.gov/pubmed/21167850

TABLE 1

Characteristics of children.

Variables	***All (n=487)***	***Boys (n=250)***	***Girls (n=237)***	**P value for difference**
Age (years)	7.6 (0.37)	7.6 (0.37)	7.6 (0.39)	0.23
Height (cm)	128.7 (5.6)	129.6 (5.5)	127.8 (5.6)	0.001
Weight (kg)	26.9 (5.1)	27.2 (4.9)	26.5 (5.1)	0.10
Total physical activity (min/day)	15.8 (5.9)	16.2 (6.1)	15.5 (5.7)	0.24
Body fat percentage (%)	18.7 (8.2)	15.0 (8.0)	20.5 (7.7)	0.001
Household income (%)				0.02
<30,000€	19.6	17.1	22.3	
30,000-60,000€	41.9	39.0	45.0	
>60,000€	35.8	40.2	31.1	
Parental education (%)				0.10
Vocational school or less	19.2	19.9	18.5	
Polytechnic	44.0	37.1	51.3	
University degree	35.6	41.4	29.4	
RCPM score	23.9 (5.1)	23.8 (5.2)	24.1 (4.9)	0.57

Data are means (standard deviations) from the Student's t-test for continuous variables and numbers (percentages) from the Chi-square test for categorical variables.
Abbreviation: RCPM, Raven's Coloured Progressive Matrices

TABLE 2

Energy and nutrient intakes in children.

Variables	*All*	*Boys*	*Girls*	*P* ***value for difference***
Energy intake (kcal/day)	1625 (310.0)	1709(310.6)	1537 (284.4)	<0.001
Carbohydrate Intake (g/day)				
Total carbohydrate	210.2 (45.7)	219.6 (47.6)	200.3 (41.4)	<0.001
Sucrose	51.2 (19.8)	53.5 (21.3)	48.7 (17.7)	<0.001
Glucose	11.3 (5.0)	11.7 (5.3)	11.0 (4.6)	0.12
Fructose	9.6 (4.8)	9.7 (5.2)	9.5 (4.4)	0.75
Starch	96.2 (23.8)	101.0 (25.2)	91.1 (21.0)	<0.001
Fibre Intake (g/day)				
Total fibre	14.2 (4.1)	14.6 (4.3)	13.8 (3.8)	0.04
Soluble fibre	3.3 (1.0)	3.4 (1.0)	3.2 (0.9)	0.20
Insoluble fibre	6.3 (2.0)	6.5 (2.1)	6.0 (1.8)	0.006
Fat Intake (g/day)				
Total fat	54.6 (14.9)	57.8 (14.5)	51.1 (14.5)	<0.001
Saturated fatty acids	22.1 (7.1)	23.4 (6.9)	20.7 (7.1)	<0.001
Monounsaturated fatty acids	18.1 (5.1)	19.2 (5.0)	16.9 (5.0)	<0.001
Polyunsaturated fatty acids	8.9 (2.8)	9.5 (3.0)	8.3 (2.6)	<0.001
Palmitic acid (C16)	9.0 (3.1)	9.6 (3.1)	8.4 (3.1)	<0.001
Stearic acid (C18)	4.1 (1.6)	4.4 (1.6)	3.7 (1.5)	<0.001
linoleic acid (C18:2)	6.6 (2.4)	7.0 (2.5)	6.1 (2.3)	<0.001

Table 2 continued

Variables	*All*	*Boys*	*Girls*	*P* ***value for difference***
Alpha-linoleic acid (C18:3)	1.4 (0.5)	1.5 (0.5)	1.3 (0.4)	<0.001
Arachidonic acid (C20:4)	0.09 (0.1)	0.1 (0.1)	0.08 (0.1)	<0.001
Eicosapentaenoic acid (C20:5 n-3)	0.04 (0.1)	0.04 (0.1)	0.03 (0.1)	0.14
Docosahexaenoic acid (C22:6 n-6)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.11

Data are means (standard deviations) from the Student's t-test.

TABLE 3

Association of dietary intakes with the RCPM score.

Variables	***All children***		***Boys***		***Girls***	
	β	*P*	*β*	*P*	*β*	*P*
Daily carbohydrate intake (g/day)						
Total Carbohydrate	0.15	0.09	0.21	0.10	0.07	0.55
Glucose	0.06	0.23	0.11	0.13	0.002	0.97
Sucrose	0.04	0.50	-0.002	0.98	0.08	0.33
Fructose	0.14	**0.002**	0.24	**0.000**	0.03	0.57
Starch	-0.02	0.72	-0.02	0.81	0.02	0.79
Daily fibre intake (g/day)						
Total fibre	0.08	0.08	0.16	**0.02**	-0.004	0.95
Soluble fibre	0.07	0.13	0.15	**0.02**	-0.02	0.77
Insoluble fibre	0.02	0.58	0.08	0.21	-0.05	0.40
Daily fat intake (g/day)						
Total fat	-0.104	0.14	-0.18	0.05	-0.006	0.96
Saturated fatty acids	-0.12	0.07	-0.09	0.16	0.04	0.68
Monounsaturated fatty acids	-0.06	0.35	-0.11	0.19	-0.005	0.96
Polyunsaturated fatty acids	-0.02	0.61	-0.01	0.88	0.04	0.55
Palmitic acid (C16)	-0.08	0.19	-0.16	0.06	0.003	0.97
Stearic acid (C18)	-0.07	0.19	-0.11	0.14	-0.04	0.52
linoleic acid (C18:2)	-0.02	0.72	-0.01	0.86	0.01	0.85
Alpha-linoleic acid (C18:3)	0.02	0.68	0.05	0.46	-0.02	0.72
Arachidonic acid (C20:4)	-0.07	0.13	-0.04	0.55	-0.10	0.12
Eicosapentaenoic acid (C20:5 n-3)	0.02	0.61	0.07	0.28	-0.02	0.73

Table 3 continued

Variables	***All children***		***Boys***		***Girls***	
	β	*P*	*β*	*P*	*β*	*P*
Docosahexaenoic acid (C22:6 n-6)	0.02	0.66	0.08	0.20	-0.04	0.51

The values are from linear regression models after adjustment for age, sex, body fat percentage, household income, parental education, total physical activity, and daily energy intake. P-values <0.05, indicating statistically significant associations, are bolded.