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Associations between free sugar intake and markers of health in the UK population: an analysis of the National Diet and Nutrition Survey rolling programme

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Abstract

Recommendations for free sugar intake in the UK should be no more than 5 % of total energy due to increased health risks associated with overconsumption. It was therefore of interest to examine free sugar intakes and associations with health parameters in the UK population. The UK National Diet and Nutrition Survey rolling programme (2008–2017) was used for this study. Dietary intake, anthropometrical measurements and clinical biomarker data collated from 5121 adult respondents aged 19–64 years were statistically analysed. Compared with the average total carbohydrate intake (48 % of energy), free sugars comprised 12·5 %, with sucrose 9 % and fructose 3·5 %. Intakes of these sugars, apart from fructose, were significantly different over collection year ($P < 0·001$) and significantly higher in males ($P < 0·001$). Comparing those consuming above or below the UK recommendations for free sugars (5 % energy), significant differences were found for BMI ($P < 0·001$), TAG ($P < 0·001$), HDL ($P = 0·006$) and homocysteine concentrations ($P = 0·028$), and significant sex differences were observed (e.g. lower blood pressure in females). Regression analysis demonstrated that free sugar intake could predict plasma TAG, HDL and homocysteine concentrations ($P < 0·0001$), consistent with the link between these parameters and CVD. We also found selected unhealthy food choices (using the UK Eatwell Guide) to be significantly higher in those that consumed above the recommendations ($P < 0·0001$) and were predictors of free sugar intakes ($P < 0·0001$). We have shown that adult free sugar intakes in the UK population are associated with certain negative health parameters that support the necessary reduction in free sugar intakes for the UK population.

Key words: Free sugar: Sucrose: Health: National Diet and Nutrition Survey

The Scientific Advisory Committee on Nutrition changed its recommendations for free sugars in 2015[1,2]. Free sugars are now defined as 'all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and unsweetened fruit juices' and should be restricted to 5 % of daily energy. The justification for these changes reflects the evidence for free sugars in the aetiology of degenerative disease.

Characteristically, free sugars increase the energy density of a food product without increasing a feeling of fullness or providing nutrients; therefore, they are often referred to as 'empty calories', with some (fructose) being shown to cause both decreased leptin and circulating insulin and increased ghrelin concentrations post-consumption[3]. These effects make free sugars a concerning contributor to the risk of developing obesity, CVD, diabetes, hypertension and obesity-related cancers[4]. One example product that has gained a great deal of attention with regard to its effect on the aforementioned health parameters are sugar-sweetened beverages (SSB). It was predicted that placing a levy on soft drinks containing free sugars would contribute to 1 million less adults being overweight, subsequently preventing approximately 275 000 to 300 000+ cases of type 2 diabetes over a 20-year period following the predicted reductions in body weight[5]. Recent data suggest that there is an approximately 30 g or 10 % reduction in free sugars per household[6] but it is yet to be confirmed whether or not this will have substantial reductive effects on health parameters after being enforced in 2018.

Regardless of the amount of sugar consumed, or as a percentage of total energy intake, parallel changes between body weight and dietary free sugar intake have been observed[7] with free sugars specifically being attributed to the increased risk of a number of chronic diseases[8]. In addition, a higher percentage of total energy from free sugars (and total fat) has been associated with greater adiposity in children and adolescents[9]; however, differences in the reliability of research outcomes conclude

Abbreviations: NDNS, National Diet and Nutrition Survey; SBP, systolic blood pressure; SSB, sugar-sweetened beverage.

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that further research will be needed to determine a more definitive relationship between free sugar intake and changes in body weight. The link between free sugar intakes and/or certain foods that have high free sugar content with the risk of obesity-related degenerative disease makes the reduction of free sugar intake a vital step in the prevention of non-communicable diseases globally.

It is therefore of interest to examine free sugar intakes within a population and identify any associations with health parameters, and this is the aim of the present study using the UK population accessed through the National Diet and Nutrition Survey (NDNS) rolling programme. The NDNS collects quantitative information on the food consumption, nutrient intake and health status of the UK population[10]. This has been achieved using a continuous, cross-sectional survey using a representative sample of around 1000 participants per year, and is therefore an excellent resource to be able to monitor dietary information and health associations in the UK population.

Methods

National Diet and Nutrition Survey dataset

The study is a secondary analysis of the NDNS dataset which was downloaded from the UK Data Service website https://ukdataservice.ac.uk/. Detailed information regarding NDNS methods is published elsewhere[10]. In brief, the NDNS is a continuous, cross-sectional survey which was carried out in the UK from 2008 to 2017 as a rolling programme. The NDNS was conducted across all four countries included in the UK to provide a representative sample of the population. The survey was designed to collect quantitative information regarding the dietary intake and nutritional status of the population aged 1·5 years and over and living in private households. The survey aimed to collect data from a representative sample of 1000 people per fieldwork year, with at least 500 adults (aged 19 years and older).

Ethical considerations

Ethical approval was obtained from the Oxfordshire A Research Ethics Committee (Ref 07/H0604/113) for the 2008–2013 data collection and from Cambridge South NRES Committee (Ref 13/EE/0016) for the 2014–2017 collection. Details of the survey were provided to the respondents who then completed a consent form when they agreed to take part in the NDNS. As this study is an analysis of secondary data, ethical approval was not required by Northumbria University.

Sampling

Private households in the UK were randomly selected to take part in the NDNS. The sample was drawn from the Postcode Address File, a list of all the addresses in the UK. Addresses were grouped into primary sampling units based on postcode areas, and a list of addresses were randomly chosen from each primary sampling unit. The addresses were randomly allocated to one of two groups to determine whether an adult and a child, or a child only, was selected for interview. There were two main parts to the survey: an interviewer stage and a nurse visit. Participants gave fully productive interviews consisting of three or four diary days and of those participants that provided a dietary diary, 50 % of adults and 25 % children went on to provide a blood sample.

Dietary assessment

Participants were asked to record all food and drink consumed over 4 consecutive days comprising 3 week-days and a weekend day, including portion sizes, brand names and recipes for home cooked foods. During the recording period, interviewers carried out a food diary check and collected the completed diaries no later than 3 d after completion. Participants were not instructed to weigh their food and drink, and portions were estimated using household measures or weights provided on packaging. Participants over the age of 16 were provided with photographs of ten frequently consumed foods to help to define portion sizes. Dietary analysis was conducted using the DINO (Diet in Nutrients Out) platform based on Public Health England's NDNS Nutrient Databank food composition data.

Health markers

At the first nurse visit, physical measurements, height and weight were taken using a portable stadiometer and a weight scale, and BMI was calculated by the fieldworkers. Waist circumference was recorded using a tape measure. Blood pressure was taken using an Omron-HEM907 automated validated monitor in the sitting position after a 5-min rest. Three measurements were taken. The blood sampling procedure was explained and taken from consenting participants by venepuncture at a second nurse visit. Haematological and biochemical analyses of blood samples were carried out at MRC-HNR and Addenbrooke's Hospital NHS Trust, Cambridge. Further information about sampling procedures can be found on the NDNS website (https://www.gov.uk/government/collections/national-diet-and-nutrition-survey).

National Diet and Nutrition Survey data

The data were filtered to remove respondents other than adults (aged 19–64 years). Only data from participants (both males and females) that completed the full 4-d food diary were used. The final number of participants was 5121, comprising 2112 males and 3009 females. The data from each year of collection were combined into a single working spreadsheet containing all the necessary variables of interest. Missing values were denoted by a specific code that was recognised by the statistical software. The appropriate weighting factors supplied by the NDNS resource were used to ensure any selection bias was considered. The variables used were wti_ for all diet and anthropometric data, and wtb_ variable for all blood measures; the weighting variables for each year of collection were combined for all years as instructed by the NDNS resource. A number of cardiovascular risk factors were investigated in the present study, BMI (bmival; kg/m^2), waist to hip ratio (whval; cm), systolic blood pressure (SBP) (omsysval; mmHg), diastolic blood pressure (omdiaval; mmHg), total cholesterol (Chol; mmol/l), TAG (Trig; mmol/l), HDL (mmol/l), low-LDL (mmol/l), glucose (Glucose; mmol/l), glycated Hb (A1C; µmol/l), C-reactive protein (mg/l) and homocysteine (Homocysteine; µmol/l). These measurements were chosen based on their relationship to CVD and glucose control.

Statistical analysis

All secondary data analysis was performed using the Statistical Package for the Social Sciences (version 23, IBM). Data are shown as means with standard deviation, or estimated marginal means (Wald 95 % CI). To examine the association between collection year and intakes of sugars in UK adults, a survey weighted generalised linear model with a scale link function was used. The analysis was performed on all participants and used total energy intake (Energykcal) and socio-economic status (WrkStat) as covariates. To examine the impact of consuming free sugars either above or below the UK recommendations of 5 % energy (30 g/d in adults), on health parameters (BMI, w/h ratio, SBP, diastolic blood pressure, plasma TAG, plasma total cholesterol, plasma HDL, plasma LDL, plasma glucose, plasma HbA1c, plasma C-reactive protein and plasma homocysteine), a generalised linear model was also used. For this, those that consumed either 0–29·97 g/d (below) or 31 g/d upwards (above) were used. During generalised linear model analysis, a number of covariates were used that could influence free sugar intakes, which include age (Age), sex, BMI groupings (bmivg5), total energy intake (Energykcal), number of days of physical activity (days) and socio-economic status (WrkStat). For the above analysis, effect sizes were calculated as eta-squared taken from comparison of means testing. A generalised linear model (GZLM) allows for variables that are not normally distributed and can analyse data from groups that are both balanced and unbalanced. To test the association between those variables that were significantly different between guidelines for intakes and free sugar intake, we used multiple linear regression, using free sugar intakes as the predictive variable and the same covariates as above. For the association between patterns of food choice and free sugars, we used predictors that explain either healthy food choices (wholemeal bread; WHOLEMEALBREAD, high fibre breakfast cereals; HIGHFIBREBREAKFASTCEREALS, nuts and seeds; NUTSANDSEEDS, fruit and vegetable portions; Fruitvegprotions; oily fish; OILYFISH) or unhealthy food choices (buns, cakes and pastries; BUNSCAKESPASTRIESFRUITPIES, burgers and kebabs; BURGERSANDKEBABS, chocolate confectionery; CHOCOLATECONFECTIONERY, butter; BUTTER) based on recommendations from the Eatwell Guide for the prevention of CVD in the UK (Public Health England[11]). The multiple regression models provide coefficients for each predictor that explains the unique variance of that predictor, and these were used in addition to the model itself. When performing linear regression analysis, we included outputs to test that the assumptions for linear regression were not violated. Linear relationships between variables and homoscedasticity were tested by scatterplots of standardised predictors *v.* standardised residuals, the approximate normal distribution of residuals was tested through a P–P plot, multicollinearity was checked through inspection of correlation coefficients and tolerance values being > 0·2. On most occasions, the dependent variables were found to be non-normally distributed. However as sample sizes increase, the normality assumption for the residuals is not needed, and hence, in a large sample size, the use of linear regression remains valid[12]. For all analysis, significance was accepted at the $P < 0·05$ level.

Results

Table 1 shows the final sample size and cumulative average intakes for carbohydrates, and types of sugar in 5121 UK adults. Compared with total carbohydrate intake (217·9 g/d, 48 % of energy), total sugars contributed 42 % of carbohydrate (20 % of energy), free sugars comprised 26 % (12·5 % of energy), sucrose comprised 18 % (9 % of energy) and fructose 7 % (3·5 % of energy).

The intakes of selected forms of sugar (total sugars, free sugars, sucrose and fructose) in UK male and female adults, adjusted for total energy and economic status, are shown across the NDNS rolling programme in Table 2 and Fig. 1. A similar pattern of intake was observed for total sugars, free sugars and sucrose, with a decrease in intake following 2013/2014 and were all significantly different over time ($P < 0·0001$). Fructose intake did not follow the same pattern as the other sugars and was only significantly different over time in females ($P = 0·048$). At every year

Table 1. Cumulative sugar intakes and nutritional parameters in UK adults from the NDNS rolling programme 2008–2017
(Mean values and standard deviations)

	All			Males			Females		
Variables	Mean	SD	% of energy	Mean	SD	% of energy	Mean	SD	% of energy
Age	42·5	12		41·0	13		42·1	12	
Sex (M/F)	5121			2112	41·5		3009	58·5	
BMI (kg/m^2)	27·5	5·5		27·37	4·8		27·12	5·9	
Total energy (kcal)	1801	582	100	2105	605	100	1613	466	100
Fat (g/d)	67·0	27	33·5	77·2	28	33·0	60·6	23	33·8
Protein (g/d)	73·1	25	16·2	85·7	29	16·3	65·6	19	16·3
Carbohydrate (g/d)	217	73	48·3	252·2	77	47·8	197·6	63	49·0
Total sugars (g/d)	91·8	44	20·4	105·1	49	19·9	84·9	40	21·0
Free sugars (g/d)	56·5	39	12·5	68·3	44	12·9	50·1	36	12·4
Sucrose (g/d)	40·5	25	8·9	45·6	28	8·6	38·3	23	9·49
Fructose (g/d)	15·6	10	3·5	17·4	11	3·3	15·6	10	3·8

All values shown are unadjusted.

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Table 2. Sugar intakes in UK adults across the NDNS rolling programme. Values shown are estimated marginal means (95 % Wald CI) with their % contribution to total energy

	Year of data collection															
	2008/2009			2009/2010			2010/2011			2011/2012			2012/2013			
Variables	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	*P**
N (M/F)	622	260/362		615	266/349		614	275/339		795	304/491		462	182/280		
Total sugars (g/d)	97·5	20	94·7, 100·2	99·2	21	96·3, 102·1	91·9	20	89·0, 94·8	93·6	20	90·8, 96·5	97·7	21	94·5, 100·8	<0·0001*
M	108·8	20	104·6, 113·1	108·5	20	104·3, 112·7	101·3	20	97·1, 105·5	105·6	20	101·2, 110·0	107·8	20	103·2, 112·5	<0·0001*
F	86·6	21	83·1, 89·9	89·2	22	85·5, 92·8	81·4	21	77·7, 85·1	82·6	21	79·1, 86·1	86·9	22	82·9, 90·9	0·005*
Free sugars (g/d)	60·8	13	58·4, 63·3	63·6	13	61·0, 66·1	58·1	13	55·5, 60·6	59·2	13	56·6, 61·7	59·9	13	57·1, 62·7	<0·0001*
M	69·9	13	66·1, 73·6	72·9	14	69·2, 76·7	67·3	13	63·6, 71·0	70·5	13	66·6, 74·4	69·5	13	65·3, 73·6	<0·0001*
F	52·2	13	49·1, 55·3	53·5	13	50·2, 56·7	47·7	12	44·4, 50·9	48·7	12	45·6, 51·9	49·8	12	46·3, 53·4	0·071
Sucrose (g/d)	42·1	9	40·5, 43·7	45·2	10	43·6, 46·9	41·5	9	39·9, 43·2	41·9	9	40·3, 43·6	43·5	9	41·7, 45·3	<0·0001*
M	45·3	8	42·9, 47·8	48·9	9	46·5, 51·4	45·1	9	42·6, 47·5	47·2	9	44·7, 49·8	47·0	9	44·3, 49·7	<0·0001*
F	39·0	10	37·0, 41·0	41·3	10	39·1, 43·4	37·6	10	35·4, 39·8	37·1	9	35·1, 39·2	39·8	10	37·4, 42·1	0·032*
Fructose (g/d)	16·9	4	16·2, 17·5	16·7	4	16·0, 17·4	16·0	4	15·3, 16·7	15·8	3	15·1, 16·4	16·4	4	15·6, 17·1	0·058
M	17·9	3	16·9, 18·9	17·4	3	16·4, 18·4	16·9	3	15·9, 17·9	16·6	3	15·6, 17·7	17·2	3	16·1, 18·3	0·462
F	15·9	4	15·0, 16·7	15·9	4	14·9, 16·8	14·9	4	14·0, 15·8	14·9	4	14·1, 15·8	15·5	4	14·5, 16·5	0·048*

	Year of data collection												
	2013/2014			2014/2015			2015/2016			2016/2017			
Variables	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	Marginal means	% contribution to total energy	95 % Wald CI	*P**
N (M/F)	487	183/304		509	230/279		550	210/340		467	202/265		
Total sugars (g/d)	98·9	21	95·5, 102·4	93·6	20	90·5, 96·8	95·1	21	91·8, 98·3	89·1	19	85·7, 92·5	<0·0001*
M	112·1	21	106·9, 117·2	99·2	19	94·7, 103·8	103·5	20	98·5, 108·5	99·1	19	94·1, 104·2	<0·0001*
F	85·5	22	81·1, 89·8	86·8	21	82·6, 90·9	87·5	22	83·5, 91·4	79·1	20	74·9, 83·3	0·005*
Free sugars (g/d)	64·5	14	61·4, 67·6	56·8	12	54·0, 59·7	57·7	13	54·8, 60·6	52·7	12	49·7, 55·8	<0·0001*
M	76·7	15	72·2, 81·3	61·3	12	57·3, 65·4	66·1	13	61·7, 70·5	59·4	11	54·9, 63·9	<0·0001*
F	51·9	13	48·1, 55·8	51·4	12	47·6, 55·1	50·0	12	46·5, 53·5	46·0	12	42·3, 49·8	0·071
Sucrose (g/d)	43·8	10	41·8, 45·7	39·9	8	38·1, 41·8	40·6	9	38·8, 42·5	39·4	9	37·4, 41·3	<0·0001*
M	49·4	9	46·4, 52·4	40·7	8	38·1, 43·3	43·0	8	40·2, 45·9	43·4	8	40·5, 46·4	<0·0001*
F	37·9	10	35·4, 40·5	39·0	9	36·6, 41·5	38·4	10	36·1, 40·8	35·3	9	32·8, 37·8	0·032*
Fructose (g/d)	16·6	4	15·8, 17·4	17·2	4	16·5, 17·9	17·2	4	16·4, 17·9	16·4	4	15·5, 17·1	0·058
M	17·7	3	16·4, 18·9	18·4	4	17·3, 19·5	17·2	3	16·0, 18·4	17·4	3	16·2, 18·6	0·462
F	15·5	4	14·4, 16·6	15·8	4	14·7, 16·8	17·2	4	16·2, 18·2	15·3	4	14·2, 16·3	0·048*

All values shown are adjusted for total energy intake (kcal) and socio-economic status.
* Significant difference in intakes over time. There was a significant difference between males and females for all sugars and all years apart from fructose in 2015/2016.

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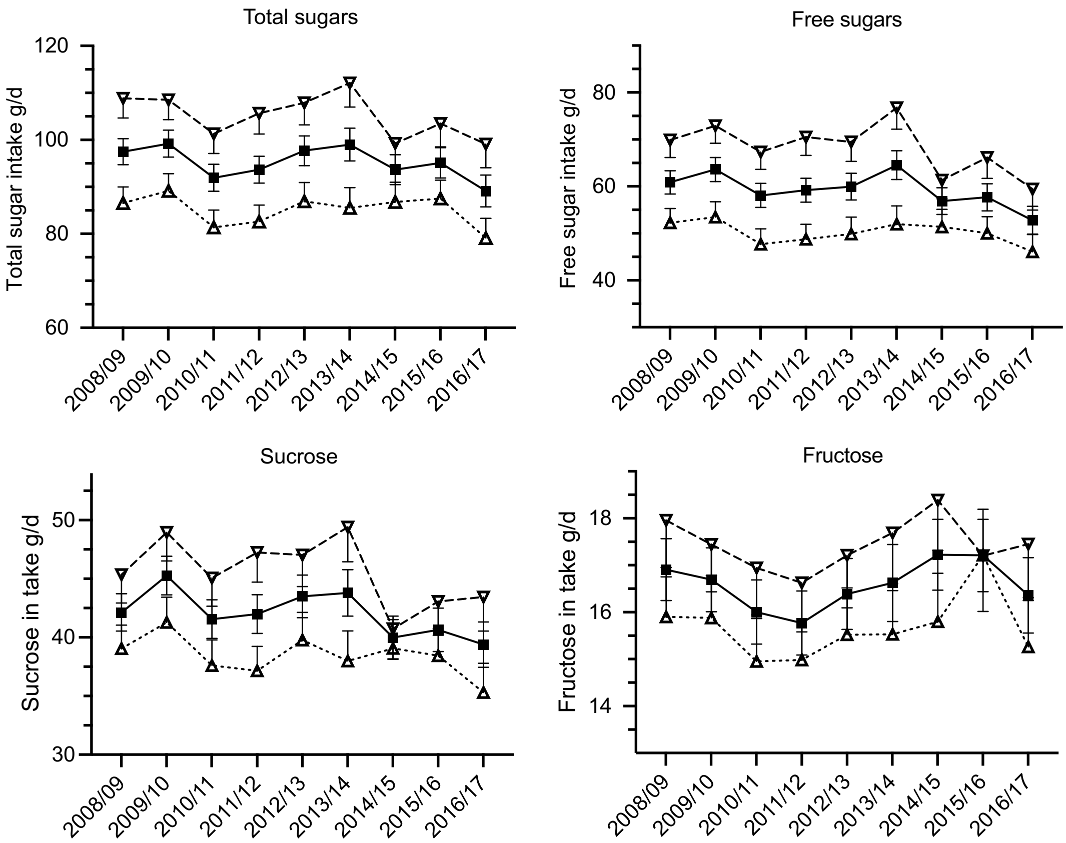

Fig. 1. The intakes of various types of sugars in the UK population. Values shown are estimated marginal means with upper and lower Wald confidence intervals (95 %). In all sugars, there was a significant difference between males and females ($P < 0{\cdot}001$) and in all sugars except fructose there was a significant difference over time ($P < 0{\cdot}001$). –■–, all; –▽–, males; -△-, females

of collection (apart from 2014/2015 for sucrose and 2015/2016 for fructose), there was a significant difference between males and females ($P < 0{\cdot}0001$) with males consuming more of the types of sugar than females although the patterns of intake were similar between sexes. When sugars intakes are shown as % of energy, free sugar intakes were at their highest point at 2013/2014 at 14 % (15 % in males), and were at 12 % in 2017 but have not displayed much change over the course of the NDNS rolling programme (2009–2017).

We then investigated the association between consuming either above or below the current UK recommendations for free sugars (5 % of energy or 30 g/d for adults) on selected health parameters, and these data are shown in Table 3. The mean free sugar intakes for these two groups were: for the below recommendations group, 19 (SD 7) for all respondents, 19(SD 8) for males and 19 (SD) 7 for females; for the above recommendations group, 73(SD 40) for all respondents, 79 (SD 41) for males and 65 (SD 35) for females. With all respondents, there was a 2·8-fold higher number of adults that consumed above than below the recommendations, and this ratio was higher in males at 4·5 but lower in females at 2·1. Consuming above the recommendations was associated with significantly lower BMI ($P < 0{\cdot}001$), significantly lower glucose concentrations and HbA1c values ($P < 0{\cdot}001$) in all respondents. Furthermore, all respondents showed significantly higher TAG concentrations ($P < 0{\cdot}001$), significantly higher homocysteine concentrations ($P = 0{\cdot}028$) but significantly lower HDL concentrations ($P = 0{\cdot}006$). Typically, males and females followed a similar pattern in response, but significant sex differences were also observed; males had significantly higher total ($P = 0{\cdot}001$) and LDL cholesterol ($P = 0{\cdot}002$) and a trend for lower HDL cholesterol ($P = 0{\cdot}073$), females had significantly lower SBP ($P = 0{\cdot}011$) and males and females had different patterns for homocysteine concentration. Even though significant differences were observed, effect sizes were relatively small and the largest effect was found with w/h ratio in males and females at 0·01–0·016 but only 0·004 for TAG concentration. Selected data are further highlighted in Fig. 2.

We also wanted to establish any dietary patterns with those that consumed above or below 5 % energy as free sugars and these data are shown in Table 4. Of the selected nutrients and food groups of interest, there was a significant higher intake of fruit, nuts and seeds and oily fish ($P < 0{\cdot}0001$) in those consuming below the recommendations. Total vegetables, 5-a-day portions and wholemeal bread were similar between the groups, while all other nutrients and foods were significantly higher in those adults consuming above the recommendations ($P < 0{\cdot}0001$). Effect sizes were larger for energy and macronutrients, the largest effect being with the difference in carbohydrate intake (0·216), and for food choices the largest effect was found with soft drink (not low energy) consumption (0·066).

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Table 3. The association between consuming the UK recommendations for free sugars (5 % of energy) and health parameters in the UK adult population. Values shown are estimated marginal means (95 % Wald CI) and effect size

	Below 5 % (<30 g/d)						Above 5 % (> 30 g/d)											
	All *n* 1328		Male *n* 381		Female *n* 947		All *n* 3726		Male *n* 1709		Female *n* 2016		All		Males		Females	
	Marginal means	95 % Wald CI	Marginal means	95 % Wald CI	Marginal means	95 % Wald CI	Marginal means	95 % Wald CI	Marginal means	95 % Wald CI	Marginal means	95 % Wald CI	*P*	Eta-squared	*P*	Eta-squared	*P*	Eta-squared
Free sugar intake (g)	35·3	33·8, 36·7	39·5	36·8, 42·1	29·8	28·1, 31·4	67·8	67·0, 68·6	74·9	73·8, 76·1	60·2	59·2, 61·3	<0·001*	0·157	<0·001*	0·130	<0·001*	0·159
BMI (kg/m^2)	28·05	27·8, 28·3	28·31	27·9, 28·7	27·91	27·5, 28·2	26·99	26·8, 27·1	27·15	26·9, 27·3	26·79	26·5, 27·0	<0·001*	0·007	<0·001*	0·0080	<0·001*	0·007
w/h ratio	0·868	0·86, 0·87	0·932	0·92, 0·94	0·833	0·83, 0·84	0·868	0·86, 0·87	0·910	0·90, 0·91	0·813	0·81, 0·82	0·982	0	<0·001*	0·01	<0·001*	0·016
SBP (mmHg)	122·9	122·0, 123·8	127·9	126·6, 129·3	120·2	119·0, 121·4	123·4	122·9, 123·9	127·3	126·7, 127·9	118·4	117·6, 119·2	0·390	0	0·441	0	0·011*	0·004
DBP (mmHg)	74·2	73·5, 74·8	75·2	74·1, 76·3	73·6	72·8, 74·4	73·7	73·3, 74·0	74·3	73·8, 74·8	72·8	72·3, 73·4	0·194	0·001	0·156	0·001	0·123	0·002
TAG (mmol/l)	1·14	1·08, 1·21	1·34	1·20, 1·48	1·06	0·99, 1·11	1·30	1·26, 1·33	1·47	1·42, 1·53	1·08	1·04, 1·12	<0·001*	0·004	0·080	0·003	0·437	0
Total cholesterol (mmol/l)	4·96	4·88, 5·05	4·65	4·51, 4·80	5·10	5·00, 5·21	5·01	4·97, 5·06	4·97	4·92, 5·03	5·07	5·00, 5·14	0·266	0	<0·001*	0·010	0·590	0
LDL-cholesterol (mmol/l)	3·00	2·93, 3·07	2·85	2·72, 2·97	3·07	2·98, 3·16	3·05	3·01, 3·08	3·06	3·01, 3·11	3·03	2·97, 3·09	0·290	0	0·002*	0·005	0·451	0
HDL-cholesterol (mmol/l)	1·46	1·43, 1·50	1·23	1·18, 1·28	1·57	1·53, 1·61	1·41	1·39, 1·43	1·28	1·26, 1·30	1·57	1·54, 1·59	0·006*	0·002	0·073	0·002	0·977	0
Glucose (mmol/l)	5·43	5·33, 5·52	5·72	5·55, 5·89	5·29	5·18, 5·41	5·18	5·13, 5·23	5·31	5·24, 5·38	5·02	4·95, 5·09	<0·001*	0·008	<0·001*	0·009	<0·001*	0·018
HbA1c (%	5·61	5·55, 5·66	5·66	5·56, 5·75	5·58	5·52, 5·65	5·46	5·43, 5·49	5·50	5·46, 5·54	5·42	5·38, 5·46	<0·001*	0·007	0·002*	0·005	<0·001*	0·015
CRP (mg/l)	3·04	2·69, 3·38	2·58	2·09, 3·06	3·25	2·76, 3·74	3·04	2·86, 3·22	2·72	2·53, 2·91	3·44	3·12, 3·76	0·991	0	0·592	0	0·531	0
Homocysteine (μmol/l)	9·16	8·71, 9·62	9·61	8·55, 10·68	9·03	8·62, 9·43	9·73	9·51, 9·95	10·40	10·06, 10·73	8·87	8·61, 9·13	0·028*	0·003	0·168	0·003	0·526	0

All values shown are adjusted for age, energy intake, BMI, socio-economic status and physical activity.
* Significant difference between intakes above or below the UK recommendations for free sugars of 5 % energy (30 g/d for adults).

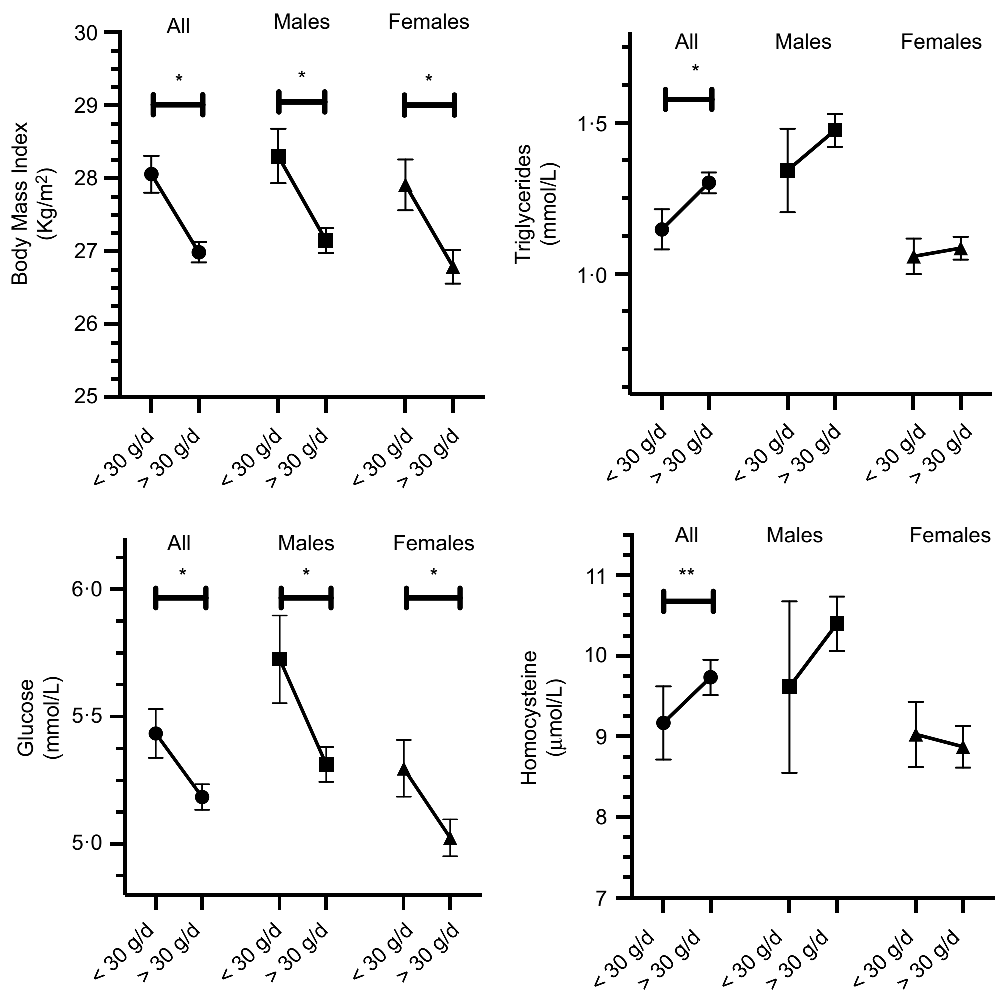

Fig. 2. The association between consuming above or below the current UK guidelines for free sugar intakes on selected health parameters in the UK population. Values shown are estimated marginal means with upper and lower Wald confidence intervals (95 %).

Table 4. The association between consuming the UK recommendations for free sugars (5 % of energy) and selected nutrients and food sources in the UK adult population. Values shown are estimated marginal means (95% Wald CI) and effect size

	Below 5 % (<30 g/d)		Above 5 % (> 30 g/d)			
Nutrient/food group (g)	Marginal means	95% Wald CI	Marginal means	95% Wald CI	*P*	Eta-squared
Food energy (kcal)	1360	1336, 1383	1907	1894, 1929	<0·0001*	0·179
Protein	68·07	66·8, 69·3	78·45	77·7, 79·1	<0·0001*	0·030
Fat	52·97	51·7, 54·2	74·49	73·8, 75·1	<0·0001*	0·116
Carbohydrates	162·9	159·7, 166·1	246·1	244·3, 247·8	<0·0001*	0·216
Saturated fat	18·49	17·9, 18·9	27·54	27·2, 27·8	<0·0001*	0·120
Alcohol	7·77	6·7, 8·8	14·85	14·3, 15·4	<0·0001*	0·017
5-a-day portions (p/d)	4·18	4·07, 4·29	4·07	4·01, 4·13	0·092	0
Fruit	106·4	101·4, 111·4	92·4	89·6, 95·1	<0·0001*	0·004
Total vegetables	162·7	157·4, 168·0	159·6	156·6, 162·5	0·319	0
AOAC fibre	17·43	17·1, 17·8	19·23	19·0, 19·4	<0·0001*	0·012
Nuts and seeds	6·04	5·2, 6·8	3·88	3·4, 4·3	<0·0001*	0·002
Wholemeal bread	16·81	15·3, 18·3	15·77	14·9, 16·6	0·237	0
Sugar confectionery	0·47	0·07, 0·87	2·61	2·38, 2·83	<0·0001*	0·011
Soft drinks not low energy	17·94	6·5, 29·4	171·06	164·7, 177·4	<0·0001*	0·066
Oily fish	13·32	12·0, 14·6	9·81	9·1, 10·5	<0·0001*	0·005

All values shown are adjusted for age, sex, energy intake, BMI, socio-economic status and physical activity.
* Significant difference between intakes above or below the UK recommendations for free sugars of 5 % energy.

Table 5. The association between selected health parameters and free sugar intake in UK adults

Health parameter	R	Adj R^2	F	β	P
BMI	0·927	0·859	7738	0·005	0·369
Males	0919	0·844	4155	0·018	0·034*
Females	0·934	0·871	5161	−0·009	0·249
SBP	0·475	0·225	226	0·001	0·839
Males	0·344	0·116	62	0·009	0·252
Females	0·455	0·205	122	−0·015	0·176
TAG	0·352	0·124	72	0·128	<0·0001*
Males	0·279	0·075	25	0·139	<0·0001*
Females	0·324	0·102	36	0·118	<0·0001*
HDL	0·478	0·227	149	−0·082	<0·0001*
Males	0·335	0·109	37	−0·079	0·011*
Females	0·387	0·147	54	−0·100	0·001*
Glucose	0·275	0·074	39	−0·011	0·625
Males	0·254	0·061	19	0·029	0·377
Females	0·258	0·064	20	−0·066	0·043*
HbA1c	0·283	0·078	42	−0·041	0·073
Males	0·289	0·080	27	−0·047	0·140
Females	0·279	0·074	24	−0·045	0·164
Homocysteine	0·232	0·051	17	0·114	<0·0001*
Males	0·157	0·019	4	0·131	0·001*
Females	0·206	0·037	8	0·077	0·065

All values shown are adjusted for age, energy intake, BMI, socio-economic status and physical activity.
* Significant linear regression model.

To further understand an association between free sugar intakes and selected health parameters in UK adults, regression models were applied to test if free sugar intake could be predictive of those parameters that were significantly different between adults that consumed above *v.* below free sugar recommendations, that is, BMI, SBP, TAG, HDL-cholesterol, glucose, HbA1c and homocysteine concentrations (Table 5). Regression models were adjusted for age, total energy intake, BMI and socio-economic status as these factors could confound both the predictor and independent variables. The regression analysis demonstrated that free sugar intake was a highly significant predictor of TAG, HDL-cholesterol and homocysteine ($P = 0·0001$). There were also sex differences in that free sugar intakes were significant predictors of BMI ($P = 0·034$) and homocysteine ($P = 0·001$) in males, but glucose ($P = 0·043$) in females. β Values give an indication of the effect size and show that the free sugar intakes are responsible for a considerable amount of change in the endpoints, for example, a 1 g increase in free sugar intake is associated with a 0·11 μmol and 0·13 mmol change in homocysteine and TAG concentrations, respectively.

Finally, we looked at if either healthy or unhealthy food choices could be used to predict free sugar intake. Data were analysed using multiple linear regression with examples of both healthy and unhealthy food choices used as predictor variables (Table 6). Interestingly, all the examples of food choices were significant at explaining the variation in free sugar intakes, although the healthy food choices had negative β values thus a negative association. Overall, the unhealthy food choices could explain higher percentages of the variance in free sugar intakes, with the highest amount of variation from soft drinks not low energy with a high β value of 0·75. Within the healthy food choices, the most significant predictor was fruit and vegetables but with a negative β of −0·31.

Discussion

The intakes of free sugars have been a major health concern for a number of years with evidence supporting the association between free sugars, weight gain, adiposity and CVD, and such data prompted a review of the dietary guidelines in the UK[2]. The result of this review was that free sugars should contribute no more than 5 % of dietary energy, equivalent to approximately 30 g/d in adults. Furthermore, it has been shown that the intake of certain foods and beverages, such as carbonated soft drinks, containing a high content of free sugars also shows an association with negative health parameters[8,13]. With this in mind, it was of interest to examine free sugar intakes in the UK population to identify any associations between free sugar intakes and health parameters.

We show here that the intakes of all forms of sugars did not show much of a trend from 2008 to 2013, but all forms except fructose showed a significant decrease from 2013 to 2014 and this decrease was mainly driven by a decrease in males more than females. The intakes of all forms of sugar were significantly higher in males, as has been observed previously in the UK[14] and in other parts of Europe[15], and reached a maximum in 2013/2014. Overall, a similar pattern was observed between total sugars, free sugars and sucrose, which lack any real trend in the data, but fructose intakes followed a different pattern and presumably this reflects the different sources for the individual types of sugars as the data obtained are from total dietary intake, although the full reason is unknown. The sex differences in macronutrient intakes are well known[14–16], and again presumably reflective of dietary intake but males appear to compensate differently following energetic beverages[17].

Overall, the average % of energy for free sugars was 12·5 %, much higher than the revised recommendations of 5 %, even though this had decreased slightly to 12 % in 2017. In response to the recommendation by Scientific Advisory Committee on Nutrition, the UK government in 2016 introduced a sugar levy to limit the amount of free sugars used by the food industry in food and beverages to be enforced by law in 2018[18,19]. This levy represents a charge of 24p on drinks containing 8 g of sugar per 100 ml and 18p a litre on those with 5–8 g of sugar per 100 ml, and is aimed at a reduction in free sugar consumption by 20 % by 2020. A levy on SSB is expected to deliver body weight benefits at a population level and across socio-economic status[20], and this initiative is similar to public health initiatives in high- and middle-income countries including USA[21], Spain[22] and Mexico[23]. Such taxes have been successful in reducing the intake of sugar-sweetened products[24]. In Mexico, for example, the levy has increased the cost of SSB by 15 % with a decline in intake between 4 and 12 %[25]. Recent data from the UK suggest that intakes per household have fallen by 10 % since the introduction of the sugar levy[6]. Interestingly, intakes of the individual sugars used as sweeteners by the food industry, sucrose and fructose, do not follow the same trend. For example, there were no major fluctuations in fructose intake over the whole course of the rolling programme (Table 2, Fig. 1). This suggests that sucrose intakes are more reflective of free sugar intakes than fructose, whereas fructose intakes may be more reflective of dietary sources such as fruits.

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Table 6. The association between markers of healthy and unhealthy food choices according to Eatwell Guide UK[11] and free sugar intakes in UK adults

Healthy choices						Unhealthy choices					
Food group (g)	*R*	Adj R^2	*F*	*β*	*P*	Food group (g)	*R*	Adj R^2	*F*	*β*	*P*
Wholemeal bread	0·212	0·044	60	–0·166	<0·0001	Buns, cakes, pastries	0·334	0·111	159	0·059	<0·0001
High fibre breakfast cereals	0·223	0·049	66	–0·197	<0·0001	Burgers, kebabs	0·214	0·045	61	0·061	<0·0001
Nuts and seeds	0·192	0·036	48	–0·164	<0·0001	Sugar confectionery	0·387	0·149	224	0·257	<0·0001
Fruit and vegetables	0·382	0·145	216	–0·309	<0·0001	Butter	0·219	0·047	64	–0·069	<0·0001
Oily fish	0·199	0·039	52	–0·184	<0·0001	Soft drinks not low energy	0·690	0·470	1139	0·751	<0·0001

All values shown are adjusted for age, sex, energy intake, BMI, socio-economic status and physical activity, *P* for coefficients shown. All linear regression models were significant.

The association of sugar intake with health parameters has been the subject of several recent reviews and meta-analyses[2,26,27], and therefore, the association between free sugar intakes with parameters of health available was investigated. We used the updated UK dietary guidelines of 5 % energy (30 g/d for adults) to examine this association, comparing those adults that consume either above or below these recommendations. We show here that adults that consume higher than the recommendations have significantly higher plasma concentrations of TAG and homocysteine yet significantly lower plasma concentrations of HDL, glucose, HbA1c and lower BMI and SBP than those adults that consume lower than the recommendations, and that free sugar intakes are significant predictors of plasma TAG, HDL and homocysteine concentrations. A large amount of evidence suggests that sugar consumption is associated with excess energy and may predispose to weight gain and adiposity[8,13]. However, two meta-analyses of randomised controlled intervention trials with sucrose[28] or fructose[29] did not show a significant association with body weight. In the current investigation, free sugar intakes were associated with parameters of body composition and interestingly all adults that consumed higher than the recommendations had significantly lower BMI and the effect size was relatively large, and this appears to be the first observation of such an association. In support of this, the w/h ratio was also significantly decreased in males and females especially. A waist to hip ratio is more reflective of abdominal or visceral fat; however, Stanhope *et al.*[30] have previously reported that fructose but not glucose supplementation at 25 % of energy content for a 10-week period increased visceral abdominal fat[30]. The findings here highlight again that any association between free sugars intakes on weight gain cannot be delineated from an overall effect on energy intake; indeed regression analysis clearly showed that free sugar intakes were not a predictor of BMI, even though effect sizes were large. It is important to remember that as the NDNS is cross-sectional there are no measurements of weight changes which need to be considered alongside other studies.

Weight gain is typically associated with dyslipidaemia and increased levels of plasma TAG and cholesterol[31], supporting our findings here although we observed this in males predominantly. Free sugar and sucrose intake has been associated with lipid status in some intervention studies[32], but in others where there was no weight gain there was no association with plasma lipid status[33]. Fructose is diverted to *de novo* lipogenesis and an increase in VLDL, so it is easy to see why an association between free sugar intake and lipid exists. We found a highly significant association between free sugar intake and plasma TAG concentration; TAG concentrations were significantly higher in those individuals that consumed above the recommendations (Table 3) and free sugars were found to be a highly significant predictor. Interestingly, these effects were predominantly observed in males. Often, increased TAG concentrations are associated with lower HDL-levels; indeed, we also found here significantly lower HDL-cholesterol in those consuming above the recommendations and again as with TAG this was mainly observed in males.

We found significantly higher homocysteine levels within individuals who consumed above the recommendations for free sugars (Table 3), although the effect size was small. Homocysteine is a known risk factor for CVD mainly due to its role in endothelial injury[34], and is known to be modifiable through exposure to dietary factors[35]. Macronutrients, including carbohydrates, are of huge importance in influencing homocysteine levels[36,37] and one potential mechanism is through elevated insulin and glucose that increases homocysteine concentrations via re-methylation[38]. Alternatively, we found that those consuming higher intakes of free sugars had lower intakes of fruit and nuts and seeds which are known to contain homocysteine-lowering nutrients such as folate[39]. Interestingly, our data for homocysteine between sex appear to follow the same pattern as those for TAG, and this is a known association[40]. The decrease in plasma glucose within individuals who consumed above the recommendations may seem a peculiar observation, but other studies have found that fructose intakes (in an isoenergetic replacement for glucose/sucrose) significantly lower postprandial blood glucose[41], and free sugars are a major source of dietary fructose. Supporting this finding we also found significantly lower HbA1c in those consuming above the recommendations, and both these results had relatively large effect sizes especially in females. There was also a difference between sexes with lower concentrations of glucose in females compared with males, as previously recognised[42] and is supported by our finding that free sugars were predictive of glucose in females only (Table 5). Differences between sexes have been quite apparent throughout our analysis. It is commonly recognised that there are differences in macronutrient metabolism between males and females[43,44] and this may be enough to impact on the health parameters as seen within this study.

We found a limited association between free sugar intakes with blood pressure in the present study. There are several studies that indicate a relationship between sugar intake and blood pressure[45,46] but this area is controversial. In a preliminary study, we found that sucrose intakes of 120 g/d for 1 week significantly raised SBP[47], whereas in the current cross-sectional study SBP was significantly lower in females consuming above the recommendations for free sugar intakes. The large epidemiological study, Framingham Heart Study, reported an association with consuming > 1 SSB on high blood pressure[46], whereas randomised controlled trials (RCT) have not shown any association. For example, the consumption of amounts of fructose containing sugars at the 50 % CI for 10 weeks had no effect on either systolic or diastolic blood pressure[48,49].

The nutritional profiles of those respondents that consumed either above or below the recommendations for free sugars were significantly different (Table 4). Those that consumed above the recommendations consumed significantly higher intakes of energy and macronutrients, as well as other food choices and nutrients more reflective of an unhealthy eating pattern, as suggested by Public Health England for the prevention of CVD[11,50]. These nutrients and foods include those such as saturated fat, alcohol, confectionery and soft drinks (not low energy). However, those that consumed below the recommendations tended towards healthy eating options such as fruit, nuts and seeds, which was also reflected in our regression models (Table 6). We found all selected food choices to be significant predictors of free sugar intake, including soft drinks (not low energy) and sugar confectionery. This was unsurprising given that soft drinks such as SSB and fruit juices provided a third of free sugar intakes in adults[2]. The most frequently consumed sources of free sugars in the UK are similar to those in other European countries[14,15], including 'cereals and cereal products, 'non-alcoholic beverages' and 'sugars, preserves, confectionery'[14]. As ultra-processed foods are major sources of free sugars in the UK[14,51], the elimination of such foods is predicted to provide substantial health benefits[51]. Recent data suggest that, following introduction of the sugar levy, the purchase of soft drinks has not changed, but the amount of free sugar consumed has decreased by approx. 30 g or 10 % per household per week[6].

Our study is a secondary analysis of the NDNS rolling programme and limitations do exist. The data are not longitudinal and represent a single observation of dietary intakes and health parameters from each participant at each given year, and this could explain weaker associations with health parameters that are more representative of transient outcomes. Furthermore, 4-d food diaries were used for dietary recall and these are more applicable to recent intake rather than usual intake. There are known issues with underreporting of dietary information, and especially regarding sex and energy and macronutrient intake[52,53], and these need to be taken into consideration.

In summary, we have shown that the intakes of free sugars in the UK population fluctuate and are currently decreasing, but this cannot yet be explained by the UK sugar levy as that was only introduced in 2016 and not enforced until 2018. We did find significant associations with established risk factors for CVD (TAG, HDL and homocysteine) and free sugar intake was found to be significant predictor of plasma levels of these. In the last year of the NDNS rolling programme (2017), free sugars accounted for 12 % of energy, so there is a long way to go to reach the updated recommendations of 5 % of energy.

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On behalf of all authors, the corresponding author states that there is no conflict of interest.

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