British Journal of Nutrition (2022), 128, 1848–1856 doi:10.1017/S0007114521004736

Association between added sugar intake and overall diet quality in the Finnish adult population

Rilla Tammi[1]*, Mirkka Maukonen[1], Satu Männistö[1], Laura Sares-Jäske[1], Noora Kanerva[2] and Niina E. Kaartinen[1]

[1]*Department of Public Health and Welfare, Finnish Institute for Health and Welfare, Helsinki, Finland*
[2]*Department of Food and Nutrition, University of Helsinki, Helsinki, Finland*

(Submitted 7 June 2021 – Final revision received 5 November 2021 – Accepted 25 November 2021 – First published online 29 November 2021)

Abstract

Added sugar intake has been associated with several health issues, but few studies have examined its association with overall diet quality. We aimed at examining the association between added sugar intake and overall diet quality in Finnish adults. Associations between added sugar intake and sociodemographic factors, lifestyle factors, and BMI were also explored. Our data comprised 5094 adults residing in Finland who participated in the National FinHealth 2017 Study. Dietary intake was assessed by a validated FFQ. Food consumption and nutrient intakes were calculated using the Finnish national food composition database. Added sugar intake was estimated based on food categorisation and identifying naturally occurring sugar sources. Overall diet quality was assessed by the modified Baltic Sea Diet Score. The average added sugar intake was 7·6 E % in women and 8·3 E % in men in this study population. Added sugar intake was inversely associated with education ($P = 0·03$ women; $P = 0·001$ men), physical activity ($P < 0·0001$), and BMI in men ($P = 0·003$), and directly with smoking ($P = 0·002$ women; $P < 0·0001$ men). Added sugar intake was inversely associated with overall diet quality in both sexes ($P < 0·0001$). No interactions were found except for men's physical activity subgroups, the inverse association being stronger among active men than moderately active or inactive men ($P_{\text{for interaction}} = 0·005$). Our findings suggest that high added sugar intake is associated with several unhealthy dietary and lifestyle habits, including poor-quality diets, smoking and leisure-time inactivity in Finnish adults. Efforts to improve diet quality should consider added sugar intake equally in the whole population.

Key words: Added sugar: Diet quality: Food consumption: Adults

The intake of added sugars has raised concerns around the world due to their suggested adverse health implications. High added sugar intake has been associated with several emerging health issues, including obesity[1,2], CVD[3], type 2 diabetes[1], certain cancer types[4] and dental caries[5]. Due to the increased concerns, several national and international health authorities have set recommendations for added sugar intake[6–10]. In the Nordic countries[6] and the USA[7], the current recommendation is to limit added sugar intake to 10 % of the daily energy intake (10 E %). The WHO applies the same recommendation for free sugars[8]. Added sugars are defined as all monosaccharides and disaccharides used as such or added to foods by manufacturers, cooks or consumers, including sugars in syrups and honey[11]. In addition to these, free sugars also include monosaccharides and disaccharides in unsweetened fruit juices and fruit juice concentrates. In general, the main dietary sources for added sugars in Western countries include table sugar, confectionery and sugar-sweetened beverages[12].

The recommendations to limit added sugar intake are also supported by studies associating high added sugar intake with unhealthier dietary habits[13–16]. High added sugar intake has been associated with, for example, lower vegetable and fruit consumption and higher consumption of discretionary foods. Inverse associations have been found between the intakes of added sugars and various micronutrients, as well as protein and fat[13,15,17,18]. However, the association between added sugar intake and overall diet quality has hardly been examined. In two American population-based studies[19,20], added sugar intake was inversely associated with overall diet quality assessed by the Healthy Eating Index, while in the Netherlands, no association was found when diet quality was assessed by the Dutch Healthy Diet-Index[14]. Some evidence on the association between sugar-sweetened beverage consumption and lower-quality diets has also occurred in previous studies[21]. Nevertheless, it is known that sugar-sweetened beverages are not the primary source of added sugars in all population

Abbreviations: mBSDS, modified Baltic Sea Diet Score.

* **Corresponding author:** R. Tammi, email rilla.tammi@thl.fi

groups[12,22], and for this, we focused on added sugars from the whole diet.

Added sugar intake has been examined varyingly regarding population subgroups. In the reviews of mostly European studies, added sugar intake was suggested to be higher among women than men[12] and younger than older adults[23]. Regarding education, the found associations have predominantly been inverse[12,15,24–28]. The associations with physical activity[15,25,29] and smoking[15,25,28] have been examined in few studies with conflicting results, while no studies exploring added sugar intake and sleep were identified. Added sugar intake's associations with obesity measures have been examined rather widely, but the results have been mixed[2,15,18,30–35]. So far, population subgroups have not been considered in the association between added sugar intake and overall diet quality. Differences in the association may occur within a population, as food consumption, diet quality and the dietary sources of added sugars are known to vary between population subgroups. Further research is required to elucidate whether there are subgroups in which added sugar intake associates especially strongly with diet quality.

As recommendations to limit added sugar intake in the population are becoming increasingly common and added sugar intake is attracting attention also among the general public, it is essential to broaden our knowledge of added sugar intake from the perspectives of the whole diet and population subgroups. Our main objective was to examine the association between added sugar intake and overall diet quality assessed by the modified Baltic Sea Diet Score (mBSDS). We also explored the association between added sugar intake and sociodemographic factors, lifestyle factors, and BMI. Finally, possible interactions between added sugar intake and sociodemographic, lifestyle, and BMI population subgroups were examined.

Methods

Study population

The FinHealth 2017 Study is a national health examination study comprising a representative sample of individuals aged 18 years or older residing in Finland. A detailed description of the study protocol has been published elsewhere[36]. The data were collected between January and May 2017 by (self-administered) questionnaires and a health examination including anthropometric measures and blood samples. The participants received an invitation letter to a health examination and a self-administered questionnaire via mail. Of the eligible sample (*n* 10 247), 58 % participated in a health examination, where the remaining questionnaires (e.g. the FFQ) were distributed. All questionnaires could also be completed electronically. The participants who took part in a health examination and completed the FFQ were included in the present study. Exclusions were made due to incompletely filled FFQ (*n* 110), duplicate answers (paper and electronic FFQ, *n* 9) and consent withdrawal (*n* 7). Furthermore, 0·5 % of participants in both ends of the sex-specific daily energy intake distributions (*n* 51), as well as pregnant women (*n* 31), were excluded. As a result, the final data comprised 5094 participants (2844 women and 2250 men).

This study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Coordinating Ethics Committee at the Hospital District of Helsinki and Uusimaa (Reference 37/13/03/00/2016). Written informed consent was obtained from all subjects.

Dietary intake

Dietary intake data were gathered by a self-administered, validated, semi-quantitative 134-item FFQ covering habitual food consumption over the past 12 months[36–39]. Participants received the FFQ in the health examination along with oral and written instructions for its completion[36]. The questionnaire items included foods, mixed dishes and beverages commonly used in Finland (based on data from the FinDiet 2017 Survey)[22]. The consumption of each item was recorded by ten frequency categories ranging from none to 6 or more times a day. Portion sizes were specified for each item (e.g. glass, slice and volume) and fixed sex-specifically. The average daily food consumption (g/d) and intake of nutrients (g/d) and energy (kJ/d) were calculated using in-house software and the Finnish national food composition database (Fineli®)[40]. In addition to basic foods, the database includes composite foods (home-made foods, industrial food products and foods prepared by catering services) with standard recipes. Foods in the database were classified into basic ingredient groups.

Information on added sugars is not generally included in food composition databases. For this, Kaartinen *et al.*[15] developed a method to calculate added sugar (added sucrose and fructose) intake based on the consumption of foods and beverages in the Finnish national food composition database. In this study, the method was developed further to include all monosaccharides and disaccharides in the estimation, to better reflect the added sugar definition given in the Nordic nutrition recommendations[6]. The general idea was to first determine the intake of naturally occurring sugars, which was then subtracted from total sugar intake, equalling added sugar intake. For this, food consumption was assessed at the level of basic ingredient groups. Furthermore, the food sources (and their content) of naturally occurring sugars were identified. For example, all sugars in fresh fruits and vegetables and 10 % of sugars in jams were deemed naturally occurring. The estimation process is depicted in detail in Fig. 1.

The modified Baltic Sea Diet Score

Overall diet quality was assessed by the mBSDS, an *a priori* diet score based on healthier food choices of ingredients typically grown and culturally adapted in the Nordic countries[41,42]. Diverging from the original Baltic Sea Diet Score[42], total fat intake was excluded from the mBSDS score components as the fat ratio was considered a more important measure for a healthy diet, based on new food recommendations[9,41]. The mBSDS includes eight score components (fruits and berries, vegetables, cereals, low-fat milk, fish, red and processed meat, fat ratio, and alcohol) (online Supplementary Table S1). The component scoring, excluding alcohol, was established using

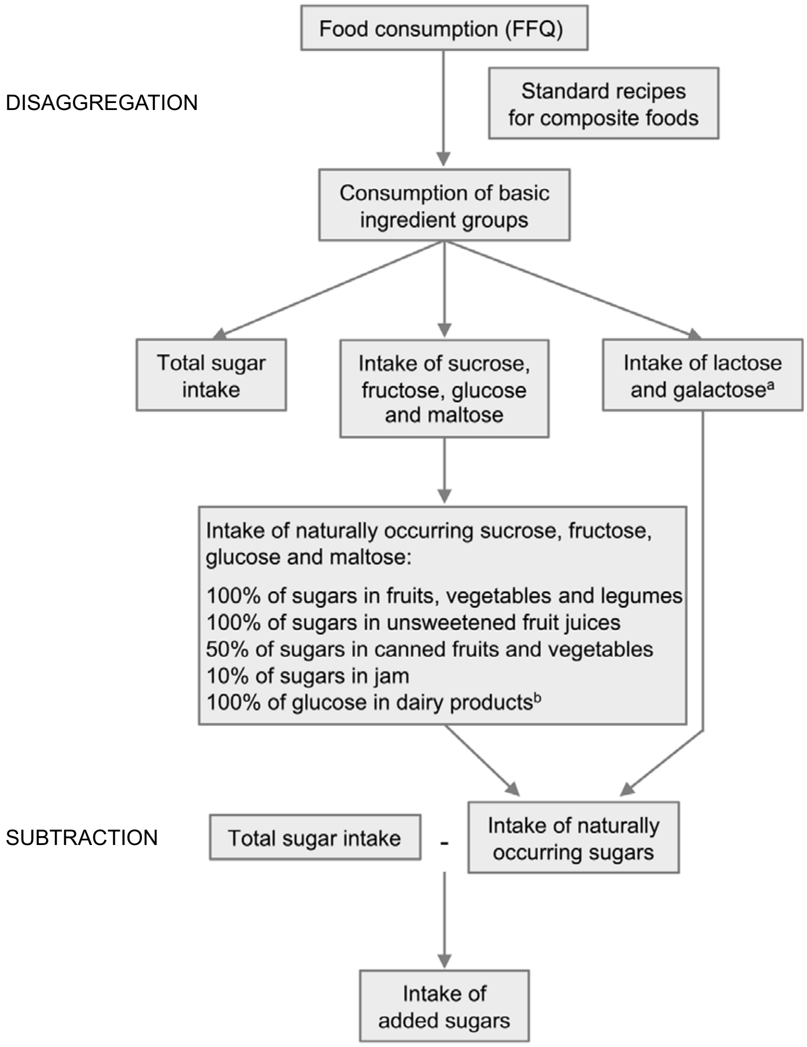

Fig. 1. A flow chart of the method to calculate added sugar intake. [a]Lactose and galactose are presumed to be always naturally occurring. [b]Sucrose is presumed to be the main sweetener in dairy products, and thus, glucose is presumed to originate from lactose degrading to glucose and galactose.

sex-specific population consumption quartiles as cut-offs, and points were assigned based on components' perceived health effects[42]. The component points ranged from 0 to 3 according to the consumption quartiles. Ascending points were assigned to the intake quartiles of the healthy perceived components (fruits and berries, vegetables, cereals, low-fat milk, fish, and fat ratio) and descending points to the intake quartiles of the unhealthy perceived component (red and processed meat). The scoring of alcohol consumption was based on the Nordic recommendation of moderate consumption level (women ≤10 g/d and men ≤20 g/d)[6], one point being assigned if the consumption was within the recommended level. The total score ranged between 0 and 22 points, higher points indicating a diet more aligned with the Baltic Sea Diet.

Anthropometric measures, sociodemographic factors and lifestyle factors

Anthropometric measures (height (cm), weight (kg) and waist circumference (cm)) were measured during the health examinations according to standard protocols by trained research staff[43,44]. BMI (kg/m^2) was calculated as weight (kg) divided by squared height (m). The data on age and sex originated from the sampling frame. The data on other sociodemographic and lifestyle factors, including education, smoking, physical activity and sleep duration, were gathered by self-administered questionnaires. The increase in average school years and the extension of the basic education system were considered in classifying participants into three educational levels (low, middle and high) according to the birth cohort. Participants' smoking status was assessed by questions on smoking history, and current smoking habits were categorised according to a four-level scale (a current smoker, quit <6 months ago, quit ≥6 months ago and a never smoker). In the present study, the smoking categories 'quit <6 months ago' and 'quit ≥6 months ago' were combined to create a new group of 'a former smoker'. The average leisure-time physical activity over the previous 12 months was assessed by four categories: inactive (light activities such as reading and watching television); moderately active (walking, gardening or other activities ≥4 h/week); active (running, swimming or other physically demanding activities ≥3 h/week) or very active (competition or other heavy sports several times/week). The categories 'active' and 'very active' were combined for the present study as only a few participants were classified as 'very active'. Sleep duration was assessed as self-estimated average sleep time at night (hours and minutes).

Statistical analyses

We conducted an exploratory analysis based on a nationally representative, population-based health examination study with a large sample size. For this, statistical power was not calculated. All analyses were performed by IBM SPSS Statistics (version 27; IBM Corp.). A two-sided value of $P<0{\cdot}05$ was considered statistically significant. Nutrient intakes were log (natural)-transformed when needed to meet the assumption of normal distribution. All analyses were conducted separately for women and men, as food consumption generally differs between sexes and added sugar intake was significantly associated with sex in our sample[22,36]. Added sugar intake was adjusted for total energy intake by residual method[45] and divided into quintiles by sex-specific cut-offs. The mBSDS, sociodemographic factors, lifestyle factors and BMI were examined by added sugar intake quintiles. The $P_{\text{for trend}}$ across added sugar intake quintiles were established by linear regression analysis for continuous variables, χ^2 test for binary background variables and logistic regression for binary variables when confounding factors were included in the model. In the trend analyses, participants were allocated the quintile median values corresponding to their added sugar intake category, which were then applied as independent continuous variables. In addition to the crude trend analyses (unadjusted), one model was applied to adjust for confounding factors, including age, education, smoking status, physical activity, BMI and energy intake (fully adjusted). Confounding factors were chosen based on literature regarding associations with added sugar intake or diet quality[12,15,42]. The applied factors are generally used in nutrition epidemiology research. Sensitivity analysis was performed for added sugar intake's association with overall diet quality by repeating the fully adjusted trend analysis after excluding energy under-reporters. Energy misreporting was considered by calculating the ratio between reported energy intake and predicted BMR[46]. Energy under-reporters were identified by the cut-off value of 1·14 (EI:BMR ≤ 1·14)[47]. $P_{\text{for interaction}}$ in added sugar intake's association with overall diet quality across population subgroups (according to age, educational level, smoking status, leisure-time physical activity, sleep duration and BMI) were calculated by linear regression analysis, including an interaction term (a categorical subgroup variable multiplied with energy-adjusted added sugar intake) as an additional confounding variable.

Results

Participant characteristics

A larger proportion of the participants were women (56 %) than men (44 %). The average mBSDS points were 11·4 in both sexes and the points ranged between 1 and 22 (Table 1). Carbohydrates covered approximately 40 % of the daily energy intake. Total sugar intake and the intake of naturally occurring sugars were slightly higher in women than men. However, added sugar intake was higher among men (46·4 g/d; 8·3 E %) compared with women (44 g/d; 7·6 E %).

Table 1. Participant characteristics and nutrient intakes
(Mean values or percentages)

	Women (*n* 2844)	Men (*n* 2250)	Total (*n* 5094)
	Mean/%	Mean/%	Mean/%
Characteristics			
Age (years)	56	56	56
Participants with low education* (%)	32	32	32
Current smokers (%)	13	17	14
Physically inactive participants† (%)	26	22	25
Sleep duration‡ (h)	7·4	7·4	7·4
BMI (kg/m²)	27·3	27·6	27·4
Waist circumference (cm)	89·4	99·2	93·7
Energy under-reporters§ (%)	36	41	38
Nutrient intake			
mBSDS‖	11·4	11·4	11·4
Energy (MJ/d)	7·9	9·7	8·7
Carbohydrate (E %)	40·9	39·8	40·4
Total sugar (E %)	19·1	17·9	18·6
Added sugar¶ (g/d)	44·0	46·4	45·1
Added sugar (E %)	7·6	8·3	7·9
Naturally occurring sugar** (E %)	6·1	4·1	5·2
Dietary fibre (g/MJ)	2·2	1·9	2·1
Protein (E %)	18·8	18·9	18·9
Fat (E %)	36·5	36·1	36·4

mBSDS, the modified Baltic Sea Diet Score; E %, percentage energy
* Self-reported total school years. The increase in average school years and the extension of the basic education system were considered in classifying participants into education levels according to birth cohort.
† Self-reported leisure-time physical activity: inactive (e.g. reading and watching television), moderately active (e.g. walking and gardening ≥4 h/week) and active (e.g. running and swimming ≥3 h/week).
‡ Self-reported average sleep duration at night.
§ Energy under-reporters were determined by the Goldberg cut-off value of ≤1·14 for the ratio between energy intake and predicted BMR[46,47].
‖ The mBSDS ranged between 0 and 22[41].
¶ Added sugars are defined as all monosaccharides and disaccharides used as such or added to foods by manufacturers, cooks or consumers, including sugars naturally present in honey and syrups.
** Naturally occurring sugars are defined as all monosaccharides and disaccharides in fruits, berries, vegetables, legumes, unsweetened fruit juices and unsweetened milk.

Association between added sugar intake and sociodemographic factors, lifestyle factors and BMI

Added sugar intake was inversely associated with education ($P=0{\cdot}03$ in women; $P=0{\cdot}001$ in men, fully adjusted) and physical activity ($P<0{\cdot}0001$) in both sexes and models (Table 2). The proportion of low educated participants increased by 39–48 % from the lowest to the highest added sugar intake quintile. The corresponding increase in the proportion of physically inactive participants was 61–70 %. An inverse association was also found with BMI in men in the fully adjusted model ($P=0{\cdot}003$). Yet, the decrease in BMI from the lowest (28 kg/m²) to the highest (27·3 kg/m²) added sugar intake quintile was very small. No association was found in women. Furthermore, added sugar intake was inversely associated with

https://doi.org/10.1017/S0007114521004736 Published online by Cambridge University Press

Table 2. Sociodemographic factors, lifestyle factors and BMI across added sugar intake quintiles
(Mean values and 95 % confidence intervals or percentages)

	Added sugar intake quintiles*							
	Q1 (*n* 568/450)†		Q3 (*n* 568/450)		Q5 (*n* 569/450)			
	Mean/%¶	95 % CI	Mean/%	95 % CI	Mean/%	95 % CI	*P*‡,§	*P*‡,‖
Age (years)								
Women	57·4	56·1, 58·7	56·6	55·2, 58·0	55·9	54·5, 57·4	0·21	0·07
Men	55·6	54·1, 57·1	56·5	55·1, 58·0	55·3	53·9, 56·8	0·99	0·62
Low educated participants								
Women	27·2	23·7, 31·0	29·4	25·8, 33·3	37·8	33·8, 41·9	0·006	0·03
Men	27·2	23·2, 31·5	25·6	21·7, 29·8	40·2	35·7, 44·8	<0·0001	0·001
Current smokers								
Women	9·3	7·1, 11·9	11·4	9·0, 14·3	18·1	15·1, 21·5	<0·0001	0·002
Men	9·9	7·4, 12·9	14·4	11·4, 17·9	26·9	22·9, 31·2	<0·0001	<0·0001
Physically inactive participants								
Women	22·2	18·9, 25·8	25·9	22·4, 29·6	37·7	33·7, 41·7	<0·0001	<0·0001
Men	19·3	15·9, 23·2	17·5	14·2, 21·3	31·0	26·8, 35·4	<0·0001	<0·0001
Sleep duration** (h/night)								
Women	7·5	7·4, 7·6	7·4	7·4, 7·5	7·3	7·2, 7·4	0·03	0·07
Men	7·3	7·2, 7·4	7·3	7·3, 7·4	7·4	7·3, 7·5	0·19	0·14
BMI (kg/m^2)								
Women	27·3	26·9, 27·8	27·2	26·7, 27·6	27·2	26·8, 27·7	0·38	0·12
Men	28·0	27·5, 28·4	27·6	27·2, 28·0	27·3	26·9, 27·7	0·10	0·003

* Quintile medians and minimum and maximum values (g/d) are in women Q1:23·2 (6·4–28·7), Q2:32·4 (28·7–36·3), Q3:40·4 (36·3–44·9), Q4:50·0 (44·9–56·6), Q5:68·3 (56·7–371·0), and in men Q1:24·5 (2·9–29·9), Q2:34·3 (29·9–38·6), Q3:42·8 (38·6–47·5), Q4:52·7 (47·5–60·5) and Q5:72·2 (60·5–206·5).
† Number of participants = (women/men).
‡ $P_{\text{for trend}}$ across added sugar intake quintiles were tested with linear regression for continuous variables and with χ^2 (unadjusted) or logistic regression (fully adjusted) for binary variables by using added sugar intake quintile medians as continuous independent variables.
§ Crude model without adjustments.
‖ Adjusted for age (continuous), education (low, middle and high), smoking (a current smoker, a former smoker and a never smoker), physical activity (inactive, moderately active and active), BMI (continuous) and energy intake (continuous). The corresponding variable was excluded from adjustment when examining it as a dependent variable.
¶ Crude model was applied to calculate means/% and 95 % CI.
** Self-reported average sleep duration at night.

sleep duration in women in the unadjusted model ($P = 0·03$). The association attenuated when the fully adjusted model was applied ($P = 0·07$). Added sugar intake was positively associated with smoking in both sexes and models ($P = 0·002$ women; $P < 0·0001$ men, fully adjusted). The proportion of current smokers doubled in women and almost tripled in men from the lowest to the highest quintile of added sugar intake.

Association between added sugar intake and overall diet quality

A highly significant inverse association was found between added sugar intake and overall diet quality in both sexes and models ($P < 0·0001$) (Table 3). The mean mBSDS points decreased from 13·2 to 9·2 in women and from 12·6 to 9·5 in men from the lowest to the highest added sugar intake quintile. Of the score components, inverse associations were found with fat ratio ($P < 0·0001$) and the consumption of fruits and berries, vegetables, cereals, low-fat milk, and fish ($P < 0·05$) in both sexes and models. The participants in the lowest added sugar intake quintile consumed, for example, almost double the amount of vegetables compared with those in the highest added sugar intake quintile. Fish consumption decreased by 35 % from the lowest to the highest added sugar intake quintile. In men, an inverse association was also found between added sugar intake and red and processed meat consumption ($P = 0·03$ unadjusted; $P = 0·01$ fully adjusted). Participants in the lowest added sugar intake quintile consumed on average 20 g/d more red and processed meats compared with those in the highest added sugar intake quintile. Added sugar intake was positively associated with alcohol consumption in both sexes and models ($P < 0·01$). The inverse association between added sugar intake and overall diet quality remained in the sensitivity analysis when energy underreporters were excluded ($P < 0·0001$, data not shown).

Association between added sugar intake and overall diet quality in sociodemographic, lifestyle and obesity subgroups

Regarding the association between added sugar intake and overall diet quality, no interactions were found in population subgroups except for the subgroups of men's physical activity ($P_{\text{for interaction}} = 0·005$, fully adjusted, online Supplementary Table S2). Among active men, the inverse association between added sugar intake and overall diet quality appeared stronger (mBSDS points in added sugar intake quintiles: Q1, 13·6; Q3, 12·2; Q5, 9·6) compared with moderately active (Q1, 12·8; Q3, 11·8; Q5, 10·4) and inactive (Q1, 10·3; Q3, 10·1; Q5, 8·2) men.

Discussion

In this population-based cross-sectional analysis of 5094 Finnish adults, added sugar intake was inversely associated with education, physical activity and BMI (in men), while the association with smoking was positive. Higher added sugar intake was associated with lower overall diet quality, which was consistently seen in all examined population subgroups. In active men,

Table 3. The modified Baltic Sea Diet Score (mBSDS) points and score components across added sugar intake quintiles
(Mean values and 95 % confidence intervals)

	Added sugar intake quintiles*							
	Q1 (*n* 568/450)†		Q3 (*n* 568/450)		Q5 (*n* 569/450)			
	Mean¶	95 % CI	Mean	95 % CI	Mean	95 % CI	*P*‡,§	*P*‡,‖
Women								
Energy (MJ/d)	7·95	7·72, 8·17	7·77	7·57, 7·97	7·66	7·45, 7·87	0·20	0·95
mBSDS**	13·2	12·9, 13·5	11·3	11·0, 11·6	9·2	8·9, 9·5	<0·0001	<0·0001
Components								
Fruits and berries (g/d)	121	113, 129	96	89, 103	73	68, 79	<0·0001	<0·0001
Vegetables (g/d)	400	380, 420	286	273, 300	214	203, 225	<0·0001	<0·0001
Cereals (g/d)	65	62, 69	55	52, 58	44	41, 47	<0·0001	<0·0001
Low-fat milk (g/d)	254	231, 277	230	211, 248	190	173, 206	0·008	0·001
Fish (g/d)	41	37, 44	34	31, 36	27	24, 29	<0·0001	<0·0001
Red and processed meat (g/d)	86	81, 91	83	79, 88	78	75, 82	0·37	0·25
Fat ratio	0·56	0·55, 0·58	0·47	0·45, 0·48	0·42	0·41, 0·43	<0·0001	<0·0001
Alcohol (g/d)	3·0	2·6, 3·4	3·8	3·4, 4·2	4·9	4·1, 5·7	0·006	0·008
Men								
Energy (MJ/d)	9·62	9·31, 9·93	9·77	9·48, 10·06	9·48	9·17, 9·80	0·35	0·66
mBSDS	12·6	12·2, 13·0	11·7	11·4, 12·0	9·5	9·2, 9·9	<0·0001	<0·0001
Components								
Fruits and berries (g/d)	89	81, 97	83	76, 91	55	49, 61	<0·0001	<0·0001
Vegetables (g/d)	312	293, 331	255	241, 269	184	173, 196	<0·0001	<0·0001
Cereals (g/d)	71	66, 76	66	62, 70	53	49, 56	<0·0001	<0·0001
Low-fat milk (g/d)	362	330, 393	306	280, 333	248	224, 273	<0·0001	<0·0001
Fish (g/d)	52	47, 56	40	37, 43	33	30, 37	<0·0001	<0·0001
Red and processed meat (g/d)	144	135, 154	141	133, 149	124	117, 130	0·03	0·01
Fat ratio	0·48	0·47, 0·50	0·44	0·43, 0·45	0·41	0·40, 0·42	<0·0001	<0·0001
Alcohol (g/d)	6·3	5·3, 7·4	10·3	9·2, 11·4	17·3	14·8, 19·7	<0·0001	<0·0001

* Quintile medians and minimum and maximum values (g/d) are in women Q1:23 2 (6 4–28 7), Q2:32 4 (28 7–36 3), Q3:40 4 (36 3–44 9), Q4:50 0 (44 9–56 6), Q5:68 3 (56 7–371 0), and in men Q1:24 5 (2 9–29 9), Q2:34 3 (29 9–38 6), Q3:42 8 (38 6–47 5), Q4:52 7 (47 5–60 5) and Q5:72 2 (60 5–206 5).
† Number of participants = (women/men).
‡ $P_{\text{for trend}}$ across added sugar intake quintiles were tested with linear regression by using added sugar intake quintile medians as continuous independent variables.
§ Crude model without adjustments.
‖ Adjusted for age (continuous), education (low, middle and high), smoking (a current smoker, a former smoker and a never smoker), physical activity (inactive, moderately active and active), BMI (continuous) and energy intake (continuous). When energy intake was used as a dependent variable, it was excluded from confounding variables used for adjusting.
¶ Crude model was applied to calculate means and 95 % CI.
** Range of mBSDS points in added sugar intake quintiles are in women Q1:3–22, Q2:2–22, Q3:1–22, Q4:2–21, Q5:1–18, and in men Q1:2–22, Q2:2–22, Q3:3–21, Q4:1–20 and Q5:2–21.

increasing added sugar intake was associated with a stronger decrease in overall diet quality compared with moderately active and inactive men. This is the first study to examine added sugar intake in relation to overall diet quality assessed by the mBSDS and in a Nordic population.

Our findings on added sugar intake's associations with education and lifestyle factors were in line with previous studies. Most earlier studies examining added sugar intake and education have reported inverse associations[12,24,25,27,28], although differing results have also occurred[12,15,27]. Regarding smoking, studies in the Portuguese (*n* 3852)[25] and American (*n* 24 967) adult populations[28] have suggested a positive association. Likewise, in Portugal (*n* 5811, aged 3–84 years)[25] and the USA (*n* 4766, 18–69 years)[29], inverse associations were found between added sugar intake and physical activity. However, in a prior study of the Finnish adult population (*n* 4842, 25–74 years), added sugar intake was not associated with education or physical activity, and the association with smoking was inverse (men) or non-significant (women)[15]. These discrepancies between our results and the earlier findings in the Finnish population could arise from the significant decrease in population carbohydrate intakes between the studies (2007 *v.* 2017)[48], as the intake may have altered differently within population subgroups. As we applied an updated version of the same FFQ used in the earlier study, it is unlikely that diverging added sugar intake estimation methods would have affected participant ranking based on added sugar intakes and thus the results. Overall, more research is needed to ascertain our findings, especially regarding smoking and physical activity. We also found a borderline inverse association between women's added sugar intake and sleep duration. As this association has not been investigated earlier, further research is warranted.

Added sugar intake has been inversely associated with BMI in Finland (*n* 4842)[15] and the UK (*n* 1734)[32] when self-reported dietary intake data have been applied. In our study, inverse association with BMI was only found in men, consistent with previous findings in the Finnish population[15]. In general, selective under-reporting is a particular challenge in examining added sugar intake[49], and its possible distorting effects cannot necessarily be eliminated by considering energy under-reporting. A better understanding of selective under-reporting could be reached by utilising biomarkers for added sugars, which have been under intensive investigation for past years[50,51]. However, using a biomarker was not, unfortunately, possible in this population-based study.

Conforming our results, two American population-based studies (*n* 31 147, ≥20 years; *n* 15 011, ≥2 years) have reported

https://doi.org/10.1017/S0007114521004736 Published online by Cambridge University Press

inverse associations between added sugar intake and overall diet quality assessed by the Healthy Eating Index[19,20]. In a Dutch study (*n* 2104, 19–69 years), overall diet quality assessed by the Dutch Healthy Diet-Index was not found to differ between participants adherent and non-adherent to different added and free sugar guidelines (e.g. Nordic, Dutch and the WHO's recommendations)[14]. Yet, inverse associations aligned with our results were reported regarding, for example, vegetable consumption. In these three studies, dietary intake was, however, assessed by 24-h dietary recalls, complicating the comparison with our results as we applied the FFQ. The FFQ was applied because our main objective was to examine the overall phenomenon of added sugar intake in relation to diet quality instead of estimating added sugar intake in the population. Furthermore, the FFQ is the primary method in nutrition epidemiology research. In general, the evidence of added sugar intake's association with overall diet quality is currently scarce, and more research, especially longitudinal studies, is needed. Studies in different populations and with other frequently used dietary indices, such as the Mediterranean Diet Score, would add to our knowledge of the culture-related dimensions of the association.

In our study, added sugar intake was inversely associated with the consumption of the healthy perceived mBSDS components, regardless of energy intake, which might suggest that foods high in added sugars would displace healthier, more nutrient-rich foods in the diet. Likewise, several studies have reported inverse associations between added sugar intake and the consumption of fruits, vegetables, cereals and fish[13,15,16]. We also found an inverse association between added sugar intake and red and processed meat consumption in men. Similar findings have earlier occurred at least in one American[20] and one Finnish[15] study. In the same Finnish data, an inverse association was also found between red and processed meat consumption and the consumption of sweets[52]. These findings indicate that high added sugar intake would not generally occur alongside high meat consumption. In our study, added sugar intake was not associated with red and processed meat consumption in women, although the consumption seemed to decrease across increasing added sugar intake. The significant association in men likely arises from the higher consumption levels and wider consumption range (0–1023 g/d) compared with women (0–788 g/d).

The inverse association between added sugar intake and overall diet quality was consistently found in all examined sociodemographic, lifestyle and BMI subgroups. Nevertheless, one significant interaction was found in the population subgroups, as the inverse association between added sugar intake and overall diet quality was stronger in active men compared with moderately active and inactive men. This suggests that the relatively small group of active men with high added sugar intake would differ from other men regarding their dietary habits. Contrary to other activity groups, active men tended to have lower energy intake in the highest added sugar intake quintile compared with the lowest quintile (data not shown). Thus, active men could have compensated for the high added sugar intake with a lower intake of other foods, including foods perceived healthy in the mBSDS. Despite this, active men tended to have higher mBSDS points, especially in comparison with inactive men, suggesting higher overall diet quality. The distribution of BMI did not differ among active men across added sugar intake quintiles but was in general lower compared with the other men. In all, the interaction did not seem to arise from active men with high added sugar intake having an overall unhealthier lifestyle. In line with our finding, a previous American population-based study (*n* 4766)[29] has shown an association between high added sugar intake and high physical activity. As this was the first study to examine the association between added sugar intake and overall diet quality in population subgroups, further studies are needed to determine whether differences within population subgroups exist in Finland or in other populations.

Comparing findings in different studies regarding added sugar intake is challenging due to the lack of uniformity in added sugar definitions, dietary assessment methods and methods to estimate added sugars in the diet. We utilised the FFQ to estimate dietary intake, while most studies examining added sugar intake have used other dietary assessment methods, such as the 24-h dietary recall. The methods to estimate added sugar intake vary considerably between studies, and their accuracy and comparability have not been investigated. We applied a newly developed method, although similar approaches have been previously utilised in Finland[15] and Sweden[24]. Due to these circumstances, the comparisons between intake levels from different studies applying different methods should be interpreted cautiously.

Our study has several strengths. We applied a large, population-based sample of the Finnish adult population. Dietary data were gathered by a validated FFQ, which has been found to measure carbohydrate fractions acceptably in our study population[37]. Overall diet quality was assessed by the mBSDS, indicating a healthy Nordic diet[42]. We estimated added sugar intake with a newly developed method that included all monosaccharides and disaccharides, enabling a more comprehensive added sugar intake assessment than has been done in Finland before. All analyses were adjusted for several confounders.

This study is also subject to limitations. As in health studies commonly, the population distribution of the participants differed from that of the general population, diminishing the result generalisability[53]. However, the participation rate was relatively good (58 %) in international comparison, reinforcing the representativeness. Furthermore, as our main objective was not to examine added sugar intake in the population but an overall phenomenon, the study sample was considered appropriate. Applying self-reported dietary intake data exposed the method to misreporting. Yet, excluding energy under-reporters did not affect the inverse association between added sugar intake and overall diet quality. Other weaknesses of the FFQ, such as recall bias, may also have distorted the results. However, the FFQ has been shown to be well equipped for epidemiological research[54], and the applied FFQ has been repeatedly validated in the Finnish adult population[37,39]. Despite adjusting the analyses for several confounders, residual confounding may remain as dietary intake associates with numerous unmeasured factors. The limitations of our method to estimate added sugar intake are linked to the inaccurate or lacking disaggregation of certain

British Journal of Nutrition

foods during the calculation processes. Due to this, naturally occurring sugars may be incorrectly classified as added sugars or vice versa, distorting the intake estimation. Nonetheless, this concerns mainly marginal food items, such as muesli bars, therefore unlikely affecting the results. The estimation accuracy also leans on the food composition database's up-to-dateness in terms of monosaccharide and disaccharide composition of foods and food recipes. This can be distorted, for example, by the constantly expanding supply of industrial food products. Finally, our statistical analyses included multiple comparisons, which could have exposed our results to type 1 error. However, our main results were highly significant, and thus, it is unlikely that they would have resulted from incorrect statistical inference.

In conclusion, our findings suggest that high added sugar intake is associated with several unhealthy dietary and lifestyle habits, including poor-quality diets, smoking and leisure-time inactivity, in Finnish adults. Efforts to improve diet quality should consider added sugar intake equally in the whole population. The findings of this study can provide important background information for stakeholders in establishing new incentives to reduce added sugar intake or maintain a satisfactory intake level in the Finnish adult population.

Acknowledgements

The authors would like to thank the personnel who took part in collecting and preparing the data and the participants of the study.

This study was supported by the Fund for Agriculture and Forestry Science, University of Helsinki (RT, grant number 1128454); the Finnish Cultural Foundation (NEK); and the Juho Vainio Foundation. The funders had no role in the design, analysis or writing of this article.

The conception, design of the study and research questions were developed by M. M., N. E. K. and R. T. M. M., N. E. K., N. K. and S. M. contributed to developing the applied FFQ and the modified Baltic Sea Diet Score. L. S. J., M. M., N. E. K. and S. M. contributed to developing the method to estimate added sugar intake. N. E. K. and S. M. contributed to the planning of the FinHealth 2017 Study. R. T. conducted the statistical analyses and the results were interpreted by M. M., N. E. K. and R. T. R. T. wrote the manuscript. L. S. J., M. M., N. E. K., N. K. and S. M. contributed to critical revisions to the manuscript. All authors approved the final manuscript.

There are no conflicts of interest.

Supplementary material

For supplementary material/s referred to in this article, please visit https://doi.org/10.1017/S0007114521004736

References

1. Hu FB & Malik VS (2010) Sugar-sweetened beverages and risk of obesity and type 2 diabetes: epidemiologic evidence. *Physiol Behav* **100**, 47–54.
2. Te Morenga L, Mallard S & Mann J (2012) Dietary sugars and body weight: systematic review and meta-analyses of randomised controlled trials and cohort studies. *BMJ* **346**, e7492.
3. Te Morenga LA, Howatson AJ, Jones RM, *et al.* (2014) Dietary sugars and cardiometabolic risk: systematic review and meta-analyses of randomized controlled trials of the effects on blood pressure and lipids. *Am J Clin Nutr* **100**, 65–79.
4. Makarem N, Bandera EV, Nicholson JM, *et al.* (2018) Consumption of sugars, sugary foods, and sugary beverages in relation to cancer risk: a systematic review of longitudinal studies. *Annu Rev Nutr* **38**, 17–39.
5. Moynihan PJ & Kelly SAM (2014) Effect on caries of restricting sugars intake: systematic review to inform WHO guidelines. *J Dent Res* **93**, 8–18.
6. Nordic Council of Ministers (2014) *Nordic Nutrition Recommendations 2012. Integrating Nutrition and Physical Activity*, 5th ed. Copenhagen: Norden.
7. U.S. Department of Agriculture & U.S. Department of Health and Human Services (2020) *Dietary Guidelines for Americans, 2020–2025*, 9th ed. Washington, DC: U.S. Department of Agriculture and U.S. National Institutes of Health.
8. World Health Organization (2015) *Guideline: Sugars Intake for Adults and Children*. Geneva: WHO.
9. Finnish National Nutrition Council (2014) Finnish Nutrition Recommendations 2014 (in Finnish). https://www.ruokavirasto.fi/globalassets/teemat/terveytta-edistava-ruokavalio/kuluttaja-ja-ammattilaismateriaali/julkaisut/ravitsemussuositukset_2014_fi_web_versio_5.pdf (accessed June 2021).
10. Scientific Advisory Committee on Nutrition (2015) *Carbohydrates and Health*. London: Public Health England.
11. Cummings JH & Stephen AM (2007) Carbohydrate terminology and classification. *Eur J Clin Nutr* **61**, Suppl. 1, S5–S18.
12. Azaïs-Braesco V, Sluik D, Maillot M, *et al.* (2017) A review of total & added sugar intakes and dietary sources in Europe. *Nutr J* **16**, 6.
13. Louie JC & Tapsell LC (2015) Association between intake of total *v.* added sugar on diet quality: a systematic review. *Nutr Rev* **73**, 837–857.
14. Sluik D, van Lee L, Engelen AI, *et al.* (2016) Total, free, and added sugar consumption and adherence to guidelines: the Dutch national food consumption survey 2007–2010. *Nutrients* **8**, 70.
15. Kaartinen NE, Similä ME, Kanerva N, *et al.* (2017) Naturally occurring and added sugar in relation to macronutrient intake and food consumption: results from a population-based study in adults. *J Nutr Sci* **6**, e7.
16. Mok A, Ahmad R, Rangan A, *et al.* (2018) Intake of free sugars and micronutrient dilution in Australian adults. *Am J Clin Nutr* **107**, 94–104.
17. Sadler MJ, McNulty H & Gibson S (2015) Sugar–fat seesaw: a systematic review of the evidence. *Crit Rev Food Sci Nutr* **55**, 338–356.
18. González-Padilla E, Dias JA, Ramne S, *et al.* (2020) Association between added sugar intake and micronutrient dilution: a cross-sectional study in two adult Swedish populations. *Nutr Metab* **17**, 15.
19. Britten P, Basiotis P, Davis CA, *et al.* (2000) Is Intake of Added Sugars Associated with Diet Quality? A Publication of the USDA Center for Nutrition Policy and Promotion. Nutrition Insights INSIGHT 21. https://fns-prod.azureedge.net/sites/default/files/nutrition_insights_uploads/Insight21.pdf (accessed June 2021).
20. Yang Q, Zhang Z, Gregg EW, *et al.* (2014) Added sugar intake and cardiovascular diseases mortality among US adults. *JAMA Intern Med* **174**, 516–524.

https://doi.org/10.1017/S0007114521004736 Published online by Cambridge University Press

21. Doherty AM, Lacko AM & Popkin BM (2021) Sugar-sweetened beverage (SSB) consumption is associated with lower quality of the non-SSB diet in US adolescents and young adults. *Am J Clin Nutr* **113**, 657–664.
22. Valsta L, Kaartinen N, Tapanainen H, *et al.* (2018) *Nutrition in Finland – The National FinDiet 2017 Survey. Report no. 12/2018*. Helsinki: Finnish Institute for Health and Welfare.
23. Newens KJ & Walton J (2016) A review of sugar consumption from nationally representative dietary surveys across the world. *J Hum Nutr Diet* **29**, 225–240.
24. Ramne S, Alves Dias J, González-Padilla E, *et al.* (2019) Association between added sugar intake and mortality is non-linear and dependent on sugar source in 2 Swedish population–based prospective cohorts. *Am J Clin Nutr* **109**, 411–423.
25. Marinho AR, Severo M, Correia D, *et al.* (2020) Total, added and free sugar intakes, dietary sources and determinants of consumption in Portugal: the national food, nutrition and physical activity survey (IAN-AF 2015–2016). *Public Health Nutr* **23**, 869–881.
26. Chatelan A, Gaillard P, Kruseman M, *et al.* (2019) Total, added, and free sugar consumption and adherence to guidelines in Switzerland: results from the first national nutrition survey menuCH. *Nutrients* **11**, 1117.
27. Thompson FE, McNeel TS, Dowling EC, *et al.* (2009) Interrelationships of added sugars intake, socioeconomic status, and race/ethnicity in adults in the United States: national health interview survey, 2005. *J Am Diet Assoc* **109**, 1376–1383.
28. Park S, Thompson FE, McGuire LC, *et al.* (2016) Sociodemographic and behavioral factors associated with added sugars intake among US adults. *J Acad Nutr Diet* **116**, 1589–1598.
29. Koehler K, Boron JB, Garvin TM, *et al.* (2019) Differential relationship between physical activity and intake of added sugar and nutrient-dense foods: a cross-sectional analysis. *Appetite* **140**, 91–97.
30. Ahmad R, Mok A, Rangan AM, *et al.* (2020) Association of free sugar intake with blood pressure and obesity measures in Australian adults. *Eur J Nutr* **59**, 651–659.
31. Malik VS, Pan A, Willett WC, *et al.* (2013) Sugar-sweetened beverages and weight gain in children and adults: a systematic review and meta-analysis. *Am J Clin Nutr* **98**, 1084–1102.
32. Kuhnle GG, Tasevska N, Lentjes MA, *et al.* (2015) Association between sucrose intake and risk of overweight and obesity in a prospective sub-cohort of the European prospective investigation into cancer in Norfolk (EPIC-Norfolk). *Public Health Nutr* **18**, 2815–2824.
33. Bingham S, Luben R, Welch A, *et al.* (2007) Epidemiologic assessment of sugars consumption using biomarkers: comparisons of obese and non-obese individuals in the European prospective investigation of cancer Norfolk. *Cancer Epidemiol Biomarkers Prev* **16**, 1651–1654.
34. Kaartinen NE, Knekt P, Kanerva N, *et al.* (2016) Dietary carbohydrate quantity and quality in relation to obesity: a pooled analysis of three Finnish population-based studies. *Scand J Public Health* **44**, 385–393.
35. Parnell W, Wilson N, Alexander D, *et al.* (2008) Exploring the relationship between sugars and obesity. *Public Health Nutr* **11**, 860–866.
36. Borodulin K & Sääksjärvi K (2019) *FinHealth 2017 Study – Methods. Report no. 17/2019*. Helsinki: Finnish Institute for Health and Welfare.
37. Kaartinen NE, Tapanainen H, Valsta LM, *et al.* (2012) Relative validity of a FFQ in measuring carbohydrate fractions, dietary glycaemic index and load: exploring the effects of subject characteristics. *Br J Nutr* **107**, 1367–1375.
38. Männistö S, Virtanen M, Mikkonen T, *et al.* (1996) Reproducibility and validity of a food frequency questionnaire in a case-control study on breast cancer. *J Clin Epidemiol* **49**, 401–409.
39. Paalanen L, Männistö S, Virtanen MJ *et al.* (2006) Validity of a food frequency questionnaire varied by age and body mass index. *J Clin Epidemiol* **59**, 994–1001.
40. Reinivuo H, Hirvonen T, Ovaskainen ML, *et al.* (2010) Dietary survey methodology of FINDIET 2007 with a risk assessment perspective. *Public Health Nutr* **13**, 915–919.
41. Suikki T, Maukonen M, Partonen T, *et al.* (2021) Association between social jet lag, quality of diet and obesity by diurnal preference in Finnish adult population. *Chronobiol Int* **38**, 720–731.
42. Kanerva N, Kaartinen NE, Schwab U, *et al.* (2014) The Baltic Sea diet score: a tool for assessing healthy eating in Nordic countries. *Public Health Nutr* **17**, 1697–1705.
43. Tolonen H (2016) *EHES Manual. Part A. Planning and Preparation of the Survey*, 2nd ed. Helsinki: Finnish Institute of Health and Welfare.
44. Tolonen H (2016) *EHES Manual. Part B. Field Work and Procedures*, 2nd ed. Helsinki: Finnish Institute of Health and Welfare.
45. Willett W & Stampfer MJ (1986) Total energy intake: implications for epidemiologic analyses. *Am J Epidemiol* **124**, 17–27.
46. World Health Organization (1985) *Energy and Protein Requirements. Report of a Joint WHO/FAO/UNU Expert Consultation. WHO Technical Report Series no. 724*. Geneva: WHO.
47. Goldberg GR, Black AE, Jebb SA, *et al.* (1991) Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. *Eur J Clin Nutr* **45**, 569–581.
48. Kaartinen NE, Tapanainen H, Männistö S, *et al.* (2021) Changes in food consumption and nutrient intake in Finnish adults 1997–2017: the national Findiet survey (in Finnish, title and abstract in English). *Finnish Med J* **76**, 273–280.
49. Johansson L, Solvoll K, Bjorneboe GE, *et al.* (1998) Under- and overreporting of energy intake related to weight status and lifestyle in a nationwide sample. *Am J Clin Nutr* **68**, 266–274.
50. Tasevska N, Midthune D, Potischman N, *et al.* (2011) Use of the predictive sugars biomarker to evaluate self-reported total sugars intake in the observing protein and energy nutrition (OPEN) study. *Cancer Epidemiol Biomarkers Prev* **20**, 490–500.
51. Hedrick VE, Davy BM, Wilburn GA, *et al.* (2016) Evaluation of a novel biomarker of added sugar intake (δ13C) compared with self-reported added sugar intake and the healthy eating index-2010 in a community-based, rural US sample. *Public Health Nutr* **19**, 429–436.
52. Fogelholm M, Kanerva N & Männistö S (2015) Association between red and processed meat consumption and chronic diseases: the confounding role of other dietary factors. *Eur J Clin Nutr* **69**, 1060–1065.
53. Koponen P, Borodulin K, Lundqvist A, *et al.* (2018) *Health, Functional Capacity and Welfare in Finland – FinHealth 2017 Study. Report 4/2018*. Helsinki: Finnish Institute for Health and Welfare.
54. Satija A, Yu E, Willett WC, *et al.* (2015) Understanding nutritional epidemiology and its role in policy. *Adv Nutr* **6**, 5–18.