Received: 22 June 2023 | Revised: 26 July 2023 | Accepted: 27 July 2023

DOI: 10.1111/sms.14464

ORIGINAL ARTICLE

WILEY

Effects of 2-year dietary and physical activity intervention on cognition in children—a nonrandomized controlled trial

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Funding information
Academy of Finland; Diabetestutkimussäätiö; Finnish Innovation Fund Sitra; Juho Vainion Säätiö; Kela; Kuopion kaupunki; Lastentautien Tutkimussäätiö; Opetus- ja Kulttuuriministeriö; Paavo Nurmen Säätiö; Research Committee of the Kuopio University Hospital Catchment Area (State Research Funding); Sosiaali- ja Terveysministeriö; Suomen Kulttuurirahasto; Sydäntutkimussäätiö; Yrjö Jahnssonin Säätiö

Abstract

Background and Objective: We investigated the effects of a combined dietary and PA intervention on cognition in children and whether changes in diet quality, PA, sedentary behavior (SB), and sedentary time (ST) are associated with changes in cognition.

Methods: We conducted a 2-year nonrandomized controlled trial in 504 children aged 6–9 years at baseline. The children were allocated to a combined dietary and PA intervention group ($n = 237$) or a control group ($n = 160$) without blinding.

Interventions: The children and their parents allocated to the intervention group had six dietary counseling sessions of 30–45 min and six PA counseling sessions of 30–45 min during the 2-year intervention period. The children were also encouraged to participate in after-school exercise clubs. Cognition was assessed by the Raven's Colored Progressive Matrices. We assessed dietary factors by 4 days food records and computed the Baltic Sea Diet Score (BSDS) as a measure of diet quality. PA and ST were assessed by a combined heart rate and body movement monitor, types of PA and SB by a questionnaire.

Results: The intervention had no effect on cognition. Increased BSDS and consumption of low-fat milk and decreased consumption of red meat and sausages were associated with improved cognition over 2 years. Increased organized sports,

Section Specialty Area: Section III: Health, Disease & Physical Activity, Senior Section Editor: Mark Hamer.

ST, and reading were positively, while unsupervised PA, computer use, and writing were negatively associated with cognition.

Conclusion: Combined dietary and PA intervention had no effect on cognition. Improved diet quality and increased organized sports and reading were associated with improved cognition.

KEYWORDS

brain, exercise, lifestyle, nutrition, pediatrics

1 | INTRODUCTION

Children typically have a higher intake of saturated fat and sucrose and lower consumption of vegetables than recommended.[1,2] Furthermore, less than half of school-aged children accumulate the recommended 60 min of moderate-to-vigorous physical activity (PA) daily and spend most of their day in sedentary behaviors (SB).[3] These observations are alarming as a healthy diet and sufficient levels of PA may be vital for optimal cognitive development in children.[4,5]

Overall diet quality, the consumption of fish, vegetables, fruit, berries, and high-fiber grain products,[2,6] and PA have been positively associated with cognition and academic achievement in observational studies among children.[5] However, few studies have investigated the effects of dietary interventions on cognition, and the effects of those studies have been weak at the best.[7,8] PA interventions may improve cognition in children,[5] but the evidence is still equivocal.[9] Because of these inconsistent results from intervention studies, it has been suggested that multi-domain lifestyle interventions combining diet and PA confer larger beneficial effects on cognition than interventions focused only on diet or PA.[7] We have previously shown that a 2-year combined dietary and PA intervention improved several factors potentially contributing to cognitive development,[2] such as diet quality,[10] PA,[10] and cardiometabolic health[11,12] in a general population of children. However, there are no previous studies on the long-term effects of combined dietary and PA interventions on cognition in general populations of children.

We investigated the effects of a 2-year combined dietary and PA intervention on cognition in a population sample of school-aged children. However, intervention is only one factor that may influence cognitive development in children. Changes in diet quality, PA, and SB may also occur independently of the intervention, which could also affect the changes in cognition. Therefore, we also assessed the longitudinal associations of changes in diet quality and PA with changes in cognition over 2 years.

2 | METHODS

A brief description of methods is provided below. A detailed method description is provided in supplemental material.

2.1 | Study population

The current analyses are based on data from the Physical Activity and Nutrition in Children (PANIC) Study (ClinicalTrials.gov *NCT01803776*), which is an ongoing combined dietary and PA intervention study in a population sample of school-aged children from the city of Kuopio, Finland.[11] The PANIC study protocol was approved by the Research Ethics Committee of the Hospital District of Northern Savo. The parents or caregivers of the children gave their written informed consent, and the children also provided their assent to participation.

A total of 736 children of 6–9 years age from primary schools of Kuopio were invited to participate in the baseline examination of PANIC study in 2007–2009. Altogether, 512 children (70% of those invited) attended the baseline examinations (Figure 1). The participants did not differ in age, sex, or body mass index standard deviation score from all children who started the first grade in 2007–2009 based on data from the standard school health examinations performed for all Finnish children before the first grade. Eight children were excluded because of either disability or withdrawal from the study. The remaining 504 children were divided in the intervention group ($n=306$) and the control group ($n=198$) (see Appendix S1). Altogether, 440 children (87% of those participating in baseline examinations) attended in the 2-year follow-up examinations. A total of 504 children (198 in control group and 306 in intervention group) from baseline examination and 435 children (176 in control group and 259 in intervention group) from 2-year follow-up examinations, who had complete data on diet, PA, and cognition were included in the current analyses.

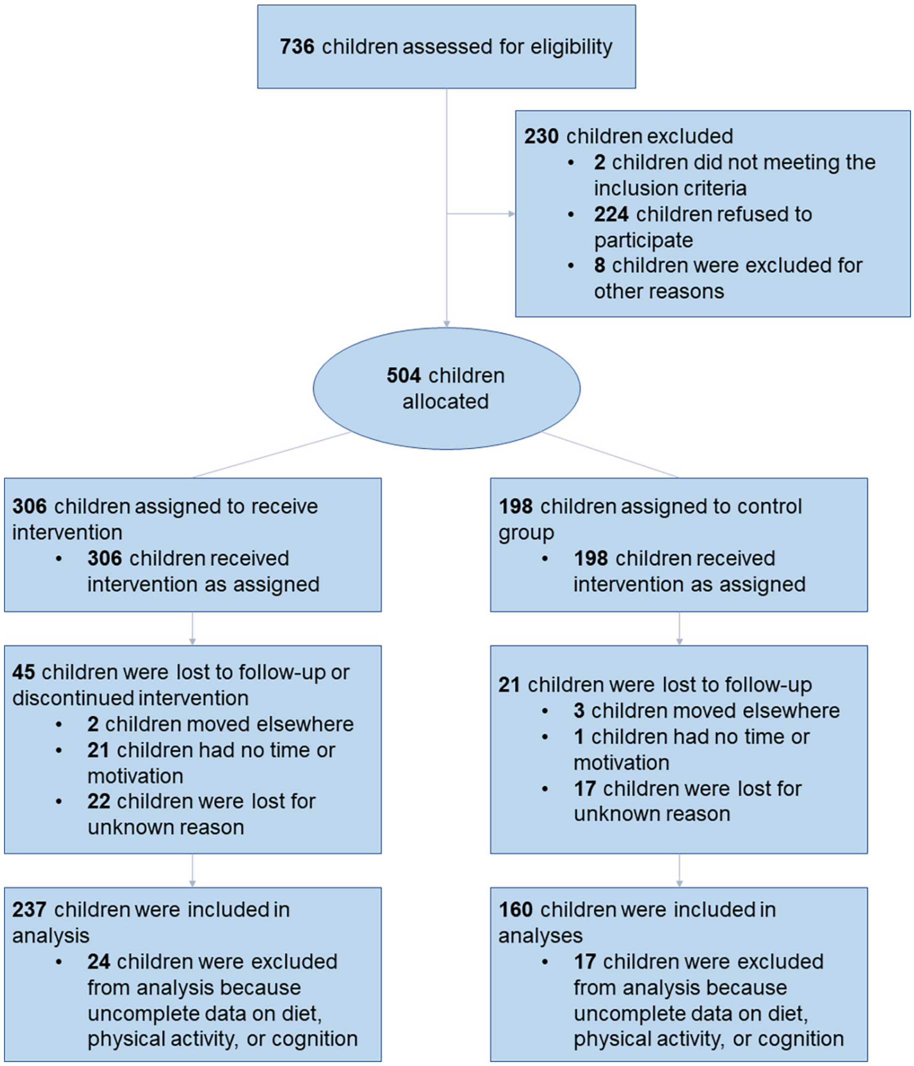

FIGURE 1 Flow chart of the study.

2.2 | Dietary and physical activity intervention

The children and their parents allocated to the intervention group had six dietary counseling sessions of 30–45 min and six PA counseling sessions of 30–45 min during the 2-year intervention period.[11] The dietary and PA counseling sessions occurred at 0.5, 1.5, 3, 6, 12, and 18 months after baseline. Authorized clinical nutritionists and specialists in exercise medicine of the PANIC study gave detailed and individualized advice on how to enhance diet quality, increase PA, and decrease SB. The children and their families also received fact sheets on diet quality, PA, and SB, verbal, and written information on opportunities to exercise in the city of Kuopio, and some financial support for PA, such as exercise equipment and admission for indoor sports. The children were also encouraged to participate in after-school exercise clubs organized by the PANIC study and supervised by trained exercise instructors. In the exercise clubs, the children had an opportunity to engage in variety of PAs. The children and their parents in the control group received general verbal and written advice on health improving diet and PA at baseline but no active intervention.

2.3 | Assessment of cognition

At the baseline and 2-year follow-up examinations, non-verbal reasoning skills were used as a measure of cognition and were assessed by Raven's Colored Progressive Matrices (RCPM)[13] that were administered by trained researchers. The RCPM require the ability to find similarities, differences, and discrete patterns and do not depend on acquired knowledge or language skills. The RCPM include three sets of 12 items. Each test page includes a large item or a pattern of items and six small items. The child was 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. The RCPM has been suggested to represent all-core components of executive functions[14] and has been found to be reliable with moderate to high Kuder–Richardson reliability coefficient (>80) in children aged 6–12 years.[15]

2.4 | Assessments of dietary factors

The consumption of foods and the intake of nutrients were assessed using 4 day food records.[16] The Baltic Sea Diet Score (BSDS) was used as an indicator of overall diet quality and was calculated using the quartiles (Q1–Q4) of the consumption of fruit and berries (scored 0–3), vegetables (0–3), high-fiber grain products (0–3), low-fat (<1%) milk (0–3), fish (0–3), red meat and sausages (reversed 0–3), the ratio of polyunsaturated fatty acids (PUFA) and saturated fatty acids (SFA) (0–3), and total fat intake (% energy intake) (reversed 0–3) as described previously.[17] BSDS ranged from 0 to 18, a higher score indicating better overall diet quality.

2.5 | Assessment of physical activity and sedentary behavior

Sedentary time (ST), light (LPA), moderate PA (MPA), and vigorous PA (VPA) were assessed at baseline and 2-year follow-up using individually calibrated combined heart rate and body movement monitor (Actiheart, CamNtech Ltd) described in detail earlier[18,19] and in the Supplemental material. Briefly, the children were asked to wear the sensor continuously for a minimum of 4 days (including sleep and water-based activities) without changing their usual behavior. Data on heart rate were cleaned and individually calibrated with parameters from the maximal exercise test and combined with movement sensor data to derive PA energy expenditure (PAEE). Instantaneous PAEE, that is, PA intensity, was estimated using branched equation modeling and summarized as daily PA volume (kJ/day/kg) and time spent at certain levels of standard metabolic equivalents of task (METs) in minutes per day.[18,19] Thereafter, LPA, MPA, and VPA were defined as time spent at intensity >1.5 and ≤4.0 metabolic equivalents of task (METs), >4.0 and ≤7.0 METs and >7.0 METs, respectively, where one MET is defined as an energy expenditure of 71 J/kg^{-1}/min^{-1} or oxygen uptake of 3.5 mL/kg^{-1}/min^{-1}. Moderate-to-vigorous PA (MVPA) was calculated by summing MPA and VPA. ST was defined as the time spent at intensity ≤1.5 METs, excluding sleep. Combined heart rate and movement sensing has been found to be more accurate in estimating PA energy expenditure than either method alone in children,[20,21] explaining 86% of variance in PAEE variance.[21]

Total PA and time spent in different types of PA and SB during a usual week were assessed by the PANIC Physical Activity Questionnaire filled out by the parents.[22] The types of PA included organized sports, organized exercise other than sports, unsupervised PA, physically active school transportation including walking and bicycling and recess PA. The types of SB included watching TV and videos, using a computer, and playing video games, using a mobile phone and playing mobile games, listening to music, playing a musical instrument, reading, writing, drawing, doing arts and crafts, playing board games, and resting. PA questionnaires with a similar structure to the PANIC Physical Activity Questionnaire, such as the Youth Physical Activity questionnaire, have shown good short-term repeatability over 4 days with an intraclass correlation of 0.86–0.92.[23]

2.6 | Statistical methods

Statistical analyses were performed using the IBM SPSS statistics for Windows, version 25.0 (IBM Corporation). In all analyses, differences and associations with p-values <0.05 are considered statistically significant. Basic characteristics between boys and girls were compared using the Student's t-test for continuous variables and the chi-square test for categorical variables.

The effects of the intervention on the RCPM score and the longitudinal associations of total BSDS and BSDS components, including red meat and sausages, fruit and berries, vegetables, high-fiber (≥5%) grain products, fish, PUFA-SFA ratio, total fat, and milk (<1% fat), TPA, LPA, MVPA, VPA, ST, media time (screen time), reading time, writing time, and computer use time with the RCPM score were analyzed using linear mixed-effects models adjusted for age, sex, parental education, household income, and BF% at baseline and pubertal status at 2-year follow-up. Please see supplemental material for detailed description of statistical analyses.

3 | RESULTS

3.1 | Basic characteristics

There were no differences in baseline characteristics between the groups, except that household income was higher in the intervention group than in the control group (Table 1).

TABLE 1 Characteristics of children at baseline and 2-year follow-up in the intervention and control groups.

	Baseline			2-year follow-up		
	Control	Intervention		Control	Intervention	
	$n=198$	$n=306$	p	$n=176$	$n=259$	p
Age (years)	7.6 (0.4)	7.6 (0.3)	0.989	9.7 (0.5)	9.7 (0.3)	0.917
Sex						
Boys	99	161	0.520	87	136	0.533
Girls	99	144		89	123	
Height (cm)	128.4 (5.8)	128.7 (5.5)	0.847	140 (6.8)	140 (5.8)	0.564
Weight (kg)	26.7 (5.6)	26.9 (4.8)	0.783	34.2 (8.0)	34.3 (6.8)	0.746
Body mass index (kg/m^2)	16 (2.3)	16 (2.0)	0.314	17 (2.8)	17 (2.6)	0.763
Body fat percentage (%)	19.9 (8.3)	19.7 (8.3)	0.372	23.4 (9.3)	23.3 (9.2)	0.250
Pubertal status, n (%)						
Pre-pubertal	193 (94)	298 (96.4)		130 (64.7)	192 (62.1)	
Pubertal	4 (2)	8 (2.6)		40 (19.9)	58 (18.8)	
Household income (%)						
<30 000€	55	51	**0.01**	41	41	**0.002**
30 000-60 000€	75	132		60	60	
>60 000€	55	117		71	130	
Parental education (%)						
Vocational school or less	41	57	0.814	29	35	0.664
Polytechnic	86	139		31	120	
University degree	72	107		64	101	
RCPM score	23.8 (4.9)	23.9 (5.3)	0.998	28.9 (3.8)	29.1 (3.7)	0.675

Note: Data are from the Student *t*-test and from the chi-square test for categorical variables and are displayed as means (SD) or percentages (%). Pubertal status was assessed using the stages described by Tanner.

Abbreviation: RCPM score, Raven colored progressive matrices score.

Statistically significant differences are bolded.

Moreover, children in the control group spent more time using computer and writing at baseline than those in the intervention group (Table 2). Furthermore, children in the accumulated more total PA and a higher BSDS, the ratio of PUFA to SFA, and the consumption of low-fat (<1%) milk after the 2 years than those in the control group (Table 2).

3.2 | Effect of combined dietary and physical activity intervention on cognition

There were no differences in the RCPM score between the control and intervention groups at baseline or at 2 years (Table 1). Moreover, the combined dietary and PA intervention had no effect on the RCPM score over 2 years after adjustment for age, sex, and BF% at baseline and pubertal status at 2-year follow-up (regression coefficient $\beta=0.73$, $p=0.75$ for study group*time interaction).

3.3 | Associations of changes in diet quality and cognition over 2 years

BSDS and the consumption of low-fat (<1%) milk were directly and the consumption of red meat and sausages was inversely associated with the RCPM score over 2 years after adjustment for age, sex, BF%, parental education, and household income at baseline and pubertal status at 2-year follow-up (Table 3). Other components of BSDS were not associated with the RCPM score over 2 years. The within-subject and between-subject effects of BSDS on the RCPM score were statistically different from each other (Table 4). Moreover, the within-subject effect of the consumption of red meat and sausages on the RCPM score was statistically significant. However, the within-subject and between-subject effects of BSDS and the consumption of low fat (<1%) milk on the RCPM score were statistically non-significant.

TABLE 2 Dietary and physical activity characteristics at baseline and 2-year follow-up in the physical activity and dietary intervention and control groups.

	Baseline			2-year follow-up		
	Control	Intervention		Control	Intervention	
	n = 192	*n* = 295	*p*	*n* = 171	*n* = 252	*p*
Dietary characteristics						
Total energy intake (kcal/day)	1666 (306.3) n = 158	1622 (306)	0.574	1688 (389)	1710 (374)	0.730
Total BSDS	11.1 (4.2)	11.5 (4.2)	0.377	11.5 (4.1)	13.8 (3.7)	**0.002**
BSDS components						
Red meat and sausages (g/d)	87.6 (48.2)	79.5 (41.2)	0.145	86.4 (43.1)	82.3 (45.2)	0.455
Fruit and berries (g/d)	104.4 (77.2)	105.6 (84.9)	0.906	93.3 (79.1)	108.8 (79.5)	0.117
Vegetables (g/d)	101.3 (55.8)	95.7 (57.6)	0.424	97.1 (61.8)	107.9 (69.5)	0.191
High-fiber (≥5%) grain products (g/d)	57.1 (37.5)	66.1 (43.1)	0.079	69.7 (45.6)	74.6 (47.0)	0.389
Fish	16.4 (23.2)	14.1 (18.5)	0.376	14.1 (20.5)	17.2 (21.1)	0.229
PUFA-SFA ratio	0.4 (0.1)	0.4 (0.1)	0.910	0.4 (0.1)	0.5 (0.1)	**0.037**
Total fat	1.3 (1.1)	1.5 (1.1)	0.178	32.0 (5.1)	31.1 (5.0)	0.140
Milk (<1% fat)	1.3 (1.1)	1.5 (1.1)	0.128	354.7 (283.8)	473.1 (267.4)	**0.001**
Physical activity characteristics						
Total physical activity (min/day)	105.1 (41.4)	116.1 (42.24)	0.166	103.5 (41.6)	122.4 (41.6)	**<0.001**
Active commuting to and from school (min/d)	20.8 (19.4)	27.3 (21.1)	**<0.001**	22.2 (18.5)	26.2 (17.1)	**<0.001**
Recess PA (min/d)	22.3 (6.1)	22.5 (5.8)	**<0.001**	22.3 (6.2)	22.7 (5.1)	**<0.001**
Organized sports (min/d)	3.3 (7.1)	6.2 (10.2)	**<0.001**	2.5 (4.5)	4.4 (7.1)	**<0.001**
Organized exercise (min/d)	48.6 (32.3)	49.9 (31.4)	**<0.001**	43.8 (32.1)	52.8 (32.1)	**<0.001**
Unsupervised PA (min/d)	105.1 (41.4)	116.1 (42.24)	0.166	103.5 (41.6)	122.4 (41.6)	**<0.001**
	n = 177	n = 278		n = 156	n = 218	
Light Physical activity (min/day)	501.5 (110.0)	518.5 (105.4)	0.101	398.0 (91.4)	410.3 (86.4)	0.184
Moderate Physical activity (min/day)	87.0 (54.1)	95.1 (52.2)	0.113	70.4 (39.9)	78.1 (41.1)	0.072
Vigorous Physical activity (min/day)	21.8 (22.6)	22.9 (22.7)	0.597	25.6 (25.1)	24.5 (24.6)	0.672
Moderate to vigorous physical activity (min/day)	108.8 (66.9)	118.0 (62.5)	0.135	96.0 (57.1)	102.6 (55.8)	0.265
Sedentary time and behaviors						
Sedentary time (min/d)	212.0 (109.4)	218.1 (101.0)	0.527	224.8 (99.8)	219.3 (86.9)	0.547
Media time (screen time) (min/d)	97.6 (50.6)	105.5 (53.9)	0.098	123.5 (60.9)	119.7 (54.1)	0.498
Reading time (min/d)	24.1 (23.6)	23.6 (23,9)	0.844	30.5 (32.4)	29.1 (26.8)	0.617
Writing time (min/d)	5.5 (10.5)	8.0 (15.1)	**0.045**	4.9 (11.6)	4.6 (10.1)	0.770
Computer use time (min/d)	26.9 (27.9)	33.2 (32.7)	**0.028**	46.4 (43.2)	41.1 (35.2)	0.165

Note: Data are from the Student *t*-test for continuous variables and from the chi-square test for categorical variables and are displayed as means (SD) or percentages (%). Diet quality was assessed by dietary records, light, moderate to vigorous intensity physical activity (PA) and sedentary time were measured by combined heart rate and movement sensor.

Statistically significant differences are bolded.

TABLE 3 Associations of diet quality, physical activity, and sedentary time and sedentary behaviors with cognition over 2 years.

	β	*p*-Value
Diet quality		
BSDS	0.097	**0.026**
Red meat and sausages (g/d)	−0.009	**0.004**
Fruit and berries (g/d)	0.002	0.116
Vegetables (g/d)	0.0003	0.887
High-fiber (≥5%) grain products (g/d)	0.005	0.846
Fish (g/d)	0.006	0.293
PUFA-SFA ratio	−0.953	0.259
Total fat (g/d)	0.005	0.986
Milk (<1% fat) (g/d)	0.001	**0.019**
Physical activity		
Light physical activity (min/d)	−0.001	0.230
Moderate to vigorous physical activity (min/d)	−0.008	0.110
Vigorous physical activity (min/d)	−0.005	0.825
Total physical activity (min/d)	−0.002	0.500
Active commuting to and from school (min/d)	0.009	0.197
Recess PA (min/d)	0.018	0.437
Organized sports (min/d)	0.032	**0.010**
Organized exercise (min/d)	0.017	0.129
Unsupervised PA (min/d)	−0.010	**0.010**
Sedentary time and behaviors		
Sedentary time (min/d)	0.002	**0.021**
Media time (screen time) (min/d)	−0.003	0.21
Reading time (min/d)	0.010	**0.042**
Writing time (min/d)	−0.031	**0.002**
Computer use time (min/d)	−0.010	**0.023**

Note: Diet quality was assessed by dietary records, light, moderate to vigorous intensity physical activity (PA) and sedentary time were measured by combined heart rate and movement sensor, and organized sports, unsupervised physical activity, reading time, writing time, and computer time were assessed by a questionnaire. Values are derived from linear mixed-effects model with intercept as random effects. Age, sex, body fat percentage, pubertal status at 2-year follow-up, study group (intervention versus control), and follow-up time were included as covariates in all analyses.
Statistically significant differences are bolded.

3.4 | Associations of changes in physical activity and cognition over 2 years

Organized sports assessed by the questionnaire was positively associated and unsupervised PA assessed by the questionnaire was negatively associated with the RCPM score over 2 years after adjustment for age, sex, BF%, parental education, and household income at baseline and pubertal status at 2-year follow-up (Table 3). Other components of PA assessed by the questionnaire were not associated with the RCPM score over 2 years. TPA, LPA, MVPA, or VPA assessed by the heart rate and body movement monitor was not associated with the RCPM score over 2 years. The between-subject effect of unsupervised PA on the RCPM score was statistically significant (Table 4). Moreover, the within-subject and between-subject effects of unsupervised PA on the RCPM score were statistically different from each other.

3.5 | Associations of changes in sedentary time, sedentary behavior, and cognition over 2 years

ST assessed by the heart rate and body movement monitor and reading assessed by the questionnaire were positively and writing and computer use assessed by the questionnaire were negatively associated with the RCPM score (Table 3). Other measures of SB assessed by the questionnaire were not associated with the RCPM score. The between-subject effects of ST assessed by the heart rate and body movement monitor and reading and writing assessed by the questionnaire on the RCPM score were statistically significant. The within-subject effect of computer use assessed by the questionnaire on the RCPM score was also statistically significant ($\beta = -0.013$, $p = 0.025$). Moreover, the within-subject and between-subject effects of ST assessed by the heart rate and body movement monitor and reading and writing assessed by the questionnaire on the RCPM score were statistically different from each other (Table 4).

4 | DISCUSSION

We found that the 2-year combined dietary and PA intervention did not affect cognition in a general population of school-aged children, as there were no differences in the cognition between the control and intervention groups at baseline or 2 years. However, changes in some lifestyle factors over 2 years were associated with cognition. A higher BSDS, higher consumption of low-fat milk, lower consumption of red meat and sausages, more time spent in organized sports, more time spent in sedentary activity, and more time spent in reading were associated with better cognition, whereas more time spent in unsupervised PA, on computer, and in writing were associated with decreased cognition. These associations were small to moderate in magnitude. For example, a three-unit increase in BSDS increased RCPM score only by 0.3 units. In contrast, a 100 g increase in red meat and sausage consumption (approximately one medium size sausage) or a 30-min increase in organized

TABLE 4 Within- and between-subject effects of diet quality, physical activity, and sedentary behaviors with cognition.

	Within subjects' effect			Between subjects' effect			Difference between within and between subjects' effect		
	β	95% CI	*p*-Value	β	95% CI	*p*-Value	β	95% CI	*p*-Value
Diet quality									
BSDS	0.113	−0.148 to 0.374	0.395	0.165	0.011 to 0.341	0.066	0.286	0.055 to 0.516	**0.015**
Red meat and sausages	−0.008	−0.016 to −0.001	**0.031**	−0.006	−0.017 to 0.004	0.244	0.001	−0.011 to 0.015	0.805
Milk (<1% fat)	−0.0009	−0.002 to 0.000	0.194	0.002	−0.000 to 0.005	0.066	0.016	−0.001 to 0.004	0.320
Physical activity									
Organized sports (min/d)	−0.022	−0.053 to −0.008	−0.148	−0.015	−0.045 to 0.014	0.313	0.006	−0.036 to 0.049	0.752
Unsupervised PA (min/d)	0.010	−0.002 to 0.024	0.105	−0.031	−0.046 to −0.017	**<0.001**	−0.042	−0.062 to −0.023	**<0.001**
Sedentary behavior									
Sedentary time	0.001	−0.001 to 0.004	0.313	0.008	0.003 to 0.013	**0.002**	0.007	0.002 to 0.013	**0.009**
Reading time (min/d)	−0.011	−0.025 to 0.003	0.126	0.035	0.018 to 0.052	**<0.001**	0.046	0.024 to 0.068	**<0.001**
Writing time (min/d)	−0.023	−0.055 to 0.008	0.150	−0.075	−0.115 to −0.035	**<0.001**	−0.052	−0.103 to −0.001	**0.046**
Computer time (min/d)	−0.013	−0.025 to −0.001	**0.025**	−0.006	−0.020 to 0.006	0.317	0.006	−0.011 to 0.024	0.483

Note: Diet quality was assessed by dietary records, moderate intensity physical activity (PA) and sedentary time were measured by combined heart rate and movement sensor, and organized sports, unsupervised physical activity, reading time, writing time, and computer time were assessed by a questionnaire. Values are derived from linear mixed-effects model with intercept as random effects.

Statistically significant differences are bolded.

sports were related to a 0.90 unit decrease or 0.93 unit increase in RCPM score, respectively. Especially the latter associations may be clinically meaningful in everyday life.

A few previous studies have reported mixed effects of dietary and PA interventions on cognition in children.[8,9] We found that a combined dietary and PA intervention had no effect on cognition over 2 years in a population sample of school-aged children. However, we have previously observed that this intervention improved overall diet quality, increased unsupervised PA, attenuated the increase in time spent using a computer, and improved cardiometabolic health.[10–12] One reason for not finding an effect of dietary and PA intervention on cognition may be that we studied a population sample of school-aged children and that the intervention focused mainly on improving health behavior but did not include a large volume of specific tasks challenging the brain, such as PA requiring complex, controlled, and adaptive movements having a greater impact on cognition than simple movements.[24]

Our finding on the positive longitudinal associations between overall diet quality and cognition in children over 2 years aligns with the results of some previous cross-sectional[25] and longitudinal[26,27] studies in children. Some earlier cross-sectional studies have also observed a positive association between low-fat milk consumption and cognition in children.[27–29] However, we report here for the first time a positive longitudinal association between the consumption of low-fat milk and cognition in children. One of the explanations for this association could be that milk contains valuable nutrients, such as proteins and calcium, that may have beneficial effects on the cognitive development of children.[30] The results of our study again strengthen the view that low-fat milk is beneficial for the children's health.

We have earlier reported an inverse cross-sectional association between the consumption of red meat and sausages and cognition in children.[17] The present finding provides evidence for a longitudinal association between red meat and sausage consumption and cognition in children. Based on the results of animal studies, one reason for our observation could be that high consumption of red meat and sausages has adverse effects on the brain-derived neurotrophic factor and brain plasticity.[31,32] The within-subject relationship suggests that increased meat and sausage consumption may impair cognition in a relatively short time of 2 years. The presence of a between-subject relationship of a higher BSDS with cognition suggests that relatively fixed effects, such as genetic factors, may underlie the association between a healthy diet and cognition over 2 years.

Time spent in organized sports, reading, and any sedentary activity were directly associated with cognition in our study. Previous studies have also suggested that sports positively affect cognition,[33] possibly through increased opportunities for motor learning and cognitively challenging activities leading to favorable neural adaptations[24,34,35] and increased social interaction and goal orientation.[36] Similarly, reading a book requires vocal, visual, auditory, and imaginary creativity and concentration, which may improve cognition.[37] Earlier studies have also suggested a positive association between objectively assessed ST and cognition in children.[38] Reading and other activities that may enhance cognition could explain the positive association between ST and cognition. Furthermore, our findings agree with the Finnish study reporting an inverse association between computer use and cognition in children.[39]

A strength of the present study is that we investigated the long-term effects of a combined dietary and PA intervention on cognition and the longitudinal associations of changes in diet quality, PA, ST, and SB with cognition in a relatively large population sample of school-aged children. Diet quality, PA, ST, SB, and confounding factors were assessed using valid and reproducible methods. Furthermore, only 15% of the children in the intervention group dropped out over 2 years. Moreover, almost 90% of the children and their parents or caregivers participated in all six dietary and PA counseling sessions, suggesting that the intervention was well accepted by the participants. A limitation of the study is that we did not randomly allocate the participants to the intervention and control groups.[11] However, the baseline characteristics of children in the intervention and control groups were relatively similar, suggesting that selection bias has minor effects on the results. Furthermore, diet quality and sedentary behaviors were assessed using self-reports, which may be prone to bias. However, these methods have been considered valid and most feasible methods to assess diet quality and different types of sedentary behavior in children. While we adjusted the data for socioeconomic status, BF% and maturation, it is possible that some other lifestyle, environmental, or genetic factors influence observed associations. RCPM measures non-verbal reasoning skills, and therefore, our findings cannot be generalized to other components of cognition. Finally, we used linear mixed-model analyses to investigate the associations of diet quality, PA, and SB with cognition, and this analysis strategy does not quantify possible non-linear associations between the predictors and outcomes.

In conclusion, an individualized and family-based lifestyle counseling intervention without a strong structured component may not be sufficiently intensive to meaningfully improve cognition in children over other factors in daily life contributing to cognitive development. Accordingly, the results suggest that improved overall diet quality, the increased consumption of low-fat milk, and increased time spent in organized sports and reading were longitudinally associated with improved cognition in children. These results suggest that a healthy diet and certain physical and sedentary activities support cognitive development in children. Further intervention studies are warranted to investigate the long-term effects of dietary and PA interventions on cognition from childhood to adolescence.

5 | PERSPECTIVE

We investigated the influence of a 2-year combined dietary and PA intervention on cognition in children. We found that the intervention had no significant effect on cognition. However, improved diet quality and increased levels of organized PA and reading were related to improved cognition. While the intervention had a weak effect on cognition, our findings suggest that improving diet quality and encouraging regular participation in organized PA and reading habits contribute to cognitive development in children. Children's diet quality[1,2] and PA levels[3] are not optimal for cognitive development and brain health.[4,5] Therefore, our findings highlight the importance of improving diet quality, providing opportunities for organized P, and encouraging leisure time reading to support cognition and brain health in children. Diet quality-, PA-, and reading-induced cognitive benefits may also have relevance on life-long learning, education career, and brain health.

ACKNOWLEDGEMENTS

The funding sources have not been involved in designing the study, collecting the data, analyzing the data, interpreting the results, writing the manuscript, or deciding to submit the paper for publication. There were no commercial sponsors for the study.

FUNDING INFORMATION

The PANIC study has been supported financially by grants from the Juho Vainio Foundation, Academy of Finland, Ministry of Education and Culture of Finland, Ministry of Social Affairs and Health of Finland, Research Committee of the Kuopio University Hospital Catchment Area (State Research Funding), Finnish Innovation Fund Sitra, Social Insurance Institution of Finland, Finnish Cultural Foundation, Foundation for Paediatric Research, Diabetes Research Foundation in Finland, Finnish Foundation for Cardiovascular Research, Paavo Nurmi Foundation, Yrjö Jahnsson Foundation, and the city of Kuopio. The work of SB was funded by the UK Medical Research Council (MC_UU_12015/3) and the NIHR Biomedical Research Centre in Cambridge (IS-BRC-1215-20014).

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest. The results of the current study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

DATA AVAILABILITY STATEMENT

The data are not publicly available due to research ethical reasons and because the owner of the data is the University of Eastern Finland and not the research group. However, the corresponding author can provide further information on the PANIC study and the PANIC data on a reasonable request.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Naveed S, Sallinen T, Eloranta A-M, et al. Effects of 2-year dietary and physical activity intervention on cognition in children—a nonrandomized controlled trial. *Scand J Med Sci Sports*. 2023;33:2340-2350. doi:10.1111/sms.14464