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Associations of diet quality, food consumption, eating frequency and eating behaviour with dental caries experience in Finnish children: a 2-year longitudinal study

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Abstract

We examined cross-sectional and longitudinal associations of dietary factors with caries experience in a population sample of 487 children aged 6–9 years at baseline examinations of the Physical Activity and Nutrition in Children (PANIC) Study. Altogether, 406 of these children attended 2-year follow-up examinations. Food consumption and eating frequency were assessed using 4-day food records, diet quality using the Baltic Sea Diet Score (BSDS) and eating behaviour using the Children's Eating Behavior Questionnaire. Caries experience was examined clinically. The cross-sectional associations of dietary factors with caries experience at baseline were analysed using linear regression and the longitudinal associations of dietary factors with a change in caries experience over follow-up using generalised mixed-effects regression adjusted for other risk factors. A higher consumption of high-fibre grain products (standardised regression coefficient $\beta = -0{\cdot}16$, $P = 0{\cdot}003$) and milk ($\beta = -0{\cdot}11$, $P = 0{\cdot}025$) and higher BSDS ($\beta = -0{\cdot}15$, $P = 0{\cdot}007$) were associated with lower caries experience, whereas a higher consumption of potatoes ($\beta = 0{\cdot}11$, $P = 0{\cdot}048$) and emotional overeating ($\beta = 0{\cdot}12$, $P = 0{\cdot}025$) were associated with higher caries experience. Higher snacking frequency (fixed coefficient $\beta = 0{\cdot}07$, $P = 0{\cdot}033$), desire to drink ($\beta = 0{\cdot}10$, $P = 0{\cdot}046$), slowness in eating ($\beta = 0{\cdot}12$, $P = 0{\cdot}027$) and food fussiness ($\beta = 0{\cdot}12$, $P = 0{\cdot}018$) were associated with higher caries experience, whereas enjoyment of food ($\beta = -0{\cdot}12$, $P = 0{\cdot}034$) and higher BSDS ($\beta = -0{\cdot}02$, $P = 0{\cdot}051$) were associated with lower caries experience.

Key words: Dental caries: Diet quality: Food consumption: Eating frequency: Eating behaviour: CEBQ: Dietary fibre: Baltic Sea diet

Dental caries is one of the most common preventable chronic diseases, and predisposition to the development of caries continues throughout life[1,2]. A number of physical, biological, socioeconomic, genetic, dietary, behavioural and psychological factors have been associated with caries expression[1,2]. Caries denotes dissolution of tooth substance resulting from metabolic events in the biofilm on tooth surfaces[1,2]. Frequent consumption of easily fermentable carbohydrates is a prerequisite for the development of caries, whereas certain foods and drinks such as cheese and milk have been found to prevent caries[3–9].

Abbreviations: BSDS, Baltic Sea Diet Score; CEBQ, Children's Eating Behaviour Questionnaire; DMFS, decayed, missing and filled surface; DMFT, decayed, missing and filled teeth; PANIC, Physical Activity and Nutrition in Children; SDS, standard deviation score.

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The effects of single food items and nutrients on health may not be separable in real life because diets consist of combinations of foods with complex nutrient compositions. Therefore, improvements in food consumption or comprehensive dietary patterns may be more easily translated to real-life conditions than improvements in the consumption of single foods and the intake of certain nutrients. Dietary quality indices have been developed to assess adherence to desirable diets comprehensively. For example, the Baltic Sea Diet Score (BSDS) has been developed to illustrate a healthy dietary pattern in Nordic countries[10,11]. A higher BSDS has been associated with better periodontal health in adults[12,13]. However, there are no published reports on the association of BSDS with caries in any age group. Some eating behaviour traits, assessed by the Children's Eating Behaviour Questionnaire (CEBQ), have also been associated with caries in children[14–16]. However, to our knowledge, no studies have investigated these associations using CEBQ in populations of European children.

Eating and dietary habits are formed in early childhood[17,18] and are crucial for the development of caries. It is therefore of utmost importance to determine which eating and dietary habits are the strongest correlates and predictors for caries in childhood. Our aim was to investigate the cross-sectional and longitudinal associations of BSDS, food consumption, eating frequency and eating behaviour with caries experience in a 2-year follow-up study in a general population of Finnish children.

Methods

Study design and study population

The present analyses are based on the baseline and 2-year follow-up data from the Physical Activity and Nutrition in Children (PANIC) study that is a non-randomised controlled trial on the effects of a combined physical activity and dietary intervention on cardiometabolic risk factors and other health outcomes in a population sample of children from the city of Kuopio, Finland (ClinicalTrials.gov NCT01803776)[19]. The Research Ethics Committee of the Hospital District of Northern Savo approved the study protocol in 2006 (Statement 69/2006). The parents or caregivers of the children gave their written informed consent, and the children provided their assent to participation. The PANIC study has been carried out in accordance with the principles of the Declaration of Helsinki as revised in 2008.

We invited 736 children aged 6–9 years who started their first grade in primary schools of Kuopio in 2007–2009 to participate in the study (Fig. 1). Altogether, 512 (70 %) children (248 girls, 264 boys) accepted the invitation and participated in the baseline examinations. The participants did not differ in gender, age, height – standard deviation score (SDS) or BMI-SDS from all children who started the first grade in the city of Kuopio in 2007–2009. We excluded six children from the study at baseline either owing to their physical disabilities that could hamper participation in the intervention or withdrawal of the families because they had no time or motivation to attend the study. We also excluded data from two children whose parents or caregivers later withdrew their permission to use these data in the study. The final study sample thus included 504 children at baseline.

These children were allocated to the intervention group (306 children, 60 %) or the control group (198 children, 40 %). The intervention group had six individualised and family-based physical activity and dietary counselling sessions over the first 2 years that occurred 0·5, 1·5, 3, 6, 12 and 18 months after baseline examinations. The control group received general verbal and written advice on health-improving physical activity and diet at baseline but no active intervention.

Of the 504 children who participated in the baseline examinations, 440 (87 %) also attended the 2-year follow-up examinations. Altogether, 487 out of the 504 children attending the baseline examinations had data on oral health and 406 out of the 440 children attending the 2-year follow-up examinations had data on oral health needed for the present analyses.

Assessment of oral health and oral self-care

Experienced dentists of the research group (authors A.V. and T.I. and three other research group dentists) performed the oral health examinations at baseline and at 2-year follow-up according to a strict predefined protocol. The dentists registered caries according to the WHO guidelines with the exception that also initial lesions were registered, although separately from decayed lesions. Caries lesions were examined visual-tactilely from five tooth surfaces, and Fibre-optic transillumination was used to transilluminate the tooth surfaces. Initial lesions were defined as primary lesions that were limited to the enamel, whereas decayed lesions were defined as lesions that extended to the dentin of a tooth. The decayed, missing and filled surfaces (DMFS/dmfs) index combining registrations in both primary (dmfs) and permanent (DMFS) teeth was calculated and used as the main outcome, but also the decayed, missing and filled teeth (DMFT/dmft) index was calculated. Missing teeth due to exfoliation were not separated from the DMFS/dmfs index. The Silness–Löe Plaque index was used to register plaque[20]. We assessed oral self-care habits, including the frequency of tooth brushing and the frequency of using xylitol-containing chewing gum, by a questionnaire filled out by the parents or caregivers. Because our participants had mixed dentition, we summed up the DMFS, dmfs and initial caries surfaces in permanent and primary teeth into our main outcome variable, describing the total number of tooth surfaces affected by caries, called in this text as 'caries experience'.

Assessment of dietary and eating habits

Food consumption, eating frequency and nutrient intake were assessed by food records. The records covered four predefined and consecutive days at baseline, including two weekdays and two weekend days or three weekdays and one weekend day[21]. Two food records at 2-year follow-up examinations covered three days and consisted of two weekdays and one weekend day[19]. Clinical nutritionists examined the filled food records together with the family and added any missing information. Food consumption and nutrient intake were assessed using the Micro Nutrica® dietary analysis software, Version 2.5, based

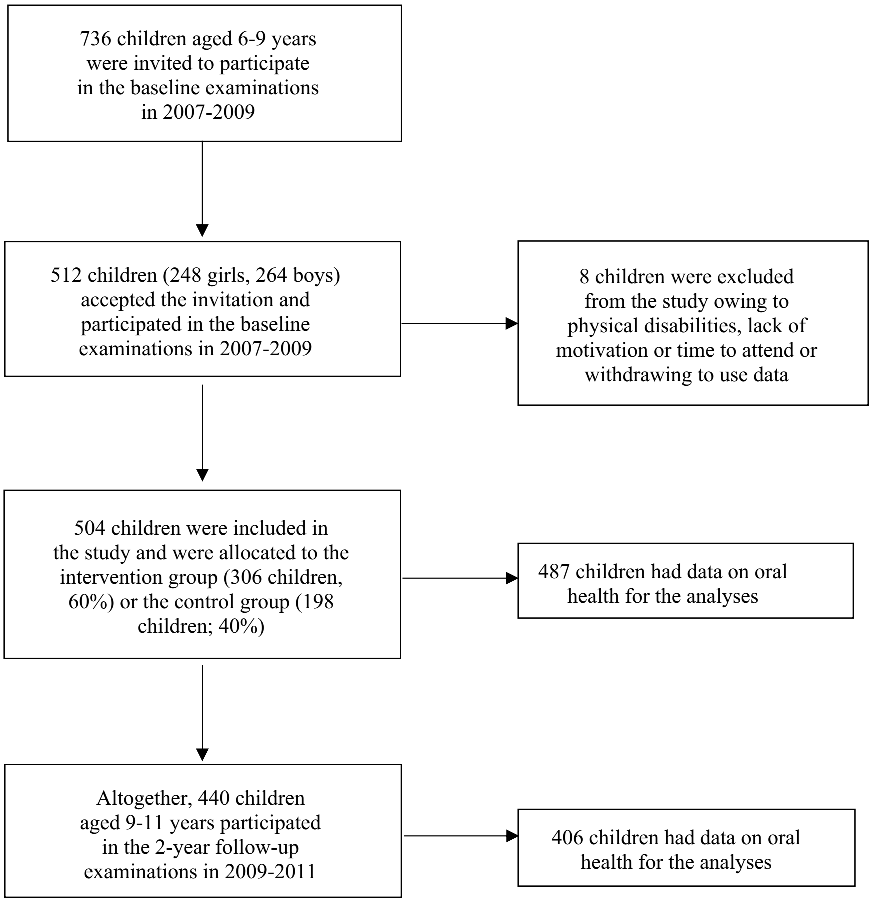

Fig. 1. Flow chart of children participating in the baseline and 2-year follow-up examinations and having data on oral health for caries analyses in the Physical Activity and Nutrition in Children (PANIC) study.

on detailed information about the nutrient content of foods in Finland and other countries[22].

Overall diet quality was assessed using BSDS, which is based on foods typically consumed by the general population in the Nordic countries[10]. BSDS was calculated by summing the scores of six components of food consumption and two components of nutrient intake in quartiles of the present population of children, as described earlier[23]. The six components of food consumption were fruits and berries (scored 0–3), vegetables excluding potatoes (0–3), high-fibre (≥ 5 %) grain products (0–3), low-fat (< 1 %) milk (0–3), fish (0–3), and red meat and sausages (3–0). The two components of nutrient intake were total fat intake as a percentage of total energy intake (3–0) and the ratio of PUFA to SFA (0–3)[11]. BSDS ranges between 0 and 24, and a higher score indicates better adherence to the diet.

Eating behaviour was assessed using CEBQ[14]. The questionnaire was translated into Finnish, and parents were given instructions on how to fill out the questionnaire on behalf of their children[24]. CEBQ contains thirty-five questions and divides eating behaviour into eight subscales: enjoyment of food, food responsiveness, satiety responsiveness, slowness in eating, emotional undereating, food fussiness, desire to drink and emotional overeating. Each subscale consists of 3–6 statements, each of which was rated on as a five-point Likert scale (never = 1, rarely = 2, sometimes = 3, often = 4, and always = 5). The scores of statements that belonged to the same subscale were summed, and the means and standard deviations were calculated. We used the mean of each eating behaviour subscale in the analyses. A higher mean value in the subscale indicates a greater likelihood for the given eating behaviour trait in a child's eating behaviour. Cronbach's α coefficients as measures of internal consistency were calculated for each eating behaviour subscale and all statements of the subscales[24]. We used the modified mean of emotional undereating because one of the statements ('My child eats more when s/he is happy') showed a low total correlation[24]. After excluding this statement, the subscale showed good internal consistency[24].

Assessment of body size, pubertal status and household income

Body height and weight were assessed by trained research staff in the morning. The children fasted for 12 h[23,25]. Body height was measured three times using a calibrated wall-mounted stadiometer to an accuracy of 0·1 cm for the children standing in the Frankfurt plane without shoes. The mean of the nearest two values was used in the analyses. Body weight was measured twice using a weight scale integrated into the Inbody 720® bioelectrical impedance device (Biospace) to an

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accuracy of 0·1 kg; the children had emptied the bladder and wore light underwear. The mean of the two values was used in the analyses. BMI was calculated by dividing body weight (kg) with body height (m) squared, and BMI-SDS was computed using Finnish reference data[26]. Overweight and obesity were defined using the International Obesity Task Force criteria corresponding to an adult BMI cut-point at 25 for overweight and at 30 for obesity[27,28]. A research physician assessed the pubertal status for girls according to breast development (B 1–5) and for boys according to testicular volume (G 1–5) using the Tanner staging method[29,30]. Girls were defined having entered clinical puberty if their breast development had started (Stage ≥ 2). Boys were defined having entered clinical puberty if their testicular volume measured by an orchidometer was ≥ 4 ml (Stage ≥ 2). We used household income reported by the parent who had higher income without taken taxes, and it was categorised as ≤ 30 000€, 30 001–60 000€ and ≥ 60 001€.

Statistical methods

The sample size calculations for the PANIC Study have been described earlier[19]. The statistical analyses were performed using the IBM SPSS Statistics software, Version 27.0 (IBM Corp.). The normality of distributions of the variables was verified visually from histograms and by the Kolmogorov–Smirnov test. Differences in basic characteristics between genders were tested using the independent samples *t* test for continuous variables with normal distributions, the Mann–Whitney´s U-test for continuous variables with skewed distributions and the Pearson's χ^2 test for categorical variables. Linear regression analyses with various adjustments were performed to study the association of BSDS, food consumption, eating frequency and eating behaviour with caries experience at baseline. First, the dietary variables were entered one by one into a model adjusted for age and gender (Model 1). Second, the dietary variables were entered one by one into a model adjusted for age, gender, household income, BMI-SDS, the frequency of tooth brushing and the frequency of using xylitol-containing chewing gum (Model 2). These potential confounding factors were chosen based on earlier evidence on their associations with caries[31–33]. Third, all these dietary variables were entered simultaneously into a stepwise model (Model 3) to study what would be the best combination of variables to be independently associated with caries experience according to model selection criteria (F-test). Differences and associations with a P-value $< 0{\cdot}05$ were considered statistically significant.

We examined the associations of changes in BSDS, food consumption, eating frequency and eating behaviour with caries a change in caries experience over 2 years using generalised linear mixed-effects models. Separate generalised linear mixed-effects models adjusted for the fixed effects of gender, study group and household income at both time points and the repeated effect of time were performed to test the associations of each variable with caries experience. The random subject-specific intercept was used in the models. A Bayesian information criterion was used to measure model adequacy and find the best predicting parameters for the change of caries experience, a lower value indicating a better model. We prioritised choosing a model with an optimal balance between good fit and complexity. We also tested models allowing dependent variable clustering on a subject within the school level. However, because the three-level structure resulted in unnecessary complexity and did not improve model fit, clustering within schools was not taken into account in the final models. We also tested a generalised linear mixed-effects model only with the study group and time to determine whether dietary and physical activity intervention had an effect on change in caries experience and found no such effect. However, to minimise residual confounding due to the effect of intervention on dietary factors that could affect caries risk, we adjusted the data for the study group in the generalised linear mixed-effects models.

Results

Characteristics of children at baseline

More than half (54 %) of the participants had DMFS/dmfs = 0, and more than a third (37 %) of the participants also did not have initial caries lesions. Most participants (62 %) brushed their teeth at least twice a day, and 43 % used xylitol-containing chewing gum every day. There were no statistically significant differences in DMFS/dmfs, the frequency of tooth brushing or the frequency of using xylitol-containing chewing gum between genders (Table 1). However, girls had less primary teeth, more permanent teeth and more initial caries on their permanent teeth than boys. Girls were also lighter and shorter than boys (Table 1). Furthermore, girls had less main meals per day, consumed less milk, red meat and sausages, and had higher satiety responsiveness and slowness in eating than boys (Table 2).

Associations of dietary factors with caries experience at baseline

BSDS and the consumption of high-fibre grain products and milk were inversely associated with caries experience adjusted for age and gender (Table 3, Model 1). The inverse association between BSDS and caries experience weakened and was no longer statistically significant and the inverse associations of high-fibre grain products and milk with caries experience remained similar after further adjustment for household income, BMI-SDS, the frequency of tooth brushing and the frequency of using xylitol-containing chewing gum (Table 3, Model 2).

Desire to drink and emotional overeating were positively associated with caries experience adjusted for age and gender (Table 3, Model 1). The positive association between emotional overeating and caries experience weakened but remained statistically significant, and desire to drink was no longer associated with caries experience after further adjustment for household income, BMI-SDS, the frequency of tooth brushing and the frequency of using xylitol-containing chewing gum (Table 3, Model 2).

BSDS and the consumption of high-fibre grain products and milk were inversely associated, and the consumption of potatoes and emotional overeating were positively associated with caries experience when age, gender and all dietary factors were entered simultaneously into a stepwise model (Table 3, Model 3).

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Table 1. Basic characteristics of Finnish children at baseline of the Physical Activity and Nutrition in Children study, *n* 487, in years 2007–2009

	All		Girls		Boys		
	Mean	SD	Mean	SD	Mean	SD	*P*-value
Age (years)	7·6	0·4	7·6	0·4	7·7	0·4	0·286
Body weight (kg)	26·9	5·1	26·6	5·1	27·3	5·0	**0·047**
Body height (cm)	128·9	5·6	127·9	5·6	129·7	5·5	**< 0·001**
BMI-SDS	−0·17	1·1	−0·15	1·1	−0·19	1·1	0·733
Body weight status (*n* (%))*							0·240
Normal weight	420	86·2	197	84·2	223	88·1	
Overweight	45	9·2	27	11·5	18	7·1	
Obesity	22	4·5	10	4·3	12	4·7	
Pubertal status (*n* (%))†							0·058
Prepubertal	473	97·5	224	96·1	249	98·8	
Pubertal	12	2·5	9	3·9	3	1·2	
Number of primary teeth	12·1	2·2	11·7	2·3	12·5	2·0	**0·001**
Number of permanent teeth	9·6	2·5	9·9	2·5	9·3	2·5	**< 0·001**
Number of decayed primary and permanent teeth	0·04	0·25	0·03	0·22	0·05	0·27	0·249
DMFT	0·39	0·92	0·37	0·88	0·41	0·96	0·756
dmft	1·21	2·02	1·28	2·11	1·13	1·94	0·877
DMFS	0·58	1·57	0·47	1·24	0·67	1·83	0·649
dmfs	2·03	3·67	2·19	3·83	1·88	3·51	0·776
Number of primary teeth with initial caries only	0·74	1·26	0·79	1·29	0·69	1·23	0·393
Number of permanent teeth with initial caries only	0·44	0·83	0·51	0·86	0·38	0·80	**0·039**
Only initial caries surfaces, permanent teeth	0·49	1·00	0·55	1·02	0·43	0·98	**0·050**
Only initial caries surfaces, primary teeth	0·79	1·40	0·85	1·43	0·74	1·37	0·428
DMFS/dmfs and initial caries surfaces‡	3·89	5·15	4·06	5·15	3·73	5·15	0·398
Tooth brushing (*n* (%))							0·093
At least twice a day	281	61·6	146	66·4	135	57·2	
Once a day	175	38·4	74	33·6	101	42·8	
Several times a week	6	1·3	3	1·3	3	1·2	
Once a week or less often	2	0·4	0	0·0	2	0·8	
Xylitol chewing gum (*n* (%))							0·124
Every day	196	42·5	105	47·3	91	37·9	
2–5 times per week	183	37·5	80	36·0	103	42·9	
Once a week or less frequently	83	17·0	37	16·7	46	19·2	
Household income (*n* (%))							0·100
≤ 30 000€	101	21·1	54	23·3	47	19·0	
30 001€–60 000€	200	41·8	103	44·4	97	39·3	
≥ 60 001€	178	37·2	75	32·3	103	41·7	

The values are means (standard deviations) from independent samples *t* tests for normally distributed variables and from Mann–Whitney's U-tests for variables with skewed distributions as well as numbers (percentages) from Pearson's χ^2 test for categorical variables. *P*-values < 0·05 are bolded.
There were 487 children (234 girls, 253 boys) for all other variables than pubertal status (485 children, 233 girls, 252 boys), household income (479 children, 232 girls, 247 boys), tooth brushing (464 children, 223 girls, 241 boys) and xylitol chewing gum (462 children, 222 girls, 240 boys).
BMI-SDS, BMI-standard deviation score calculated using Finnish reference values[26]; DMFT, Decayed, Missing and Filled Teeth; dmft, decayed, missing, and filled teeth; DMFS, Decayed, Missing and Filled Surface; dmfs, decayed missing and filled surfaces. Written in lowercase letters dmft/dmfs refers to primary dentition.
* Body weight status was defined using the International Obesity Task Force criteria corresponding to an adult BMI cut-point at 25 for overweight and 30 for obesity[27,28].
† Pubertal status was defined using Tanner 5-stage criteria[29,30].
‡ Includes DMFS, dmfs and initial caries surfaces in primary and permanent teeth.

Associations of changes in dietary factors with a change in caries experience over 2 years

The mean (SD) of caries experience was 3·89 (5·15) for all 487 children at baseline and 3·82 (4·70) for all 406 children after 2 years. Increases in the number of snacks, slowness in eating, food fussiness and desire to drink were associated with an increase in caries experience, and increases in BSDS and enjoyment of food were associated with a decrease in caries experience over 2 years (Table 4).

Discussion

This study showed that higher adherence to the Baltic Sea diet and a higher consumption of high-fibre grain products and milk were independently associated with lower caries experience in a general population of school-aged children. In contrast, a higher consumption of potatoes, higher desire to drink and higher emotional overeating were associated with higher caries experience. Consistent with these cross-sectional results, an increase in adherence to the Baltic Sea diet was associated with a decrease in caries experience and an increase in desire to drink was associated with an increase in caries experience over 2 years in a general population of school-aged children. Moreover, an increase in the enjoyment of food was associated with a decrease in caries experience and increases in snacking frequency, slowness in eating and food fussiness were associated with an increase in caries experience over 2 years.

To our knowledge, there are no previous published reports on the associations of overall diet quality assessed by BSDS, and several single dietary factors with caries experience in any age group. One explanation for our finding on the inverse association between BSDS and caries experience is that BSDS consists of several foods, such as fruits, berries, vegetables,

Table 2. Eating frequency, diet quality, food consumption and eating behaviour at baseline

	All		Girls		Boys		
	Mean	SD	Mean	SD	Mean	SD	*P*-value
Eating frequency							
Main meals (number/d)	2·8	0·26	2·7	0·26	2·8	0·26	**0·044**
Snacks (number/d)	2·7	0·88	2·7	0·91	2·7	0·86	0·602
Diet quality							
Baltic Sea Diet Score (range 0–24)	11·8	4·3	11·9	4·2	11·7	4·4	0·562
Food consumption (g/d)							
High-fibre (≥ 5 %) grain products*	63·3	39·4	60·9	36·3	65·5	42·1	0·294
Low-fibre (< 5 %) grain products*	113	52·5	108	45·2	118	58·2	0·242
Vegetables and nuts†	103	58·5	105	59·1	102	58·1	0·559
Potato	76·2	41·8	73·7	41·7	78·7	41·7	0·164
Fruits and berries	109	83·9	114	83·5	104	84·2	0·123
Butter and butter–oil mixtures	5·8	7·1	5·3	6·1	6·2	7·9	0·994
Vegetable oil-based margarine (60–80 % fat)	7·3	8·1	7·4	8·0	7·3	8·2	0·435
Vegetable oil-based margarine (< 60 % fat)	3·9	6·9	3·3	5·6	4·4	7·9	0·422
Vegetable oils	4·1	4·2	3·6	3·6	4·6	4·7	0·055
Low-fat (< 1 %) and high-fat (≥ 1 %) milk	567	252	532	226	599	270	**0·007**
Low-fat (< 1 %) and high-fat (≥ 1 %) sour milk‡	104	94·3	95·6	79·9	111	106	0·458
Cheese	15·9	15·9	14·9	14·2	16·8	17·3	0·629
Fish and fish products§	16·0	21·4	14·1	19·1	17·8	23·2	0·386
Poultry	16·9	21·6	16·1	21·7	17·7	21·6	0·670
Red meat and sausages‖	79·1	38·9	69·4	33·1	87·9	41·8	< **0·001**
Sugar-sweetened beverages¶	136	128	123	117	147	136	0·098
Artificially sweetened beverages¶	42·8	81·2	39·3	74·5	46·1	86·9	0·991
Fruit juices	36·0	67·4	32·5	50·3	39·3	80·1	0·401
Sugar, syrup and honey	9·8	8·0	9·8	7·9	9·8	8·1	0·957
Pudding and ice cream	27·1	31·4	27·8	32·2	26·4	30·8	0·827
Sweets	20·9	24·1	18·2	21·9	23·5	25·7	0·098
Chocolate	9·7	12·4	8·8	11·6	10·6	12·9	0·361
Salty snacks**	4·2	10·4	4·4	12·2	4·0	8·5	0·460
Eating behaviour							
Enjoyment of food (range 1–5)	3·2	0·7	3·2	0·7	3·3	0·7	0·231
Food responsiveness (range 1–5)	1·7	0·6	1·7	0·5	1·7	0·7	0·923
Satiety responsiveness (range 1–5)	3·0	0·6	3·1	0·6	2·9	0·6	< **0·001**
Slowness in eating (range 1–5)	2·7	0·8	2·9	0·7	2·5	0·7	< **0·001**
Emotional undereating (range 1–5)	2·5	0·9	2·4	0·8	2·5	0·9	0·134
Food fussiness (range 1–5)	2·8	0·8	2·9	0·6	2·8	0·8	0·562
Desire to drink (range 1–5)	1·8	0·7	1·8	0·7	1·8	0·8	0·954
Emotional overeating (range 1–5)	1·4	0·5	1·4	0·5	1·5	0·5	0·123

The values are means (standard deviations) from independent samples *t* tests for normally distributed variables and Mann–Whitney's U-tests for variables with skewed distributions. *P*-values < 0·05 are bolded.

The numbers of children vary from 400 to 485 in different variables: 485 children (234 girls and 251 boys) for desire to drink; 484 children (234 girls and 250 boys) for slowness in eating; 483 children (233 girls and 250 boys) for enjoyment of food and food responsiveness; 480 children (233 girls and 247 boys) for emotional overeating; 479 children (232 girls and 247 boys) for satiety responsiveness; 473 (226 girls and 247 boys) for emotional undereating; 413 children (199 girls and 214 boys) for eating frequency and food consumption variables; 400 children (200 girls and 200 boys) for Baltic Sea Diet Score.

* Includes bread, cereal, porridge, flour, pasta and rice.

† Includes vegetables, nuts, roots, beans and mushrooms, excluding potato.

‡ Includes yoghurt, curdled milk, sour milk and quark.

§ Includes fish, shellfish and fish products.

‖ Includes pork, beef, lamb, reindeer, game meat and sausages.

¶ Includes carbonated and non-carbonated beverages.

** Includes popcorn, crisps and salted nuts.

high-fibre grain products, milk and fish, which are considered protective for dental health[7,9,34,35], and that diet including these foods tends to restrict the consumption of high-sugar products, such as sweets and ice cream[10]. Although BSDS does not include high-sugar products, a higher BSDS was associated with lower caries experience at baseline and with a decrease in caries experience over 2 years. A lower BSDS has been associated with higher abdominal adiposity in Finnish adults[11], and adiposity has been associated with caries in children and adolescents[32,36]. Moreover, we found that the association between BSDS and caries experience was attenuated after controlling for adiposity. Our results are consistent with the observations of previous studies concerning the inverse association between overall diet quality and caries in children[37,38]. For example, children with a higher Healthy Eating Index, indicating a better overall diet quality based on healthy eating guidelines for Americans that recommend a diet rich in fruits, whole grains, milk and low on saturated fats and added sugars[37], were less likely to exhibit severe early childhood caries compared with children with a lower Healthy Eating Index[38]. One's diet consists of a wide variety of foods and drinks, and there are complex interactions and cumulative effects of multiple foods, drinks and nutrients within the diet. Therefore, the indices of overall diet quality, such as BSDS, could be useful tools when studying the association between diet and caries.

Table 3. Associations of dietary factors with caries experience in children at baseline

	Model 1*			Model 2*			Model 3*		
	Standardised β	95 % CI	*P*-value	Standardised β	95 % CI	*P*-value	Standardised β	95 % CI	*P*-value
Age (years)							−0·160	−0·267, −0·055	**0·003**
Eating frequency									
Main meals (number/d)	−0·012	−0·102, 0·080	0·808	0·024	−0·071, 0·113	0·652			
Snacks (number/d)	0·095	−0·003, 0·179	0·058	0·073	−0·024, 0·157	0·150			
Diet quality									
Baltic Sea Diet Score	−0·122	−0·216, −0·022	**0·016**	−0·092	−0–187, 0·007	0·068	−0·146	−0·264, −0·040	**0·007**
Food consumption (g/d)									
High-fibre (≥ 5 %) grain products†	−0·136	−0·215, −0·031	**0·009**	−0·129	−0·208, −0·028	**0·010**	−0·161	−0·267, −0·055	**0·003**
Low-fibre (< 5 %) grain products†	−0·024	−0·114, 0·069	0·632	0·002	−0·089, 0·094	0·961			
Vegetables and nuts‡	−0·073	−0·157, 0·024	0·148	−0·063	−0·146, 0·034	0·218			
Potato	0·094	−0·004, 0·184	0·060	0·096	−0·004, 0·187	0·061	0·106	0·001, 0·209	**0·048**
Fruits and berries	−0·030	−0·121, 0·065	0·555	−0·028	−0·118, 0·066	0·578			
Butter and butter–oil mixtures	−0·088	−0·172, 0·010	0·081	−0·094	−0·175, 0·005	0·064			
Vegetable oil-based margarine (60–80 % fat)	−0·017	−0·108, 0·077	0·739	0·007	−0·086, 0·098	0·898			
Vegetable oil-based margarine (< 60 % fat)	0·016	−0·076, 0·105	0·748	0·027	−0·066, 0·114	0·601			
Vegetable oil	0·030	−0·065, 0·122	0·599	0·043	−0·054, 0·132	0·408			
Milk (< 1 % and ≥ 1 % fat)	−0·111	−0·196, −0·010	**0·030**	−0·110	−0·196, −0·008	**0·033**	−0·114	−0·200, −0·013	**0·025**
Sour milk (< 1 % and ≥ 1 % fat)§	−0·007	−0·097, 0·084	0·889	0·003	−0·092, 0·092	0·998			
Cheese	−0·084	−0·166, 0·013	0·095	−0·071	−0·154, 0·027	0·166			
Fish and fish products‖	0·055	−0·041, 0·141	0·277	0·069	−0·028, 0·154	0·176			
Poultry	−0·003	−0·094, 0·089	0·960	−0·009	−0·099, 0·082	0·859			
Red meat and sausages¶	0·064	−0·035, 0·152	0·220	0·041	−0·058, 0·133	0·441			
Sugar-sweetened beverages**	−0·020	−0·109, 0·074	0·700	−0·030	−0·118, 0·063	0·552			
Artificially sweetened beverages**	0·024	−0·070, 0·115	0·635	0·016	−0·077, 0·108	0·748			
Fruit juices	−0·082	−0·165, 0·015	0·103	−0·071	−0·154, 0·026	0·163			
Sugar, syrup and honey	−0·063	−0·149, 0·033	0·208	−0·057	−0·142, 0·039	0·264			
Pudding and ice cream	0·096	−0·003, 0·182	0·058	0·057	−0·041, 0·146	0·268			
Sweets	−0·017	−0·106, 0·076	0·743	0·000	−0·090, 0·090	0·998			
Chocolate	0·048	−0·046, 0·132	0·344	0·059	−0·036, 0·140	0·245			
Salty snacks††	−0·023	−0·112, 0·070	0·647	−0·026	−0·114, 0·066	0·603			
Eating behaviour									
Enjoyment of food	0·044	−0·047, 0·135	0·346	0·020	−0·071, 0·111	0·668			
Food responsiveness	0·054	−0·037, 0·141	0·248	−0·017	−0·112, 0·079	0·735			
Satiety responsiveness	0·026	−0·066, 0·118	0·579	0·026	−0·068, 0119	0·595			
Slowness in eating	0·008	−0·085, 0·100	0·871	0·008	−0·085, 0·101	0·864			
Emotional undereating	0·021	−0·361, 0·577	0·651	0·002	−0·450, 0·474	0·960			
Food fussiness	0·027	−0·064, 0·119	0·556	−0·006	−0·098, 0·086	0·896			
Desire to drink	0·112	0·022, 0·205	**0·015**	0·061	−0·030, 0·154	0·189			
Emotional overeating	0·135	0·045, 0·227	**0·004**	0·099	0·007, 0·190	**0·035**	0·122	0·015, 0·215	**0·025**

Caries experience includes DMFS, dmfs and initial caries surfaces in primary and permanent teeth.

The values are standardised regression coefficients (β), their 95 % CI, and *P*-values from linear regression models by entering each variable first one by one into a model with age and gender (Model 1), second entering each variable one by one into a model with age, gender, household income, the frequency of tooth brushing and the frequency of using xylitol-containing chewing gum (Model 2), and third entering all these variables simultaneously into a stepwise model (Model 3) to study what would be the best combination of variables to be associated with caries experience according to model selection criteria (F-test). Standardised βs refer to how many standard deviations a dependent variable will change per standard deviation increase in the predictor variable. *P*-values < 0·05 are bolded.

* Data on variables were available for the following numbers of children in Model 1 and Model 2, respectively: eating frequency and food consumption variables 392 and 385; Baltic Sea Diet Score 382 and 377; desire to drink 461 and 454; slowness in eating 460 and 453; enjoyment of food and food responsiveness 459 and 452; food fussiness and emotional undereating 458 and 451; emotional overeating 456 and 449; satiety responsiveness 455 and 448. For Model 3, the data were available for 327 children.

† Includes bread, cereal, porridge, flour, pasta and rice.

‡ Includes vegetables, nuts, roots, beans and mushrooms, excluding potato.

§ Includes yoghurt, curdled milk, sour milk and quark.

‖ Includes fish, shellfish and fish products.

¶ Includes pork, beef, lamb, reindeer, game meat and sausages.

** Includes carbonated and non-carbonated beverages.

†† Includes popcorn, crisps and salted nuts.

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Our finding that the consumption of high-fibre grain products and milk were inversely associated with caries experience independent of various other dietary factors is in line with the results of previous studies[4,7,9,34]. High-fibre foods stimulate saliva secretion, cleanse teeth, modify the composition of oral biofilm microbiota and encase cariogenic carbohydrates in a non-fermentable covering[35,39,40]. Milk is an excellent dietary source of calcium, proteins and phosphate, which all have been considered to have features that inhibit caries[7,8]. Milk proteins, such as casein, form stable calcium phosphate complexes on the tooth surfaces that promote remineralisation and prevent demineralisation in enamel[7,34]. Moreover, milk, excluding organic milk, is in Finland fortified with vitamin D[41,42], which has been suggested to reduce the risk of caries[43]. However, the results of some studies suggest that a disaccharide lactose from milk could increase the risk of caries by acid production due to oral bacteria metabolism[44]. Studies suggest that more prolonged and frequent exposure to lactose from milk is warranted to increase caries risk[45]. The protective components present in milk, such as minerals and proteins, might overcome the adverse effects of lactose[45,46].

The direct association between potato consumption and caries experience in children was a surprising finding. Potato is a recommended dietary source of carbohydrate when served cooked or baked without added sources of fat, and starch is the predominant carbohydrate in potatoes[47]. Previous studies have found that highly processed starch products, such as potato chips, are associated with caries, but unprocessed starch seems to have little or no association with caries[4,5,34]. We observed no association between salty snacks, including potato chips, with caries experience in children. Interestingly, one study suggested that the cariogenic potential of sucrose increases when it is combined with starch[48]. One possible explanation for our result may be that children who preferred potatoes consumed less high-fibre grain products, such as rice and pasta, that were inversely associated with caries experience. Further studies are warranted to confirm our surprising finding on the direct association between potato consumption and higher caries experience in children.

Our observations on the direct cross-sectional association between emotional overeating and caries experience and the direct longitudinal association between snacking and increased caries experience in children are potentially important. Our results are in accordance with the findings that emotional overeating was associated with caries in children aged 3–6 years[16] and that constant snacking predisposed to obesity and caries in children and adolescents[49,50]. These observations suggest that children who have higher eating frequency and food consumption are at increased risk of not only overweight but also caries. Emotional stress had been found to stimulate appetite in some children but has been argued to inhibit appetite in non-obese children[51]. Therefore, more research is warranted to clarify the association between emotional overeating and caries in children.

We found that desire to drink was cross-sectionally associated with higher caries experience and longitudinally associated with an increase in caries experience over 2 years. This observation is in line with the results of few previous studies in children[15,16]. Desire to drink does not sort out the type of drink but indicates food approach, and the association with caries may reflect the drink preferences of children. Other dietary factors partly explained the association between desire to drink and higher caries experience in our study. Earlier studies have shown that children prefer foods and drinks that are not consistent with a healthy diet and contain lots of sugar and fat[52,53]. Children with higher desire to drink also prefer sugar-sweetened soft drinks and consume carbonated soft drinks frequently[54]. However, it is interesting that we did not observe an association between the consumption of sugar-sweetened beverages and caries experience in children. It may be that the drinks have been consumed as part of a meal and therefore are not as cariogenic than those drunk between meals[55].

In our study, food fussiness and slowness in eating had direct longitudinal associations with increased caries experience over 2 years, whereas enjoyment of food was associated with a decrease in caries experience. Food fussiness is common in childhood and has been defined as avoiding familiar and unfamiliar foods, leading to consuming an inadequate variety or quantity of foods[56]. Slowness in eating represents the lack of enjoyment and interest in food, whereas enjoyment of food represents higher interest and responsiveness for food[14]. Similarly to the desire to drink, food fussiness may describe the food preferences of children towards cariogenic foods[52]. Indeed, it has been shown that food fussiness is associated with a lower consumption of vegetables, cheese and meat in children, whereas enjoyment of food has been associated with a higher consumption of these foods[24]. It may be that children who enjoy food more and have less food fussiness may, in general, consume healthier foods and therefore have more favourable eating behaviour traits for oral health and preventing caries. One explanation for the association between slowness in eating and increased caries experience could be a more prolonged exposure time for demineralisation when eating slowly. These observations of our study are in line with those of previous studies[16,57]. It is interesting that the intervention was not associated with a change in caries experience over 2 years, although we have previously shown that the intervention improved diet quality in children[19,23,58]. However, 2 years is a relatively short time given the slow progression of caries[59] and the complex interrelationships between the pathogenic and protective factors for caries progression[59]. The oral self-care habits of the children in our study were relatively good, and their caries prevalence was low. Protective factors such as frequent tooth brushing may partly explain the low caries experience in this study population. It may be that a more extended time period would be needed to examine whether the intervention is beneficial in preventing caries.

The strengths of our study include the relatively large representative population sample of children and the longitudinal study design. Oral health examinations were also performed by two experienced dentists. Moreover, we evaluated caries experience by calculating initial caries surfaces and the DMFS/dmfs index, one of the most common caries indices in epidemiological studies[2,60]. By including initial caries lesions in the analyses, we were able to assess caries status more precisely than by

Table 4. Associations of changes in dietary factors with a change in caries experience over 2 years

	Fixed coefficient	95 % CI	*P*-value
Eating frequency			
Main meals (number/d)	0·014	–0·180, 0·208	0·889
Snacks (number/d)	0·068	0·006, 0·130	**0·033**
Diet quality			
Baltic Sea Diet Score	–0·016	–0·032, $7·590 \times 10^{-5}$	0·051
Food consumption (g/d)			
High-fibre (≥ 5 %) grain products*	$-2·39 \times 10^{-4}$	–0·002, 0·001	0·726
Low-fibre (< 5 %) grain products*	$2·59 \times 10^{-4}$	–0·001, 0·001	0·601
Vegetables and nuts†	–0·001	–0·002, 0·000	0·274
Potato	$1·65 \times 10^{-4}$	–0·001, 0·001	0·785
Fruits and berries	$-8·81 \times 10^{-5}$	–0·001, 0·001	0·809
Butter and butter–oil mixtures	–0·007	–0·014, 0·001	0·107
Vegetable oil-based margarine (60–80 % fat)	0·002	–0·002, 0·006	0·394
Vegetable oil-based margarine (< 60 % fat)	–0·001	–0·010, 0·008	0·806
Vegetable oils	0·001	–0·013, 0·014	0·296
Milk (< 1 % and ≥ 1 % fat)	$2·60 \times 10^{-4}$	$1·003 \times 10^{-5}$, 0·001	0·059
Sour milk (< 1 % and ≥ 1 % fat)‡	$4·56 \times 10^{-4}$	0·000, 0·001	0·162
Cheese	–0·001	–0·005, 0·003	0·556
Fish and fish products§	–0·001	–0·003, 0·001	0·172
Poultry	–0·001	–0·003, 0·002	0·585
Red meat and sausages‖	0·001	–0·001, 0·002	0·278
Sugar-sweetened beverages¶	$-1·55 \times 10^{-4}$	–0·001, 0·000	0·526
Artificially sweetened beverages¶	$2·20 \times 10^{-4}$	0·000, 0·001	0·489
Fruit juices	$2·59 \times 10^{-4}$	–0·001, 0·001	0·528
Sugar, syrup and honey	–0·005	–0·012, 0·001	0·114
Pudding and ice cream	0·001	0·000, 0·003	0·117
Sweets	$-3·04 \times 10^{-4}$	–0·003, 0·002	0·803
Chocolate	0·002	–0·002, 0·006	0·304
Salty snacks**	0·004	0·000, 0·008	0·077
Eating behaviour			
Enjoyment of food	–0·118	–0·227, –0·009	**0·034**
Food responsiveness	0·028	–0·087, 0·143	0·637
Satiety responsiveness	0·024	–0·084, 0·133	0·658
Slowness in eating	0·117	0·013, 0·230	**0·027**
Emotional undereating	–0·059	–0·158, 0·040	0·241
Food fussiness	0·118	0·020, 0·216	**0·018**
Desire to drink	0·095	0·002, 0·188	**0·046**
Emotional overeating	0·055	–0·063, 0·172	0·361

Caries experience includes DMFS, dmfs and initial caries surfaces in primary and permanent teeth. The values are fixed coefficients, their 95 % CI and *P*-values from generalised linear mixed-effects models, adjusted for the fixed effects of gender, study group and household income at both time points and the repeated effect of time. The random subject-specific intercept was used in the models. *P*-values < 0·05 are bolded.

Data on variables were available for the following numbers of children at baseline and 2-year follow-up, respectively: caries experience 487 and 406; main meals, snacks, BSDS and food consumption variables 423 and 389. Eating behaviour variables vary from 500 to 495 at baseline and 431 to 427 at 2-year follow-up.

* Includes bread, cereal, porridge, flour, pasta and rice.

† Includes vegetables, nuts, roots, beans and mushrooms, excluding potato.

‡ Includes yoghurt, curdled milk, sour milk and quark.

§ Includes fish, shellfish and fish products.

‖ Includes pork, beef, lamb, reindeer, game meat and sausages

¶ Includes carbonated and non-carbonated beverages.

** Includes popcorn, crisps and salted nuts.

using the DMFS/dmfs index alone. In addition, initial caries lesions represent a considerable portion of children's caries lesions in the Nordic countries[31,61]. Another strength of our study is that we assessed eating behaviour using CEBQ, which is an internationally validated questionnaire[62]. We also used food records to assess diet quality, food consumption and eating frequency. Our food records covered 4 days which offers higher reporting accuracy and provides more representative information on the diet than retrospective methods[63] that are subject to recall bias. Food records have been stated as an accurate method for estimating food consumption in children[63]. Furthermore, parents were carefully instructed to fill out the food records that were examined and completed by a clinical nutritionist, if needed. However, the food records are also subject to inaccuracy in reporting food consumption and eating frequency and tendency not to follow a regular diet during reporting. For example, parents may have omitted the consumption of foods that are generally recognised as non-healthy. Our result may not be directly generalised to children other than those living in the Nordic countries because BSDS consists of foods typically grown and consumed in the Nordic countries, such as wholegrain rye, oat and barley. An essential point to consider is that children participated in a physical activity and dietary intervention study. Thus, the families involved in the study may have been more health conscious than the general population. Moreover, participation in the study may have affected our results on caries because the children and their caregivers in the intervention group were given individualised dietary counselling and the control group also received general verbal and written guidance on a healthy lifestyle. The PANIC study was not designed to study the effect of the lifestyle intervention on caries, and no difference was found in caries experience between the groups. However, we adjusted the data for the study group to control for possible confounding due to the intervention.

In conclusion, we demonstrated here that enjoyment of food, better overall diet quality and a higher consumption of high-fibre grain products and milk were associated with lower caries experience in a general population of school-aged children. Furthermore, higher snacking frequency, slowness in eating, food fussiness and desire to drink were associated with increased caries experience over 2 years in these children. Further research is needed to confirm these observations in other pediatric populations. If confirmed, these results could be utilised in the prevention of caries among children.

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