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Keywords:	Food processing, Ultra-processed, Free sugar, United Kingdom

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study

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ABSTRACT

Objectives: to describe dietary sources of free sugars in different age groups of the UK population and to estimate the proportion of excessive free sugars that could potentially be avoided by reducing consumption of their main sources.

Design and setting: Cross-sectional data from the UK National Diet and Nutrition Survey (2008–14) were analysed. Food items collected using a four-day food diary were classified according to the NOVA system.

Participants: 9,364 individuals aged 1.5 years and above.

Main outcome measures: Average dietary content of free sugars and proportion of individuals consuming more than 10% of total energy from free sugars.

Data analysis: Poisson regression was used to estimate the associations between each of the NOVA food group and intake of free sugars. We also estimated population attributable fraction for excessive free sugar intake associated with consumption of ultra-processed foods and table sugar. Analyses were stratified by age group and adjusted for age, sex, ethnicity, region, and equivalised household income (sterling pounds).

Results: Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Free sugars represent 12.4% of total energy intake and 61.3% of the sample exceeded the recommended limit of 10% energy from free sugars. This percentage was higher among children (74.9%) and adolescents (82.9%). Excessive free sugar intake increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly. We estimated that 47% of excessive free sugars intake in the UK population could be avoided if the consumption of ultra-processed foods was eliminated.

Conclusion: Our findings suggest that actions to reduce the ultra-processed food consumption generally rich in free sugars could lead to substantial public health benefits.

Keywords: Food processing; Ultra-processed; Free sugar; United Kingdom.

ARTICLE SUMMARY

Strengths and limitations of this study

- Use of a large and nationally representative sample of the UK population, increasing generalisability.
- Use of data on free sugars rather than total sugars or sugar-sweetened beverages, which correspond to the guidelines relevant area of prioritisation.
- Use of NOVA system, which has been recognised as a valid tool for public health and nutrition research and policy by international organizations.
- Dietary data obtained by food diaries are subject to potential error and bias.
- NDNS collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items.

INTRODUCTION

Excessive consumption of free sugar is associated with obesity, type 2 diabetes, dental caries, and several other health outcomes [1-4]. To address this associated health burden, the World Health Organization (WHO) [5] recommends that free sugars should be reduced to less than 10% of total energy intake and also suggests a level below 5% to obtain additional health benefits. Achievement of this ambitious target will require bold and systematic efforts to reduce sugar across a variety of food products in most settings.

As defined by the NOVA food classification system, ultra-processed foods are industrial formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed) [6]. In some high-income countries, including the UK, ultra-processed foods account for more than half of total dietary energy intake [7-9]. Importantly, national dietary surveys conducted in high- and middle-income countries [8-12] have shown a strong and positive association between consumption of ultra-processed foods and excessive dietary added (or free) sugar intake.

Free sugar intake in the UK is high, ranging from 11 to 15% of total energy intake [13]. To address this, the UK has implemented a number of measures including a sugar-sweetened beverage levy in 2018. However, action on sugar sweetened beverages alone is unlikely to reduce population level sugar intake to WHO recommended levels. In a more recent publication, the voluntary sugar reduction programme continues being endorsed by the government, but other measures such as restriction of advertising and in-store promotions of some sugary foods are also being considered as strategies to reduce childhood obesity [14]. A better understanding of the key sources of sugar intake in the UK diet is required to inform policy development. In this study, we describe the dietary sources of free sugars in different age groups of the UK population taking into account food groups classified according to the NOVA classification system and estimated the proportion of excessive free sugars that could be potentially avoided by reducing the consumption of their main dietary sources.

METHODS

Data source and collection

We used data from the National Diet and Nutrition Survey Rolling Programme (NDNS) years 1-6 (2008/09-2009/10, 2010/11-2011/12, 2012/13-2013/14) combined, which is a cross-sectional survey of people aged 1.5 years or older. The survey was designed to be representative of the UK population and provides comprehensive information on food intake. Details of the rationale, design, and methods of the survey have been described in detail elsewhere [15]. Briefly, the sample was drawn from households randomly selected from the UK Postcode Address File, a list of all UK addresses. One adult (aged 19 years and older) and one child (aged 1.5–18 years), if available, were randomly selected from each household. Only a child was selected from some households to be part of a 'child boost' to ensure approximately equal numbers of children and adults. Participants (or in the case of children ≤11 years, their parent/carer) completed a four-day food diary and participated in an interview that included data on socio-demographic status.

Participants were asked to report all foods and drinks consumed both within and outside the home. Portion sizes were estimated using household measures or weights from packaging. Once completed, diaries were checked by interviewers with respondents and missing details added to improve completeness. Diary days were randomly selected to ensure balanced representation of all days of the week. All individuals who completed three or four days of dietary recording were eligible for inclusion in the study, giving a sample size of 9,374 (4,738 adults and 4,636 children) participants for years 1 to 6 (2008/09 to 2013/14) combined.

The food intake data from completed records were coded and edited using the software DINO (Diet In, Nutrients Out) and food and nutrient intakes estimated using nutrient composition data from the Department of Health's Nutrient Databank, updated for each survey year [16, 17]. Free sugars are defined as sugars added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups, fruit juices and fruit concentrates [5]. Intakes in the UK NDNS are currently expressed as non-milk extrinsic sugars (NMES). The term NMES captures all the sugars defined by the term free sugars while also including half of the sugars present in dried, stewed or canned fruit. Based on the assumption that those definitions are sufficiently similar for assessment and monitoring purposes [1,3], this study used the term free sugars.

Computerized raw data files and documentation from this survey were obtained under license from the UK Data Archive (http://www.esds.ac.uk). All relevant research ethics and governance committees approved the survey.

Food classification according to processing

We classified all recorded food items according to NOVA, a food classification system based on the nature, extent, and purpose of the industrial food processing [6]. This classification includes four groups: 1) unprocessed or minimally processed foods (e.g. fresh, dry or frozen fruits or vegetables; grains, flours and pasta; pasteurized or power plain milk, plain yogurt, fresh or frozen meat); 2) processed culinary ingredients (e.g. table sugar, oils, butter, and salt); 3) processed foods (e.g. vegetables in brine, cheese, simple breads, fruits in syrup, canned fish); and 4) ultra-processed foods (e.g. soft drinks, sweet or savoury packaged snacks, confectionery; packaged breads and buns; reconstituted meat products and pre-prepared frozen or shelf-stable dishes) (**see Suppl. Table S1**). The detailed description of NOVA classification can be found elsewhere [6, 18].

All foods in NDNS are coded as food number and grouped into subsidiary food groups (n = 155). When possible, subsidiary food groups were directly classified according to NOVA (**see Suppl. Table S2**). When foods within a subsidiary food group pertained to different NOVA groups (n = 52), it was the food codes instead of the group, which were individually classified. By doing so, we were able to classify each underlying ingredient of homemade dishes in its corresponding NOVA group.

Although most food items in NDNS were systematically disaggregated into their individual components, about 4% of composite food codes were still mixed dishes compiled from two or more single-ingredient food codes [19]. Using the core sample of years 1 to 4 (2008/09 to 2011/12) (n = 4,125), we estimated that these represented only 3% of total calories. In this case, dishes were categorised according to the main constituent ingredient. Dishes in which a main constituent ingredient was not clearly identified (e.g. chicken and vegetable soup) were classified as a specific subgroup of freshly prepared dishes based on one or more unprocessed or minimally processed food (group 1). Non-caloric supplements were not included in the analyses.

Covariates

Covariates included were age (years), sex, ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region (England North, England Central/Midlands, England South (including London), Scotland, Wales, and Northern Ireland), and equivalised household income (equivalised for different household sizes and composition using the McClements equivalence scale [15]). Due to the significant proportion of missing values for the equivalised household income (12.8%), we applied multiple imputation by chained equation method based on age, sex, ethnicity, excessive free sugars intake and ultra-processed food consumption. Multiple imputation was performed 20 times, and the Monte Carlo error analysis showed good statistical reproducibility of the results [20].

Data analysis

For each survey day and age group (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years), we defined extreme total energy intake outliers as values below the 1st and above the 99th percentiles [21]. Based on these criteria, we excluded ten individuals who had all days of food diary classified as outliers. In total, 9,364 (4,729 adults and 4,635 children) participants were eligible for inclusion in the analyses and more than 91% completed the four food diary days. We used the mean of all available days of food diary for each individual.

Food items were sorted into mutually exclusive food groups according to NOVA classification. We combined the group of unprocessed or minimally processed foods with the group of processed culinary ingredients, as foods belonging to these two groups are usually combined together in culinary preparations and, therefore, consumed together. Thus, we performed the analyses considering three groups of foods: unprocessed or minimally processed foods and processed culinary ingredients, processed foods, and ultra-processed foods.

First, we estimated the distribution of total energy and free sugars intake according to the food groups. Then, we calculated the mean free sugars intake of the overall diet and the prevalence of excessive intake of free sugars. We used the WHO recommendations [5] to assess the excessive intake of free sugars (≥10% of total energy). Analyses using the UK recommendations to further limit free sugars intake to less than 5% of total energy intake are presented in a supplementary table **(Suppl. Table S3)**. Analyses were carried out for the entire population and also stratified by age group.

Next, the prevalence of excessive intake of free sugars (≥10% of total energy) was compared across quintiles of the energy share provided by each of the three food groups. Poisson regression was used to estimate prevalence ratios (PR) and 95% confidence intervals for the associations between each of the three food group quintiles and prevalence of individuals consuming more than 10% of total energy from free sugars. Tests of linear trend were performed to evaluate the quintiles as a single continuous variable. All analyses were stratified by age group. Multiple regression models were also performed to adjust for age, sex, ethnicity, region, and equivalised household income (sterling pounds).

Analyses using the entire population are presented in a supplementary table **(Suppl. Table S4)**.

Finally, we estimated the proportion of excessive free sugar intake that could be potentially avoided under two counterfactual scenarios regarding the consumption of the main dietary sources of free sugar. The first counterfactual scenario assumed no consumption of ultra-processed food, while in the second scenario the table sugar consumption was set to zero. Table sugar included honey, molasses, maple syrup (100%), and also both sugar added to coffee/juice and sugar from homemade dishes. We calculated population attributable fraction (PAF) through the following equation:

$$PAF = \frac{P_{population} - P_{nonexposed}}{P_{population}}$$

Where $P_{population}$ is the prevalence of excessive free sugar intake in the UK population and $P_{nonexposed}$ is the prevalence of excessive free sugar intake in the counterfactual scenarios. Prevalences were adjusted for sex, age, ethnicity, region, and household income.

NDNS study weights were used in all analyses to account for sampling and non-response error. All statistical analyses were carried out using Stata Statistical Software version 14. The *p* values reported were two-tailed, and a threshold of <0.01 was considered for statistically significant associations.

RESULTS

Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Unprocessed or minimally processed foods and processed culinary ingredients represented an additional 34.3% of total energy intake and 23.8% of free sugars, and processed foods the remaining 8.8% of total energy intake and 11.5% of free sugars. Ultra-processed foods accounted for a higher percentage of total energy intake among children (63.5%) and adolescents (68%). The average UK daily intake of free sugars was 12.4% (SE 0.1) of total energy intake and 61.3% of British exceeded the recommended limit of 10% energy from free sugars. This proportion was even higher among children (74.9%) and adolescents (82.9%) (**Table 1**).

Table 1. Dietary contribution of NOVA food groups and indicators of the dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

	Dietary contribution (% of total energy intake)						% of total energy intake from free sugars								Individuals with ≥10% of total energy intake from free sugars		
Age groups	**Unprocessed or minimally processed foods + Processed culinary ingredients**		**Processed foods**		**Ultra-processed foods**		**Unprocessed or minimally processed foods + Processed culinary ingredients**		**Processed foods**		**Ultra-processed foods**		**Total**		**Overall diet**		
	Mean	*SE*					*Mean*	*SE*							*%*	*95%CI*	
1.5 - 10 years	31.96	0.33	4.51	0.10	63.53	0.34	18.82	0.45	5.15	0.22	76.03	0.49	14.00	0.14	74.94	72.78	76.99
11 - 18 years	27.25	0.37	4.75	0.16	68.00	0.40	18.63	0.55	2.48	0.19	78.89	0.57	15.78	0.19	82.91	80.72	84.90
19 - 64 years	34.75	0.32	10.37	0.19	54.89	0.35	24.68	0.50	12.96	0.38	62.36	0.56	11.93	0.14	56.59	54.47	58.68
≥65 years	38.57	0.49	8.45	0.29	52.98	0.52	26.77	0.96	15.38	0.69	57.86	1.01	11.36	0.23	56.83	52.98	60.59
Total	**34.35**	**0.22**	**8.83**	**0.13**	**56.82**	**0.24**	**23.78**	**0.36**	**11.46**	**0.27**	**64.75**	**0.40**	**12.44**	**0.10**	**61.27**	**59.76**	**62.76**

Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups stratified by age groups are shown in **Tables 2 to 5** (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years, respectively). The dietary contents of free sugars increased linearly across quintiles of ultra-processed food consumption for children (from 10.4% in the lowest quintile to 15.3% in the highest quintile), adolescents (from 12.7% to 17.4%, respectively) and adults (from 9.6% to 15.2%, respectively), whereas the increase for elderly was not significant (from 10.6% to 11.7%, respectively). The prevalence of excessive free sugar intake also increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly group. Children in the highest quintiles of ultra-processed food consumption had a prevalence of excessive free sugar intake 60% higher (PRadj 1.6; 95% CI 1.3 to 1.9) than those in the lowest quintile group. The same trend was observed for adolescents (PRadj 1.6 95% IC 1.2 – 1.9) and adults (PRadj 1.7 95% IC 1.5 – 1. 9), while no difference in prevalence was observed for elderly (PRadj 1.1 95% IC 0.8 – 1.4).

Opposite trends were observed for the group of unprocessed or minimally processed foods and processed culinary ingredients, where the prevalence of excessive free sugars intake decreased from the first to the last quintile of these food groups in all age groups. The prevalence of excessive free sugars intake also decreased from the first to the last quintile of processed foods, but only in adolescents and adults.

Table 2. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 - 10 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.36	0.00	20.92	15.80	0.33	82.99	1.00	1.00	–	–
2nd	24.86	20.93	28.41	14.60	0.30	79.62	0.96	0.95	0.89	1.02
3rd	31.57	28.46	34.96	14.37	0.28	81.68	0.98	0.99	0.93	1.06
4th	39.30	34.98	43.86	13.66	0.36	73.40	0.88	0.91	0.84	0.99
5th	52.46	43.97	79.93	11.13¥	0.26	53.87	0.65¥	0.69¥	0.61	0.78
Processed foods										
1st	0.41	0.00	1.33	13.93	0.29	72.58	1.00	1.00	–	–
2nd	2.56	1.34	3.79	14.82	0.30	80.23	1.11	1.11	1.03	1.19
3rd	5.18	3.79	6.82	13.77	0.25	73.85	1.02	1.04	0.95	1.13
4th	8.96	6.83	11.95	13.37	0.31	73.23	1.01	1.02	0.93	1.12
5th	16.05	12.04	41.71	13.16	0.52	69.20	0.95	0.99	0.86	1.14
Ultra-processed foods										
1st	36.38	15.11	43.67	10.35	0.38	46.41	1.00	1.00	–	–
2nd	49.00	43.72	53.03	12.37	0.30	66.78	1.44	1.40	1.15	1.70
3rd	57.17	53.06	60.95	13.84	0.37	74.22	1.60	1.50	1.24	1.81
4th	65.58	60.96	70.14	14.48	0.26	80.95	1.74	1.62	1.35	1.95
5th	78.05	70.15	100	15.32¥	0.25	81.41	1.75¥	1.62¥	1.35	1.95

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, and household income.

¥Significant linear trend across all quintiles (p≤0.001).

Table 3. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 11 - 18 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	14.43	0.00	20.89	17.28	0.36	88.89	1.00	1.00	–	–
2nd	24.61	20.92	28.43	15.87	0.35	84.30	0.95	0.95	0.89	1.01
3rd	31.46	28.44	34.93	15.50	0.37	81.82	0.92	0.92	0.86	0.99
4th	39.24	34.98	43.84	13.96	0.43	78.15	0.88	0.89	0.82	0.96
5th	52.96	43.88	79.86	13.60¥	0.80	66.92	0.75¥	0.77¥	0.66	0.88
Processed foods										
1st	0.29	0.00	1.33	17.18	0.41	85.11	1.00	1.00	–	–
2nd	2.56	1.34	3.79	15.81	0.35	81.74	0.96	0.96	0.90	1.03
3rd	5.16	3.80	6.81	15.62	0.35	86.87	1.02	1.02	0.96	1.09
4th	8.94	6.82	11.95	14.52	0.43	79.40	0.93	0.93	0.86	1.01
5th	17.53	12.05	41.62	13.68¥	0.57	74.89	0.88¥	0.88¥	0.78	0.99
Ultra-processed foods										
1st	35.29	18.40	42.94	12.72	1.39	56.18	1.00	1.00	–	–
2nd	49.35	43.70	53.03	13.65	0.56	75.73	1.35	1.34	1.03	1.74
3rd	56.91	53.08	60.96	14.19	0.40	79.24	1.41	1.40	1.09	1.80
4th	65.63	60.96	70.13	14.99	0.32	80.76	1.44	1.42	1.11	1.82
5th	79.05	70.14	100	17.37¥	0.29	89.04	1.58¥	1.56¥	1.23	1.99

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, and household income.
¥Significant linear trend across all quintiles (p≤0.001).

Table 4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 19 - 64 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*[¦]	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.06	0.00	20.92	15.11	0.36	35.87	1.00	–	–	
2nd	24.93	20.95	28.41	12.87	0.31	31.12	0.85	0.87	0.79	0.96
3rd	31.65	28.43	34.96	11.97	0.31	30.87	0.79	0.85	0.77	0.94
4th	38.95	34.97	43.88	11.01	0.28	28.45	0.66	0.72	0.64	0.80
5th	54.24	43.93	91.90	9.89[¥]	0.25	25.28	0.57[¥]	0.63[¥]	0.55	0.71
Processed foods										
1st	0.28	0.00	1.32	13.09	0.50	59.14	1.00	1.00	–	–
2nd	2.60	1.34	3.79	12.82	0.41	60.65	1.03	1.04	0.92	1.19
3rd	5.35	3.79	6.82	12.17	0.30	61.42	1.04	1.04	0.92	1.18
4th	9.36	6.82	12.03	11.62	0.26	55.92	0.95	0.98	0.87	1.11
5th	19.80	12.04	65.22	11.27[¥]	0.22	52.47	0.89[¥]	0.92[¥]	0.82	1.03
Ultra-processed foods										
1st	34.45	1.82	43.67	9.62	0.27	39.42	1.00	1.00	–	–
2nd	48.70	43.69	53.04	11.11	0.25	53.34	1.35	1.30	1.13	1.50
3rd	57.08	53.06	60.96	11.83	0.29	56.84	1.44	1.37	1.19	1.57
4th	65.34	60.96	70.14	13.09	0.32	66.31	1.68	1.57	1.37	1.79
5th	78.04	70.15	100	15.21[¥]	0.38	74.30	1.88[¥]	1.67[¥]	1.46	1.92

*PR=Prevalence ratios estimated using Poisson regression.

[¦]PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, and household income.

[¥]Significant linear trend across all quintiles (p≤0.001).

Table 5. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 65 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	16.63	6.34	20.82	11.67	0.87	56.16	1.00	1.00	–	–
2nd	25.04	20.95	28.36	12.83	0.61	67.39	1.20	1.19	0.90	1.57
3rd	32.06	28.44	34.90	11.98	0.48	64.37	1.15	1.15	0.87	1.52
4th	39.30	34.98	43.85	10.93	0.44	53.96	0.96	0.97	0.73	1.28
5th	52.26	43.89	78.36	10.70	0.42	50.94	0.91¥	0.91¥	0.69	1.21
Processed foods										
1st	0.38	0.00	1.32	9.70	0.72	43.52	1.00	1.00	–	–
2nd	2.42	1.34	3.78	12.13	0.56	64.30	1.48	1.49	1.14	1.96
3rd	5.23	3.79	6.81	12.16	0.45	65.00	1.49	1.52	1.17	1.98
4th	9.27	6.82	12.02	11.10	0.47	54.46	1.25	1.27	0.96	1.67
5th	19.10	12.04	50.86	11.23	0.46	53.62	1.23	1.29	0.97	1.69
Ultra-processed foods										
1st	35.98	7.79	43.69	10.63	0.49	47.63	1.00	1.00	–	–
2nd	48.67	43.74	53.02	11.30	0.48	58.67	1.23	1.20	0.97	1.47
3rd	56.97	53.05	60.91	11.61	0.45	59.89	1.26	1.21	0.98	1.50
4th	64.99	61.01	70.08	12.01	0.54	65.53	1.38	1.35	1.09	1.66
5th	75.66	70.17	92.30	11.67	0.70	53.75	1.13	1.06	0.81	1.40

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, and household income.
¥Significant linear trend across all quintiles (p≤0.001).

In our counterfactual scenarios, we calculated the percentage of excessive free sugar intake avoided if the consumption of ultra-processed foods and table sugar were zero (**Figure 1**). We estimated that about 47% of excessive free sugars intake in the UK population could be potentially avoided if the consumption of ultra-processed foods was eliminated. Eliminating table sugar could potentially avoid 9.4% of the excessive free sugars intake. This greater reduction in the percentage of excessive free sugar intake due to elimination of ultra-processed foods, relative to table sugar, was observed in all age groups, except in the elderly group where both scenarios had similar impacts on total free sugar intake.

DISCUSSION

In this large, nationally representative sample of the UK population, higher consumption of ultra-processed food was associated with greater dietary content of free sugars in children, adolescents, and adults. We also showed that by eliminating ultra-processed food consumption, the prevalence of excessive free sugar intake (10% or more of total energy intake) could be potentially reduced from 60% to 28%. Greater reduction could be achieved in children (from 74% to 28%) and adolescents (from 83% to 29%).

Our findings confirm an excessive consumption of free sugars in the UK diet [13] and show that ultra-processed foods contributed nearly 65% of all free sugars in all age groups and nearly 80% in children and adolescents. Unprocessed or minimally processed foods (mostly fresh juice) and processed culinary ingredients (mostly table sugar) contributed between 19% and 27% of the dietary content of free sugars, while processed foods provided the lowest contribution in all age groups.

Our findings are similar to previous studies conducted in high- and middle-income countries that have shown strong associations between the intake of ultra-processed foods and the dietary content of free sugars [8-11]. A previous study conducted in Chile similarly showed that the association between ultra-processed food consumption and the dietary content of added sugars is more pronounced among children and adolescents [12]. In our study there was no association between ultra-processed food consumption and dietary content of free sugars among the elderly, probably due to differences in the type of ultra-processed foods consumed in this age group, with salted products more likely to be consumed than the sweetened products.

There is strong evidence that the high consumption of free sugars contributes to excess obesity, type 2 diabetes, dyslipidaemia, hypertension and coronary heart disease [2-4]. Consequently, most dietary recommendations now advise limiting free sugar intake, but more focused efforts are needed to put this recommendation into practice. Changing personal behaviour and choice alone is not an effective or realistic option as our findings confirm that the majority of free sugar is added to food before it is marketed and sold. Voluntary agreements between industry and government have been shown repeatedly to be ineffective in improving public health [22]. This is confirmed by recent UK experience where the early stages of the government's sugar reduction programme, which challenged the food industry to voluntarily cut sugar in some products, has produced only slow progress toward proposed targets [23]. Thus, more drastic measures that change the availability, price and marketing of these products is necessary.

The analyses presented here suggest that actions to reduce the consumption of ultra-processed foods generally rich in free sugars could lead to larger public health benefits. Policies concerning the use of fiscal measures to reduce intake of free sugars and improve diet quality should consider extending beyond artificially sweetened beverages to include the main driver of excessive free sugar intake, including dairy drinks, cakes, biscuits and confectionery [13].

To our knowledge, this is the first study to examine the association between consumption of ultra-processed foods, as defined per NOVA [6], and dietary content of free sugar in different age groups of the UK population. The use of NOVA is a key strength of the study as it classified foods by their level of processing level using standardised and objective criteria. NOVA has been recognised as a valid tool for public health and nutrition research and policy by the Food and Agricultural Organization of the United Nations [24] and the Pan American Health Organization [25]. In addition, we used data from the NDNS - a large and nationally representative sample of the UK population, applying weighting to reduce any sampling and non-response bias. Unlike household budget data, food diaries employed in the NDNS take food wastage into account, include food eaten out of home, and do not assume that all individuals within a household consume the same diet. Importantly, the dietary data also allowed for the disaggregation of dishes into their constituents and classification of the underlying ingredients, which enabled the calculation of more precise estimates of intakes of each NOVA group and reduced misclassification.

Potential limitations should be considered. The dietary data we used were self-reported and may be subject to misclassification. A constant limitation of dietary assessment methods is underreporting of some foods (particularly unhealthy foods), though food diaries are recognised to be one of the most comprehensive methods for assessing dietary intake. Possible underreporting of unhealthy foods may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of free sugars, but may less likely affect the association between these variables. Nevertheless, accurate and valid NDNS data were achieved through optimal methods for collecting dietary intake [26] which helped to minimise missing information. NDNS collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items. This bias is more likely for a small number of specific food items such as pizza where there is insufficient information for classification purposes (see **Suppl. Table S2**). In those cases, the most frequently consumed alternative (culinary preparation or manufactured product) was chosen.

Conclusions

Almost half of excessive intake of free sugars in the UK can be attributed to ultra-processed foods. Policies to reduce sugar consumption should focus on minimizing consumption of ultra-processed foods and replacing them with unprocessed or minimally processed foods alternatives. The study adds to a growing body of evidence that ultra-processed foods are a major contributor to growth of diet related non-communicable diseases globally.

Author contributions: CAM, EMS, FR, MLdCL, and RBL designed the research. FR and RBL took care of data management and analyses. CAM, CM, EMS, FR, LFMR, MLdCL, and RBL interpreted the data. FR wrote the first draft of the manuscript. All authors read, edited and approved the final manuscript.

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Competing interests: None declared.

Data sharing statement: This study is based on open data of the UK population that is available in the UK Data Archive website (http://www.esds.ac.uk).

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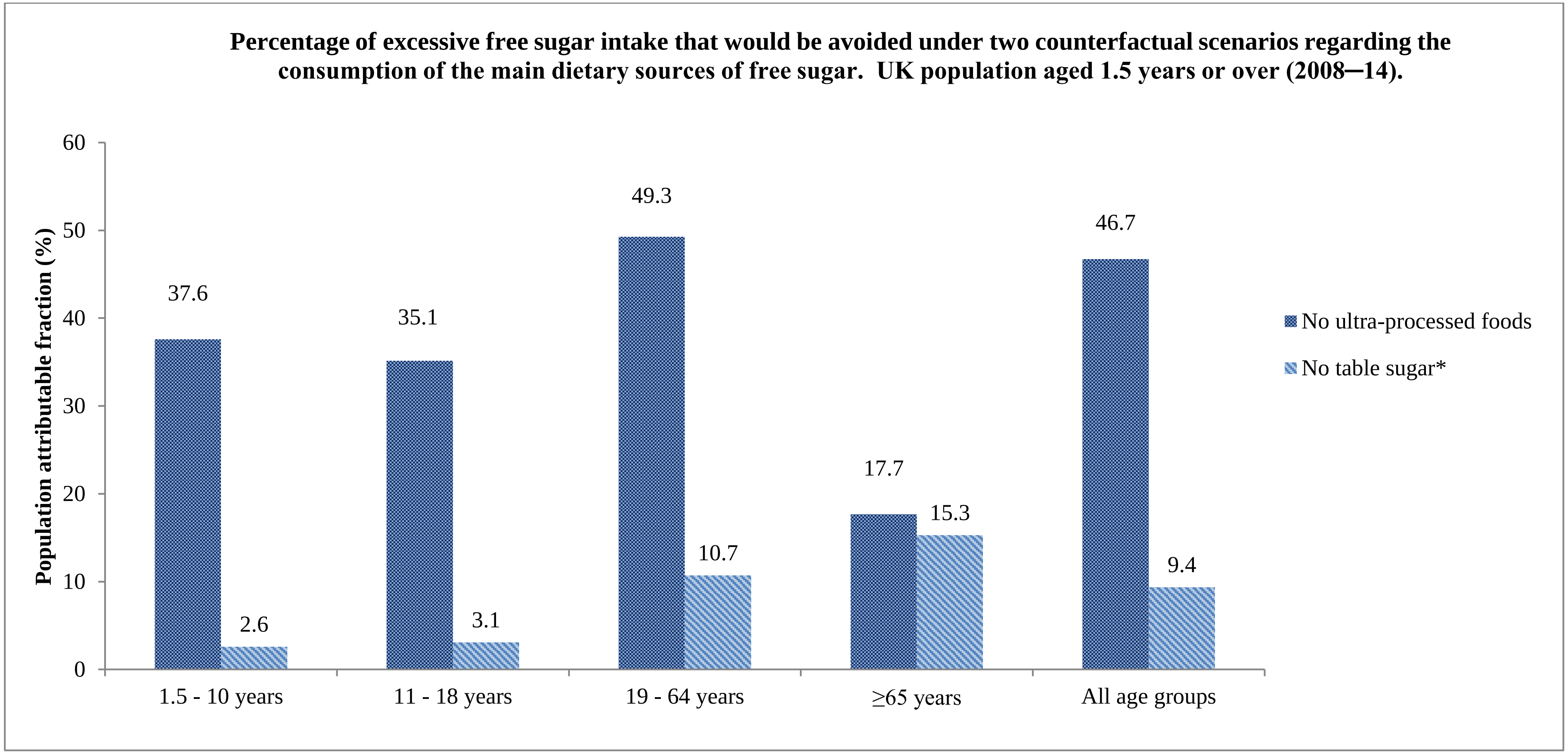
Figure 1.



*Including honey, molasses, maple syrup (100%).

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study.

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Supplementary table S1. The Nova food classification system*

Food groups	Examples
1) Unprocessed foods or minimally processed foods Natural foods altered by methods such as freezing, pasteurization, fermentation, removal of inedible or unwanted parts, grinding, and other methods that do not include the addition of substances such as salt, sugar and/or oils or fats.	Fresh, dry or frozen fruits or vegetables; legumes; grains, roots and tubers, flours and pasta; pasteurized or power plain milk and plain yogurt; fresh or frozen meat (fish, poultry and red meat); eggs; nuts and seeds; fungi; fresh or pasteurised fruit or vegetable juices without added sugar, sweeteners or flavours; tea, coffee and drinking water.
2) Processed culinary ingredients Substances obtained directly from group 1 foods or from nature by processes that include pressing, refining, grinding, milling, and drying, and consumed in combination with group 1 foods in freshly prepared dishes or drinks.	Salt; sugar, honey and molasses; vegetable oils; butter and lard; starches extracted from corn and other plants.
3) Processed foods Products manufactured with the addition of group 2 substances (e.g. salt, sugar, oil, and fats) to group 1 foods and alcoholic drinks produced by fermentation of group 1 foods such as beer, cider and wine.	Canned or bottled vegetables, fruits and legumes; salted or sugared nuts and seeds; salted, cured, or smoked meats; canned fish; fruits in syrup; cheeses and unpackaged freshly made breads.
4) Ultra-processed foods Food and drink formulations made from several ingredients. Such ingredients include salt, sugar, oils, and fats but also other substances derived from foods but not commonly used as culinary ingredients (such as protein isolates, hydrogenated oils, modified starches) and additives used to imitate sensory quality of natural foods and freshly prepared dishes or to disguise unpalatable aspects of the final product (such as flavours, colours, sweeteners, emulsifiers). Alcoholic drinks produced by fermentation of group 1 foods followed by distillation of the resulting alcohol, such as whisky, gin, rum, vodka, are classified in group 4.	Carbonated drinks; sweet or savoury packaged snacks; confectionery; mass-produced packaged breads and buns; margarines and spreads; biscuits, pastries, cakes, and cake mixes; breakfast 'cereals', 'cereal' and 'energy' bars; 'energy' drinks; milk drinks, 'fruit' yoghurts and 'fruit' drinks; cocoa drinks; meat and chicken extracts and 'instant' sauces; ready to heat products including pre-prepared pies and pasta and pizza dishes; poultry and fish 'nuggets' and 'sticks', sausages, burgers, hot dogs, and other reconstituted meat products, and powdered and packaged 'instant' soups, noodles and desserts.

Adapted from Monteiro et al. (2016 and 2018).

Monteiro CA, Cannon G, Moubarac JC et al. (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr 21, 5-17.
Monteiro CA, Cannon G, Levy RB, et al. NOVA. The star shines bright. World Nutrition. 2016;7(1-3):28-38.

Supplementary Table S2. Coding of subsidiary food groups from National Diet and Nutrition Survey according to NOVA classification.

Subsidiary food group code	Subsidiary food group name	NOVA food group†
1C	Pizza	4
1D	Pasta (manufactured products and ready meals	4
1E	Pasta (other, including homemade dishes)	*
1F	Rice (manufactured products and ready meals)	4
1G	Rice (other, including homemade dishes)	*
1R	Other cereals	*
2R	White bread (not high fibre, not multiseed bread)	4
3R	Wholemeal bread	4
4R	Other bread	4
5R	High fibre breakfast cereals	4
6R	Other breakfast cereals (not high fibre)	4
7A	Biscuits(manufactured/retail)	4
7B	Biscuits (homemade)	*
8B	Fruit pies (manufactured)	4
8C	Fruit pies (homemade)	*
8D	Buns cakes and pastries (manufactured)	4
8E	Buns cakes and pastries (homemade)	*
9C	Cereal based milk puddings (manufactured)	4
9D	Cereal based milk puddings (homemade)	*
9E	Sponge puddings (manufactured)	4
9F	Sponge puddings (homemade)	*
9G	Other cereal based puddings (manufactured)	4
9H	Other cereal based puddings (homemade)	*
10R	Whole milk	1
11R	Semi-skimmed milk	1
12R	Skimmed milk	1
13A	Infant formula	4
13B	Cream (including imitation cream)	*
13R	Other milk	*
14A	Cottage cheese	3
14B	Cheddar cheese	3
14R	Other cheese	*
15B	Yogurt	*
15C	Fromage frais and other dairy desserts (manufactured)	4
15D	Dairy desserts (homemade)	*
16C	Manufactured egg products, including ready meals	4
16D	Other eggs and egg dishes, including homemade	*
17R	Butter	2
18A	Polyunsaturated margarine	4
18B	Polyunsaturated oils	2
19A	Polyunsaturated low fat spread	4
19R	Low fat spread not polyunsaturated	4
20A	Block margarine	4
20B	Soft margarine not polyunsaturated	4
20C	Other cooking fats and oils not polyunsaturated	2
21A	Reduced fat spread (polyunsaturated)	4
21B	Reduced fat spread (not polyunsaturated)	4
22A	Ready meals/meal centres based on bacon and ham	4
22B	Other bacon and ham (including homemade dishes)	*
23A	Manufactured beef products (including ready meals)	4
23B	Other beef & veal (including homemade recipe dishes)	*
24A	Manufactured lamb products (including ready meals)	4
24B	Other lamb (including homemade recipe dishes)	*
25A	Manufactured pork products(including ready meals)	4
25B	Other pork (including homemade recipe dishes)	*
26A	Manufactured coated chicken/turkey products	4
27A	Manufactured chicken products (including ready meals)	4
27B	Other chicken/turkey (including homemade recipe dishes)	*
28R	Liver and dishes	*
29R	Burgers and kebabs purchased	4
30A	Ready meals based on sausages	4

30B	Other sausages (including homemade dishes)	*
31A	Meat pies and pastries (manufactured)	4
31B	Meat pies and pastries (homemade)	*
32A	Other meat products (manufactured including ready meals)	4
32B	Other meat (including homemade recipe dishes)	*
33R	White fish coated or fried	*
34C	Manufactured white fish products (including ready meals)	4
34D	Other white fish (including homemade dishes)	*
34E	Manufactured shellfish products (including ready meals)	4
34F	Other shellfish (including homemade dishes)	*
34G	Manufactured canned tuna products (including ready meals)	*
34H	Other canned tuna (including homemade dishes)	*
35A	Manufactured oily fish products (including ready meals)	4
35B	Other oily fish (including homemade dishes)	*
36A	Carrots (raw)	1
36B	Salad and other raw vegetables	*
36C	Tomatoes raw	1
37A	Peas not raw	*
37B	Green beans not raw	*
37C	Baked beans	4
37D	Leafy green vegetables not raw	*
37E	Carrots not raw	*
37F	Tomatoes not raw	*
37I	Beans and pulses (including ready meal & homemade dishes)	*
37K	Meat alternatives (including ready meals and homemade dishes)	4
37L	Other manufactured vegetable products (including ready meals)	4
37M	Other vegetables (including homemade dishes)	*
38A	Chips purchased including takeaway	4
38C	Other manufactured potato products fried/baked	4
38D	Other fried/roast potatoes (including homemade dishes)	*
39A	Other potato products and dishes(manufactured)	4
39B	Other potatoes (including homemade dishes)	*
40A	Apples and pears not canned	*
40B	Citrus fruit not canned	*
40C	Bananas	*
40D	Canned fruit in juice	*
40E	Canned fruit in syrup	3
40R	Other fruit not canned	*
41A	Sugar	*
41B	Preserves	3
41R	Sweet spreads fillings and icing	4
42R	Crisps and savoury snacks	4
43R	Sugar confectionery	4
44R	Chocolate confectionery	4
45R	Fruit juice	*
47A	Liqueurs	4
47B	Spirits	4
48A	Wine	3
48B	Fortified wine	4
48C	Low alcohol and alcohol free wine	3
49A	Beers and lagers	3
49B	Low alcohol & alcohol free beer & lager	3
49C	Cider and Perry	4
49D	Low alcohol & alcohol free cider & Perry	4
49E	Alcoholic soft drinks (Alcopops)	4
50A	Beverages dry weight	4
50C	Soup (manufactured/retail)	4
50D	Soup (homemade)	*
50E	Nutrition powders and drinks	4
50R	Savoury sauces pickles gravies & condiments	4
51A	Coffee (made up weight)	*
51B	Tea (made up)	*
51C	Herbal tea (made up)	1
51D	Bottled water still or carbonated	*
51R	Tap water only	1
52A	Commercial toddlers drinks	3
52R	Commercial toddlers foods	3

53R	Ice cream	4
54A	Cod liver oil and other fish oils	**
54B	Evening primrose oil and other plant oils	**
54C	Single vitamins/minerals not Folic acid, iron, calcium	**
54D	Folic acid	**
54E	Iron only or with vitamin C	**
54F	Calcium only or with vitamin D	**
54G	Vitamins (two or more including multivitamins) no minerals	**
54H	Minerals (two or more including multimineral) no vitamins	**
54I	Vitamins and minerals (including multivitamins & minerals)	**
54J	Non-nutrient supplements (including herbal)	**
54K	Other nutrient supplements	**
54L	Vitamin C	**
54M	Single vitamins/minerals not Folic acid, iron, calcium or vitamin C	**
54N	Cod liver oil and other fish oils (including with vitamins A, D, E)	**
54P	Multivitamins and/or minerals with omega ultra-processed	**
55R	Artificial sweeteners	4
56R	Nuts and seeds	*
57A	Soft drinks not low calorie concentrated	4
57B	Soft drinks not low calorie carbonated	4
57C	Soft drinks not low calorie, ready to drink, still	4
58A	Soft drinks low calorie concentrated	4
58B	Soft drinks low calorie carbonated	4
58C	Soft drinks low calorie, ready to drink, still	4
59R	Brown, granary and wheat germ bread	4
60R	1% Milk	1
61R	Smoothies	1

† NOVA food groups defined as 1) unprocessed or minimally processed foods; 2) processed culinary ingredients; 3) processed foods; and 4) ultra-processed foods.
* All foods within this subsidiary food group were individually coded (by food name).
** Supplements were not included in any of the NOVA food groups.
Source: Rauber F, Louzada MLC, Steele EM, Millett C, Monteiro CA, Levy RB. Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). Nutrients 2018, 10, 587; doi:10.3390/nu10050587.

Supplementary table S3. Dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008─14).

Age groups	% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars		
	mean	**SE**	*%*	*95%CI*	
1.5 - 10 years	14.00	0.14	97.16	96.29	97.84
11 - 18 years	15.78	0.19	96.77	95.62	97.62
19 - 64 years	11.93	0.14	88.82	87.48	90.04
≥65 years	11.36	0.23	87.62	84.88	89.93
All age groups	**12.44**	**0.10**	**90.34**	**89.39**	**91.21**

Supplementary table S4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars					Individuals with ≥10% of total energy intake from free sugars				
Quintile	mean	min	max	mean	SE	%	PR*	PRadj[¦]	95%CI		%	PR*	PRadj[¦]	95%CI	
Unprocessed or minimally processed foods + Processed culinary ingredients															
1st	15.10	0.00	20.92	15.36	0.24	95.94	1.00	1.00	—	—	77.42	1.00	1.00	—	—
2nd	24.90	20.92	28.43	13.44	0.22	94.28	0.98	0.99	0.97	1.01	68.55	0.89	0.92	0.86	0.97
3rd	31.68	28.43	34.96	12.62	0.21	91.92	0.96	0.97	0.95	1.00	65.09	0.84	0.89	0.84	0.95
4th	39.08	34.97	43.88	11.46	0.21	89.70	0.93	0.96	0.93	0.98	55.09	0.71	0.77	0.72	0.83
5th	53.57	43.88	91.90	10.32[¥]	0.19	82.41	0.86	0.89	0.86	0.92	46.36	0.60[¥]	0.67[¥]	0.61	0.73
Processed foods															
1st	0.32	0.00	1.33	13.53	0.29	87.19	1.00	1.00	—	—	64.14	1.00	1.00	—	—
2nd	2.55	1.34	3.79	13.48	0.24	92.34	1.06	1.06	1.03	1.10	67.93	1.06	1.08	1.01	1.16
3rd	5.28	3.79	6.82	12.83	0.19	92.39	1.06	1.07	1.03	1.10	67.10	1.05	1.08	1.00	1.16
4th	9.28	6.82	12.03	11.89	0.20	90.61	1.04	1.06	1.02	1.09	58.87	0.92	0.98	0.91	1.06
5th	19.54	12.04	65.22	11.38[¥]	0.19	89.40	1.03	1.04	1.01	1.08	53.70	0.84[¥]	0.91[¥]	0.84	0.98
Ultra-processed foods															
1st	34.89	1.82	43.69	9.94	0.22	80.50	1.00	1.00	—	—	41.87	1.00	1.00	—	—
2nd	48.74	43.69	53.04	11.34	0.20	89.16	1.11	1.10	1.05	1.15	56.35	1.35	1.31	1.18	1.46
3rd	57.06	53.05	60.96	12.16	0.21	92.65	1.15	1.14	1.09	1.18	60.76	1.45	1.39	1.25	1.54
4th	65.37	60.96	70.14	13.38	0.21	94.08	1.17	1.15	1.10	1.19	70.18	1.68	1.55	1.41	1.72
5th	78.06	70.14	100.00	15.41[¥]	0.21	95.30	1.18[¥]	1.15[¥]	1.10	1.19	77.20	1.84[¥]	1.64[¥]	1.48	1.81

*PR=Prevalence ratios estimated using Poisson regression.

[¦]PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, and household income.

[¥]Significant linear trend across all quintiles (p≤0.001).

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1, 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-8
Bias	9	Describe any efforts to address potential sources of bias	6,7
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	7-9
		(*b*) Describe any methods used to examine subgroups and interactions	7,9
		(*c*) Explain how missing data were addressed	7
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	7

Outcome data	15*	Report numbers of outcome events or summary measures	9
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	10-15
		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	8
Discussion			
Key results	18	Summarise key results with reference to study objectives	16
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	17,18
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18
Generalisability	21	Discuss the generalisability (external validity) of the study results	17
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	18

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Nutrition and metabolism
Keywords:	Food processing, Ultra-processed, Free sugar, United Kingdom

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study

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Word count: 3,586

ABSTRACT

Objectives: to describe dietary sources of free sugars in different age groups of the UK population considering food groups classified according to the NOVA system and to estimate the proportion of excessive free sugars that could potentially be avoided by reducing consumption of their main sources.

Design and setting: Cross-sectional data from the UK National Diet and Nutrition Survey (2008–14) were analysed. Food items collected using a four-day food diary were classified according to the NOVA system.

Participants: 9,364 individuals aged 1.5 years and above.

Main outcome measures: Average dietary content of free sugars and proportion of individuals consuming more than 10% of total energy from free sugars.

Data analysis: Poisson regression was used to estimate the associations between each of the NOVA food group and intake of free sugars. We also estimated population attributable fraction for excessive free sugar intake associated with consumption of ultra-processed foods and table sugar. Analyses were stratified by age group and adjusted for age, sex, ethnicity, region, and equivalised household income (sterling pounds).

Results: Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Free sugars represent 12.4% of total energy intake and 61.3% of the sample exceeded the recommended limit of 10% energy from free sugars. This percentage was higher among children (74.9%) and adolescents (82.9%). Excessive free sugar intake increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly. We estimated that 47% of excessive free sugars intake in the UK population could be avoided if the consumption of ultra-processed foods was eliminated.

Conclusion: Our findings suggest that actions to reduce the ultra-processed food consumption generally rich in free sugars could lead to substantial public health benefits.

Keywords: Food processing; Ultra-processed; Free sugar; United Kingdom.

ARTICLE SUMMARY

Strengths and limitations of this study

- Use of a large and nationally representative sample of the UK population, increasing generalisability.
- Use of data on free sugars rather than total sugars or sugar-sweetened beverages, which correspond to the guidelines relevant area of prioritisation.
- Use of NOVA system, which has been recognised as a valid tool for public health and nutrition research and policy by international organizations.
- Dietary data obtained by food diaries are subject to potential error and bias.
- UK national dietary survey collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items.

INTRODUCTION

Excessive consumption of free sugar is associated with obesity, type 2 diabetes, dental caries, and several other health outcomes [1-4]. To address this associated health burden, the World Health Organization (WHO) [5] recommends that free sugars should be reduced to less than 10% of total energy intake and also suggests a level below 5% to obtain additional health benefits, such as reduction of dental caries. Achievement of this ambitious target will require bold and systematic efforts to reduce sugar across a variety of food products in most settings.

As defined by the NOVA food classification system, ultra-processed foods are industrial formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed) [6]. In some high-income countries, including the UK, ultra-processed foods account for more than half of total dietary energy intake [7-9]. Importantly, national dietary surveys conducted in high- and middle-income countries [8-12] have shown a strong and positive association between consumption of ultra-processed foods and excessive dietary added (or free) sugar intake. Free sugars include sugars added to foods by the manufacturer, cook and consumer, plus sugars naturally present in honey, syrups and fruit juices [5], while added sugars captures all free sugars, but exclude naturally occurring sugars in fruit juices.

Free sugar intake in the UK is high, ranging from 11 to 15% of total energy intake [13]. To address this, the UK has implemented a number of measures including a sugar-sweetened beverage levy in 2018. However, action on sugar sweetened beverages alone is unlikely to reduce population level sugar intake to WHO recommended levels. In a more recent publication, the voluntary sugar reduction programme continues being endorsed by the government, but other measures such as restriction of advertising and in-store promotions of some sugary foods are also being considered as strategies to reduce childhood obesity [14]. A better understanding of the key sources of sugar intake in the UK diet is required to inform policy development. This study aims to describe the dietary sources of free sugars in different age groups of the UK population taking into account food groups classified according to the NOVA classification system and estimate the proportion of excessive free sugars that could be potentially avoided by reducing the consumption of their main dietary sources.

METHODS

Data source and collection

We used data from the National Diet and Nutrition Survey Rolling Programme (NDNS) years 1-6 (2008/09-2009/10, 2010/11-2011/12, 2012/13-2013/14) combined, which is a cross-sectional survey of people aged 1.5 years or older. The survey was designed to be representative of the UK population and provides comprehensive information on food intake. Details of the rationale, design, and methods of the survey have been described elsewhere [15]. Briefly, the sample was drawn from households randomly selected from the UK Postcode Address File, a list of all UK addresses. One adult (aged 19 years and older) and one child (aged 1.5–18 years), if available, were randomly selected from each household. Only a child was selected from some households to be part of a 'child boost' to ensure approximately equal numbers of children and adults. Participants (or in the case of children ≤11 years, their parent/carer) completed a four-day food diary and participated in an interview that included data on socio-demographic status.

Participants were asked to report all foods and drinks consumed both within and outside the home. Portion sizes were estimated using household measures or weights from packaging. Once completed, diaries were checked by interviewers with respondents and missing details added to improve completeness. Diary days were randomly selected to ensure balanced representation of all days of the week. All individuals who completed three or four days of dietary recording were eligible for inclusion in the study, giving a sample size of 9,374 (4,738 adults and 4,636 children) participants for years 1 to 6 (2008/09 to 2013/14) combined.

The food intake data from completed records were coded and edited using the software DINO (Diet In, Nutrients Out) and food and nutrient intakes estimated using nutrient composition data from the Department of Health's Nutrient Databank, updated for each survey year [16, 17]. Free sugars are defined as sugars added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups, fruit juices and fruit concentrates [5]. Intakes in the UK NDNS years 1-6 were expressed as non-milk extrinsic sugars (NMES). The term NMES captures all sugars defined by the term free sugars while also including half of the sugars present in dried, stewed or canned fruit. The NMES values could be slightly higher in some cases than the free sugar values, mostly in the non-ultra-processed food group since the term free sugar does not include sugars contributed by dried and processed fruits. Based on the assumption that those definitions are sufficiently similar for assessment and monitoring purposes [1,3], this study used the term free sugars.

Computerized raw data files and documentation from this survey were obtained under license from the UK Data Archive (http://www.esds.ac.uk). All relevant research ethics and governance committees approved the survey.

Food classification according to processing

We classified all recorded food items according to NOVA, a food classification system based on the nature, extent, and purpose of the industrial food processing [6]. This classification includes four groups: 1) unprocessed or minimally processed foods (e.g. fresh, dry or frozen fruits or vegetables; grains, flours and pasta; pasteurized or power plain milk, plain yogurt, fresh or frozen meat); 2) processed culinary ingredients (e.g. table sugar, oils, butter, and salt); 3) processed foods (e.g. vegetables in brine, cheese, simple breads, fruits in syrup, canned fish); and 4) ultra-processed foods (e.g. soft drinks, sweet or savoury packaged snacks, confectionery; packaged breads and buns; reconstituted meat products and pre-prepared frozen or shelf-stable dishes) (**see Suppl. Table S1**). The detailed description of NOVA classification can be found elsewhere [6, 18].

All foods in NDNS are coded as food number and grouped into subsidiary food groups (n = 155). When possible, subsidiary food groups were directly classified according to NOVA (**see Suppl. Table S2**). When foods within a subsidiary food group pertained to different NOVA groups (n = 52), it was the food codes instead of the group, which were individually classified. By doing so, we were able to classify each underlying ingredient of homemade dishes in its corresponding NOVA group. Subsidiary food groups as classified by NOVA are described in the Supplementary Table S2.

Although the NDNS database was provided with most food items systematically disaggregated into their individual components, about 4% of composite food codes were still mixed dishes compiled from two or more single-ingredient food code [19]. The method we adopted to disaggregate food codes has been described previously [19]. Using the core sample of years 1 to 4 (2008/09 to 2011/12) (n = 4,125), we estimated that composite food codes represented only 3% of total calories. In this case, dishes were categorised according to the main constituent ingredient. Dishes in which a main constituent ingredient was not clearly identified (e.g. chicken and vegetable soup) were classified as a specific subgroup of freshly prepared dishes based on one or more unprocessed or minimally processed food (group 1). Non-caloric supplements were not included in the analyses.

Covariates

Covariates included were age (years), sex, ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region (England North, England Central/Midlands, England South (including London), Scotland, Wales, and Northern Ireland), survey year (years 1-6), and equivalised household income (equivalised for different household sizes and composition using the McClements equivalence scale [15]). Due to the significant proportion of missing values for the equivalised household income (12.8%), we applied multiple imputation by chained equation method based on age, sex, ethnicity, excessive free sugars intake and ultra-processed food consumption. Multiple imputation was performed 20 times, and the Monte Carlo error analysis showed good statistical reproducibility of the results [20].

Data analysis

For each survey day and age group (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years), we defined extreme total energy intake outliers as values below the 1st and above the 99th percentiles [21]. Based on these criteria, we excluded ten individuals who had all days of food diary classified as outliers. In total, 9,364 (4,729 adults and 4,635 children) participants were eligible for inclusion in the analyses and more than 91% completed the four food diary days. We used the mean of all available days of food diary for each individual.

Food items were sorted into mutually exclusive food groups according to NOVA classification. We combined the group of unprocessed or minimally processed foods with the group of processed culinary ingredients, as foods belonging to these two groups are usually combined together in culinary preparations and, therefore, consumed together. Thus, we performed the analyses considering three groups of foods: unprocessed or minimally processed foods and processed culinary ingredients, processed foods, and ultra-processed foods.

First, we estimated the distribution of total energy and free sugars intake according to the food groups. Then, we calculated the mean free sugars intake of the overall diet and the prevalence of excessive intake of free sugars. We used the WHO recommendations [5] to assess the excessive intake of free sugars (≥10% of total energy). Analyses using the UK recommendations to further limit free sugars intake to less than 5% of total energy intake are presented in a supplementary table **(Suppl. Table S3)**. Analyses were carried out for the entire population and also stratified by age group.

Next, the prevalence of excessive intake of free sugars (≥10% of total energy) was compared across quintiles of the energy share provided by each of the three food groups. Poisson regression was used to estimate prevalence ratios (PR) and 95% confidence intervals for the associations between each of the three NOVA food group quintiles and prevalence of individuals consuming more than 10% of total energy from free sugars. Tests of linear trend were performed to evaluate the quintiles as a single continuous variable. All analyses were stratified by age group. Multiple regression models were also performed to adjust for age, sex, ethnicity, region, survey year, and equivalised household income (sterling pounds). Analyses using the entire population are presented in a supplementary table **(Suppl. Table S4)**. We also evaluated the extent to which the association between the exposure (dietary contribution of NOVA food groups) and the dietary content in free sugars changed according to the survey year, by including a multiplicative interaction term (survey year*dietary contribution of NOVA food groups) in the fully adjusted models.

Finally, we estimated the proportion of excessive free sugar intake that could be potentially avoided if exposure to the risk factors were eliminated (theoretical minimum risk exposure level scenarios) [22, 23]. The counterfactual scenarios were defined considering the main dietary sources of free sugars. The first counterfactual scenario assumed no consumption of ultra-processed food (potentially hidden sugars), while in the second scenario table sugar consumption was set to zero. Table sugar included honey, molasses, maple syrup (100%), and sugar added to coffee/juice and homemade dishes (potentially sugar that can be measured by the consumer). Examples of homemade dishes include: biscuits, fruit pies, buns cakes and pastries, cereal based milk puddings, and sponge pudding (**see Suppl. Table S2**).

In both scenarios, we first calculated the prevalence of excessive free sugar intake in the UK population ($P_{population}$). We then estimated the predicted prevalence of excessive free sugar intake that would be expected had the consumption of each of these main sources of free sugars being zero ($P_{nonexposed}$). Lastly, we calculated the proportion of excessive free sugar intake that could be potentially avoided in each scenario using the following formula: ($P_{population}$ - $P_{nonexposed}$) / $P_{population}$. Prevalences were adjusted for sex, age, ethnicity, region, survey year, and household income.'

NDNS study weights were used in all analyses to account for sampling and non-response error. All statistical analyses were carried out using Stata Statistical Software version 14. The *p* values reported were two-tailed, and a threshold of <0.01 was considered for statistically significant associations.

Patient and public involvement

Patients and/or public were not involved in this study.

RESULTS

Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Unprocessed or minimally processed foods and processed culinary ingredients represented an additional 34.3% of total energy intake and 23.8% of free sugars, and processed foods the remaining 8.8% of total energy intake and 11.5% of free sugars. Ultra-processed foods accounted for a higher percentage of total energy intake among children (63.5%) and adolescents (68%). The average UK daily intake of free sugars was 12.4% (SE 0.1) of total energy intake and 61.3% of British exceeded the recommended limit of 10% energy from free sugars. This proportion was even higher among children (74.9%) and adolescents (82.9%) (**Table 1**).

Table 1. Dietary contribution of NOVA food groups and indicators of the dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

Age groups	Dietary contribution (% of total energy intake)						% of total energy intake from free sugars								Individuals with ≥10% of total energy intake from free sugars		
	Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Total		Overall diet		
	Mean	*SE*					*Mean*	*SE*							*%*	*95%CI*	
1.5 - 10 years	31.96	0.33	4.51	0.10	63.53	0.34	18.82	0.45	5.15	0.22	76.03	0.49	14.00	0.14	74.94	72.78	76.99
11 - 18 years	27.25	0.37	4.75	0.16	68.00	0.40	18.63	0.55	2.48	0.19	78.89	0.57	15.78	0.19	82.91	80.72	84.90
19 - 64 years	34.75	0.32	10.37	0.19	54.89	0.35	24.68	0.50	12.96	0.38	62.36	0.56	11.93	0.14	56.59	54.47	58.68
≥65 years	38.57	0.49	8.45	0.29	52.98	0.52	26.77	0.96	15.38	0.69	57.86	1.01	11.36	0.23	56.83	52.98	60.59
Total	**34.35**	**0.22**	**8.83**	**0.13**	**56.82**	**0.24**	**23.78**	**0.36**	**11.46**	**0.27**	**64.75**	**0.40**	**12.44**	**0.10**	**61.27**	**59.76**	**62.76**

No significant interaction was observed between the exposure and the survey year for the total energy intake from free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.254; processed foods: p = 0.538; ultra-processed foods: p = 0.137), nor for the prevalence of excessive intake of free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.609; processed foods: p = 0.262; ultra-processed foods: p = 0.258). Even so, we included variable survey year (1-6) in the adjusted model.

Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups stratified by age groups are shown in **Tables 2 to 5** (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years, respectively). The dietary contents of free sugars increased linearly across quintiles of ultra-processed food consumption for children (from 10.4% in the lowest quintile to 15.3% in the highest quintile), adolescents (from 12.7% to 17.4%, respectively) and adults (from 9.6% to 15.2%, respectively), whereas the increase for elderly was not significant (from 10.6% to 11.7%, respectively). The prevalence of excessive free sugar intake also increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly group. Children in the highest quintiles of ultra-processed food consumption had a prevalence of excessive free sugar intake 60% higher (PRadj 1.6; 95% CI 1.3 to 1.9) than those in the lowest quintile group. The same trend was observed for adolescents (PRadj 1.6 95% IC 1.2 – 1.9) and adults (PRadj 1.7 95% IC 1.5 – 1. 9), while no difference in prevalence was observed for elderly (PRadj 1.1 95% IC 0.8 – 1.4).

Opposite trends were observed for the group of unprocessed or minimally processed foods and processed culinary ingredients, where the prevalence of excessive free sugars intake decreased from the first to the last quintile of these food groups in all age groups. The prevalence of excessive free sugars intake also decreased from the first to the last quintile of processed foods, but only in adolescents and adults.

Table 2. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 - 10 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.36	0.00	20.92	15.80	0.33	82.99	1.00	1.00	–	–
2nd	24.86	20.93	28.41	14.60	0.30	79.62	0.96	0.95	0.89	1.02
3rd	31.57	28.46	34.96	14.37	0.28	81.68	0.98	0.99	0.93	1.06
4th	39.30	34.98	43.86	13.66	0.36	73.40	0.88	0.91	0.84	0.99
5th	52.46	43.97	79.93	11.13¥	0.26	53.87	0.65¥	0.69¥	0.61	0.78
Processed foods										
1st	0.41	0.00	1.33	13.93	0.29	72.58	1.00	1.00	–	–
2nd	2.56	1.34	3.79	14.82	0.30	80.23	1.11	1.11	1.03	1.19
3rd	5.18	3.79	6.82	13.77	0.25	73.85	1.02	1.04	0.95	1.13
4th	8.96	6.83	11.95	13.37	0.31	73.23	1.01	1.02	0.93	1.12
5th	16.05	12.04	41.71	13.16	0.52	69.20	0.95	0.99	0.86	1.14
Ultra-processed foods										
1st	36.38	15.11	43.67	10.35	0.38	46.41	1.00	1.00	–	–
2nd	49.00	43.72	53.03	12.37	0.30	66.78	1.44	1.39	1.15	1.70
3rd	57.17	53.06	60.95	13.84	0.37	74.22	1.60	1.50	1.24	1.81
4th	65.58	60.96	70.14	14.48	0.26	80.95	1.74	1.62	1.35	1.95
5th	78.05	70.15	100	15.32¥	0.25	81.41	1.75¥	1.62¥	1.35	1.95

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.001).

Table 3. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 11 - 18 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	14.43	0.00	20.89	17.28	0.36	88.89	1.00	1.00	–	–
2nd	24.61	20.92	28.43	15.87	0.35	84.30	0.95	0.95	0.89	1.01
3rd	31.46	28.44	34.93	15.50	0.37	81.82	0.92	0.92	0.86	0.99
4th	39.24	34.98	43.84	13.96	0.43	78.15	0.88	0.89	0.82	0.96
5th	52.96	43.88	79.86	13.60¥	0.80	66.92	0.75¥	0.77¥	0.66	0.88
Processed foods										
1st	0.29	0.00	1.33	17.18	0.41	85.11	1.00	1.00	–	–
2nd	2.56	1.34	3.79	15.81	0.35	81.74	0.96	0.96	0.90	1.03
3rd	5.16	3.80	6.81	15.62	0.35	86.87	1.02	1.02	0.96	1.09
4th	8.94	6.82	11.95	14.52	0.43	79.40	0.93	0.93	0.86	1.01
5th	17.53	12.05	41.62	13.68¥	0.57	74.89	0.88¥	0.87¥	0.78	0.99
Ultra-processed foods										
1st	35.29	18.40	42.94	12.72	1.39	56.18	1.00	1.00	–	–
2nd	49.35	43.70	53.03	13.65	0.56	75.73	1.35	1.34	1.03	1.74
3rd	56.91	53.08	60.96	14.19	0.40	79.24	1.41	1.40	1.09	1.80
4th	65.63	60.96	70.13	14.99	0.32	80.76	1.44	1.42	1.11	1.82
5th	79.05	70.14	100	17.37¥	0.29	89.04	1.58¥	1.56¥	1.23	1.99

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles ($p \leq 0.001$).

Table 4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 19 - 64 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.06	0.00	20.92	15.11	0.36	35.87	1.00	–	–	
2nd	24.93	20.95	28.41	12.87	0.31	31.12	0.85	0.87	0.79	0.96
3rd	31.65	28.43	34.96	11.97	0.31	30.87	0.79	0.85	0.77	0.94
4th	38.95	34.97	43.88	11.01	0.28	28.45	0.66	0.72	0.64	0.80
5th	54.24	43.93	91.90	9.89¥	0.25	25.28	0.57¥	0.62¥	0.55	0.71
Processed foods										
1st	0.28	0.00	1.32	13.09	0.50	59.14	1.00	1.00	–	–
2nd	2.60	1.34	3.79	12.82	0.41	60.65	1.03	1.04	0.92	1.19
3rd	5.35	3.79	6.82	12.17	0.30	61.42	1.04	1.04	0.92	1.18
4th	9.36	6.82	12.03	11.62	0.26	55.92	0.95	0.98	0.87	1.11
5th	19.80	12.04	65.22	11.27¥	0.22	52.47	0.89¥	0.92¥	0.82	1.03
Ultra-processed foods										
1st	34.45	1.82	43.67	9.62	0.27	39.42	1.00	1.00	–	–
2nd	48.70	43.69	53.04	11.11	0.25	53.34	1.35	1.30	1.13	1.50
3rd	57.08	53.06	60.96	11.83	0.29	56.84	1.44	1.37	1.19	1.57
4th	65.34	60.96	70.14	13.09	0.32	66.31	1.68	1.57	1.37	1.79
5th	78.04	70.15	100	15.21¥	0.38	74.30	1.88¥	1.67¥	1.46	1.92

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.001).

Table 5. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 65 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	16.63	6.34	20.82	11.67	0.87	56.16	1.00	1.00	–	–
2nd	25.04	20.95	28.36	12.83	0.61	67.39	1.20	1.19	0.90	1.57
3rd	32.06	28.44	34.90	11.98	0.48	64.37	1.15	1.15	0.87	1.52
4th	39.30	34.98	43.85	10.93	0.44	53.96	0.96	0.97	0.73	1.28
5th	52.26	43.89	78.36	10.70	0.42	50.94	0.91¥	0.91¥	0.69	1.21
Processed foods										
1st	0.38	0.00	1.32	9.70	0.72	43.52	1.00	1.00	–	–
2nd	2.42	1.34	3.78	12.13	0.56	64.30	1.48	1.49	1.14	1.96
3rd	5.23	3.79	6.81	12.16	0.45	65.00	1.49	1.52	1.17	1.98
4th	9.27	6.82	12.02	11.10	0.47	54.46	1.25	1.27	0.96	1.67
5th	19.10	12.04	50.86	11.23	0.46	53.62	1.23	1.29	0.97	1.69
Ultra-processed foods										
1st	35.98	7.79	43.69	10.63	0.49	47.63	1.00	1.00	–	–
2nd	48.67	43.74	53.02	11.30	0.48	58.67	1.23	1.20	0.97	1.47
3rd	56.97	53.05	60.91	11.61	0.45	59.89	1.26	1.21	0.98	1.50
4th	64.99	61.01	70.08	12.01	0.54	65.53	1.38	1.35	1.09	1.66
5th	75.66	70.17	92.30	11.67	0.70	53.75	1.13	1.06	0.81	1.40

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles (p≤0.001).

In our counterfactual scenarios, we calculated the percentage of excessive free sugar intake avoided if the consumption of ultra-processed foods and table sugar were zero (**Figure 1**). We estimated that about 47% of excessive free sugars intake in the UK population could be potentially avoided if the consumption of ultra-processed foods was eliminated. Eliminating table sugar could potentially avoid 9.4% of the excessive free sugars intake. This greater reduction in the percentage of excessive free sugar intake due to elimination of ultra-processed foods, relative to table sugar, was observed in all age groups, except in the elderly group where both scenarios had similar impacts on total free sugar intake.

DISCUSSION

In this large, nationally representative sample of the UK population, higher consumption of ultra-processed food was associated with greater dietary content of free sugars in children, adolescents, and adults. Using theoretical minimum risk exposure level scenarios, we also showed that by eliminating ultra-processed food consumption, the prevalence of excessive free sugar intake (10% or more of total energy intake) could be potentially reduced from 60% to 28%. Greater reduction could be achieved in children (from 74% to 28%) and adolescents (from 83% to 29%).

Our findings confirm an excessive consumption of free sugars in the UK diet [13] and show that ultra-processed foods contributed nearly 65% of all free sugars in all age groups and nearly 80% in children and adolescents. Unprocessed or minimally processed foods (mostly fresh juice) and processed culinary ingredients (mostly table sugar) contributed between 19% and 27% of the dietary content of free sugars, while processed foods provided the lowest contribution in all age groups.

Our findings are similar to previous studies conducted in high- and middle-income countries that have shown strong associations between the intake of ultra-processed foods and the dietary content of free sugars [8-11]. A previous study conducted in Chile similarly showed that the association between ultra-processed food consumption and the dietary content of added sugars is more pronounced among children and adolescents [12]. In our study there was no association between ultra-processed food consumption and dietary content of free sugars among the elderly, probably due to differences in the type of ultra-processed foods consumed in this age group, with salted products more likely to be consumed than the sweetened products.

There is strong evidence that the high consumption of free sugars contributes to excess obesity, type 2 diabetes, dyslipidaemia, hypertension and coronary heart disease [2-4]. Consequently, most dietary recommendations now advise limiting free sugar intake, but more focused efforts are needed to put this recommendation into practice. Changing personal behaviour and choice alone is not an effective or realistic option as our findings confirm that the majority of free sugar is added to food before it is marketed and sold. Voluntary agreements between industry and government have been shown repeatedly to be ineffective in improving public health [24]. This is confirmed by recent UK experience where the early stages of the government's sugar reduction programme, which challenged the food industry to voluntarily cut sugar in some products, has produced only slow progress toward proposed targets [25]. Thus, more drastic measures that change the availability, price and marketing of these products is necessary.

The analyses presented here suggest that actions to reduce the consumption of ultra-processed foods generally rich in free sugars could lead to larger public health benefits. Policies concerning the use of fiscal measures to reduce intake of free sugars and improve diet quality should consider extending beyond artificially sweetened beverages to include the main driver of excessive free sugar intake, including dairy drinks, cakes, biscuits and confectionery [13].

To our knowledge, this is the first study to examine the association between consumption of ultra-processed foods, as defined per NOVA [6], and dietary content of free sugar in different age groups of the UK population. The use of NOVA is a key strength of the study as it classified foods by their level of processing level using standardised and objective criteria. NOVA has been recognised as a valid tool for public health and nutrition research and policy by the Food and Agricultural Organization of the United Nations [26] and the Pan American Health Organization [27]. In addition, we used data from the NDNS - a large and nationally representative sample of the UK population, applying weighting to reduce any sampling and non-response bias. Unlike household budget data, food diaries employed in the NDNS take food wastage into account, include food eaten out of home, and do not assume that all individuals within a household consume the same diet. Importantly, the dietary data also allowed for the disaggregation of dishes into their constituents and classification of the underlying ingredients, which enabled the calculation of more precise estimates of intakes of each NOVA group and reduced misclassification.

Potential limitations should be considered. The dietary data we used were self-reported and may be subject to misclassification. A constant limitation of dietary assessment methods is underreporting of some foods (particularly unhealthy foods), though food diaries are recognised to be one of the most comprehensive methods for assessing dietary intake. Possible underreporting of unhealthy foods may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of free sugars, but may less likely affect the association between these variables. Nevertheless, accurate and valid NDNS data were achieved through optimal methods for collecting dietary intake [28] which helped to minimise missing information. NDNS collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items. This bias is more likely for a small number of specific food items such as pizza where there is insufficient information for classification purposes (see **Suppl. Table S2**). In those cases, the most frequently consumed alternative (culinary preparation or manufactured product) was chosen. Finally, our theoretical minimum risk exposure models estimate the potential impact of eliminating each of the main sources of free sugars on excessive free sugar intake, ignoring substitutions that may occur in the consumption of other foods. Although our findings suggest that greater reduction in excessive free sugar intake could be achieved by eliminating ultra-processed food consumption, guidance to the public about reducing the consumption of table sugar remains an important component of any public health guidance.

Conclusions

Almost half of excessive intake of free sugars in the UK can be attributed to ultra-processed foods. Policies to reduce sugar consumption should focus on minimizing consumption of ultra-processed foods and replacing them with unprocessed or minimally processed foods alternatives. The study adds to a growing body of evidence that ultra-processed foods are a major contributor to growth of diet related non-communicable diseases globally.

Author contributions: CAM, EMS, FR, MLdCL, and RBL designed the research. FR and RBL undertook data management and analysis. CAM, CM, EMS, FR, LFMR, MLdCL, and RBL interpreted the data. FR wrote the first draft of the manuscript. All authors read, edited and approved the final manuscript.

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Competing interests: None declared.

Data sharing statement: This study is based on open data of the UK population that is available in the UK Data Archive website (http://www.esds.ac.uk).

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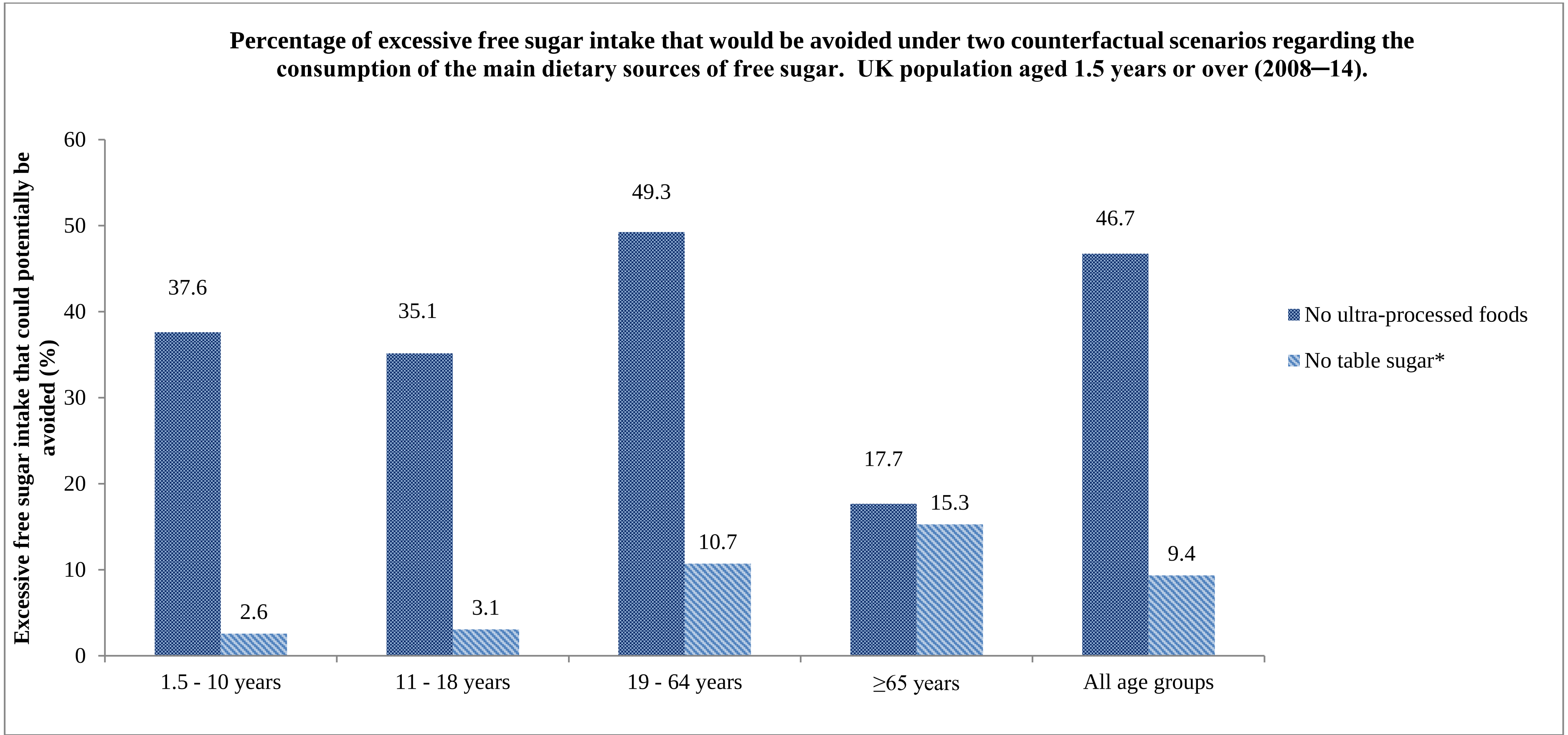
Firgure 1. Percentage of excessive free sugar intake that would be avoided under two counterfactual scenarios regarding the consumption of the main dietary sources of free sugar. UK population aged 1.5 years or over (2008–14).

Figure 1.



*Including honey, molasses, maple syrup (100%).

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study.

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Supplementary table S1. The Nova food classification system*

Food groups	Examples
1) Unprocessed foods or minimally processed foods Natural foods altered by methods such as freezing, pasteurization, fermentation, removal of inedible or unwanted parts, grinding, and other methods that do not include the addition of substances such as salt, sugar and/or oils or fats.	Fresh, dry or frozen fruits or vegetables; legumes; grains, roots and tubers, flours and pasta; pasteurized or power plain milk and plain yogurt; fresh or frozen meat (fish, poultry and red meat); eggs; nuts and seeds; fungi; fresh or pasteurised fruit or vegetable juices without added sugar, sweeteners or flavours; tea, coffee and drinking water.
2) Processed culinary ingredients Substances obtained directly from group 1 foods or from nature by processes that include pressing, refining, grinding, milling, and drying, and consumed in combination with group 1 foods in freshly prepared dishes or drinks.	Salt; sugar, honey and molasses; vegetable oils; butter and lard; starches extracted from corn and other plants.
3) Processed foods Products manufactured with the addition of group 2 substances (e.g. salt, sugar, oil, and fats) to group 1 foods and alcoholic drinks produced by fermentation of group 1 foods such as beer, cider and wine.	Canned or bottled vegetables, fruits and legumes; salted or sugared nuts and seeds; salted, cured, or smoked meats; canned fish; fruits in syrup; cheeses and unpackaged freshly made breads.
4) Ultra-processed foods Food and drink formulations made from several ingredients. Such ingredients include salt, sugar, oils, and fats but also other substances derived from foods but not commonly used as culinary ingredients (such as protein isolates, hydrogenated oils, modified starches) and additives used to imitate sensory quality of natural foods and freshly prepared dishes or to disguise unpalatable aspects of the final product (such as flavours, colours, sweeteners, emulsifiers). Alcoholic drinks produced by fermentation of group 1 foods followed by distillation of the resulting alcohol, such as whisky, gin, rum, vodka, are classified in group 4.	Carbonated drinks; sweet or savoury packaged snacks; confectionery; mass-produced packaged breads and buns; margarines and spreads; biscuits, pastries, cakes, and cake mixes; breakfast 'cereals', 'cereal' and 'energy' bars; 'energy' drinks; milk drinks, 'fruit' yoghurts and 'fruit' drinks; cocoa drinks; meat and chicken extracts and 'instant' sauces; ready to heat products including pre-prepared pies and pasta and pizza dishes; poultry and fish 'nuggets' and 'sticks', sausages, burgers, hot dogs, and other reconstituted meat products, and powdered and packaged 'instant' soups, noodles and desserts.

Adapted from Monteiro et al. (2016 and 2018).

Monteiro CA, Cannon G, Moubarac JC et al. (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr 21, 5-17.

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Supplementary Table S2. Coding of subsidiary food groups from National Diet and Nutrition Survey according to NOVA classification.

Subsidiary food group code	Subsidiary food group name	NOVA food group†
1C	Pizza	4
1D	Pasta (manufactured products and ready meals	4
1E	Pasta (other, including homemade dishes)	*
1F	Rice (manufactured products and ready meals)	4
1G	Rice (other, including homemade dishes)	*
1R	Other cereals	*
2R	White bread (not high fibre, not multiseed bread)	4
3R	Wholemeal bread	4
4R	Other bread	4
5R	High fibre breakfast cereals	4
6R	Other breakfast cereals (not high fibre)	4
7A	Biscuits(manufactured/retail)	4
7B	Biscuits (homemade)	*
8B	Fruit pies (manufactured)	4
8C	Fruit pies (homemade)	*
8D	Buns cakes and pastries (manufactured)	4
8E	Buns cakes and pastries (homemade)	*
9C	Cereal based milk puddings (manufactured)	4
9D	Cereal based milk puddings (homemade)	*
9E	Sponge puddings (manufactured)	4
9F	Sponge puddings (homemade)	*
9G	Other cereal based puddings (manufactured)	4
9H	Other cereal based puddings (homemade)	*
10R	Whole milk	1
11R	Semi-skimmed milk	1
12R	Skimmed milk	1
13A	Infant formula	4
13B	Cream (including imitation cream)	*
13R	Other milk	*
14A	Cottage cheese	3
14B	Cheddar cheese	3
14R	Other cheese	*
15B	Yogurt	*
15C	Fromage frais and other dairy desserts (manufactured)	4
15D	Dairy desserts (homemade)	*
16C	Manufactured egg products, including ready meals	4
16D	Other eggs and egg dishes, including homemade	*
17R	Butter	2
18A	Polyunsaturated margarine	4
18B	Polyunsaturated oils	2
19A	Polyunsaturated low fat spread	4
19R	Low fat spread not polyunsaturated	4
20A	Block margarine	4
20B	Soft margarine not polyunsaturated	4
20C	Other cooking fats and oils not polyunsaturated	2
21A	Reduced fat spread (polyunsaturated)	4
21B	Reduced fat spread (not polyunsaturated)	4
22A	Ready meals/meal centres based on bacon and ham	4
22B	Other bacon and ham (including homemade dishes)	*
23A	Manufactured beef products (including ready meals)	4
23B	Other beef & veal (including homemade recipe dishes)	*
24A	Manufactured lamb products (including ready meals)	4
24B	Other lamb (including homemade recipe dishes)	*
25A	Manufactured pork products(including ready meals)	4
25B	Other pork (including homemade recipe dishes)	*
26A	Manufactured coated chicken/turkey products	4
27A	Manufactured chicken products (including ready meals)	4
27B	Other chicken/turkey (including homemade recipe dishes)	*
28R	Liver and dishes	*
29R	Burgers and kebabs purchased	4
30A	Ready meals based on sausages	4
30B	Other sausages (including homemade dishes)	*
31A	Meat pies and pastries (manufactured)	4
31B	Meat pies and pastries (homemade)	*
32A	Other meat products (manufactured including ready meals)	4
32B	Other meat (including homemade recipe dishes)	*

33R	White fish coated or fried	*
34C	Manufactured white fish products (including ready meals)	4
34D	Other white fish (including homemade dishes)	*
34E	Manufactured shellfish products (including ready meals)	4
34F	Other shellfish (including homemade dishes)	*
34G	Manufactured canned tuna products (including ready meals)	*
34H	Other canned tuna (including homemade dishes)	*
35A	Manufactured oily fish products (including ready meals)	4
35B	Other oily fish (including homemade dishes)	*
36A	Carrots (raw)	1
36B	Salad and other raw vegetables	*
36C	Tomatoes raw	1
37A	Peas not raw	*
37B	Green beans not raw	*
37C	Baked beans	4
37D	Leafy green vegetables not raw	*
37E	Carrots not raw	*
37F	Tomatoes not raw	*
37I	Beans and pulses (including ready meal & homemade dishes)	*
37K	Meat alternatives (including ready meals and homemade dishes)	4
37L	Other manufactured vegetable products (including ready meals)	4
37M	Other vegetables (including homemade dishes)	*
38A	Chips purchased including takeaway	4
38C	Other manufactured potato products fried/baked	4
38D	Other fried/roast potatoes (including homemade dishes)	*
39A	Other potato products and dishes(manufactured)	4
39B	Other potatoes (including homemade dishes)	*
40A	Apples and pears not canned	*
40B	Citrus fruit not canned	*
40C	Bananas	*
40D	Canned fruit in juice	*
40E	Canned fruit in syrup	3
40R	Other fruit not canned	*
41A	Sugar	*
41B	Preserves	3
41R	Sweet spreads fillings and icing	4
42R	Crisps and savoury snacks	4
43R	Sugar confectionery	4
44R	Chocolate confectionery	4
45R	Fruit juice	*
47A	Liqueurs	4
47B	Spirits	4
48A	Wine	3
48B	Fortified wine	4
48C	Low alcohol and alcohol free wine	3
49A	Beers and lagers	3
49B	Low alcohol & alcohol free beer & lager	3
49C	Cider and Perry	4
49D	Low alcohol & alcohol free cider & Perry	4
49E	Alcoholic soft drinks (Alcopops)	4
50A	Beverages dry weight	4
50C	Soup (manufactured/retail)	4
50D	Soup (homemade)	*
50E	Nutrition powders and drinks	4
50R	Savoury sauces pickles gravies & condiments	4
51A	Coffee (made up weight)	*
51B	Tea (made up)	*
51C	Herbal tea (made up)	1
51D	Bottled water still or carbonated	*
51R	Tap water only	1
52A	Commercial toddlers drinks	3
52R	Commercial toddlers foods	3
53R	Ice cream	4
54A	Cod liver oil and other fish oils	**
54B	Evening primrose oil and other plant oils	**
54C	Single vitamins/minerals not Folic acid, iron, calcium	**
54D	Folic acid	**
54E	Iron only or with vitamin C	**
54F	Calcium only or with vitamin D	**
54G	Vitamins (two or more including multivitamins) no minerals	**
54H	Minerals (two or more including multimineral) no vitamins	**
54I	Vitamins and minerals (including multivitamins & minerals)	**
54J	Non-nutrient supplements (including herbal)	**

54K	Other nutrient supplements	**
54L	Vitamin C	**
54M	Single vitamins/minerals not Folic acid, iron, calcium or vitamin C	**
54N	Cod liver oil and other fish oils (including with vitamins A, D, E)	**
54P	Multivitamins and/or minerals with omega ultra-processed	**
55R	Artificial sweeteners	4
56R	Nuts and seeds	*
57A	Soft drinks not low calorie concentrated	4
57B	Soft drinks not low calorie carbonated	4
57C	Soft drinks not low calorie, ready to drink, still	4
58A	Soft drinks low calorie concentrated	4
58B	Soft drinks low calorie carbonated	4
58C	Soft drinks low calorie, ready to drink, still	4
59R	Brown, granary and wheat germ bread	4
60R	1% Milk	1
61R	Smoothies	1

† NOVA food groups defined as 1) unprocessed or minimally processed foods; 2) processed culinary ingredients; 3) processed foods; and 4) ultra-processed foods.
* All foods within this subsidiary food group were individually coded (by food name).
** Supplements were not included in any of the NOVA food groups.
Source: Rauber F, Louzada MLC, Steele EM, Millett C, Monteiro CA, Levy RB. Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). Nutrients 2018, 10, 587; doi:10.3390/nu10050587.

Supplementary table S3. Dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008─14).

Age groups	% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars		
	mean	**SE**	*%*	*95%CI*	
1.5 - 10 years	14.00	0.14	97.16	96.29	97.84
11 - 18 years	15.78	0.19	96.77	95.62	97.62
19 - 64 years	11.93	0.14	88.82	87.48	90.04
≥65 years	11.36	0.23	87.62	84.88	89.93
All age groups	**12.44**	**0.10**	**90.34**	**89.39**	**91.21**

Supplementary table S4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars					Individuals with ≥10% of total energy intake from free sugars				
Quintile	**mean**	**min**	**max**	**mean**	**SE**	**%**	**PR***	**PRadj[¦]**	**95%CI**		**%**	**PR***	**PRadj[¦]**	**95%CI**	
Unprocessed or minimally processed foods + Processed culinary ingredients															
1st	15.10	0.00	20.92	15.36	0.24	95.94	1.00	1.00	—	—	77.42	1.00	1.00	—	—
2nd	24.90	20.92	28.43	13.44	0.22	94.28	0.98	0.99	0.97	1.01	68.55	0.89	0.92	0.86	0.97
3rd	31.68	28.43	34.96	12.62	0.21	91.92	0.96	0.97	0.95	1.00	65.09	0.84	0.89	0.84	0.95
4th	39.08	34.97	43.88	11.46	0.21	89.70	0.93	0.96	0.93	0.98	55.09	0.71	0.77	0.72	0.83
5th	53.57	43.88	91.90	10.32[¥]	0.19	82.41	0.86	0.89	0.86	0.92	46.36	0.60[¥]	0.67[¥]	0.61	0.73
Processed foods															
1st	0.32	0.00	1.33	13.53	0.29	87.19	1.00	1.00	—	—	64.14	1.00	1.00	—	—
2nd	2.55	1.34	3.79	13.48	0.24	92.34	1.06	1.06	1.03	1.10	67.93	1.06	1.08	1.01	1.16
3rd	5.28	3.79	6.82	12.83	0.19	92.39	1.06	1.07	1.03	1.10	67.10	1.05	1.08	1.00	1.16
4th	9.28	6.82	12.03	11.89	0.20	90.61	1.04	1.06	1.02	1.09	58.87	0.92	0.98	0.91	1.06
5th	19.54	12.04	65.22	11.38[¥]	0.19	89.40	1.03	1.04	1.01	1.08	53.70	0.84[¥]	0.91[¥]	0.84	0.98
Ultra-processed foods															
1st	34.89	1.82	43.69	9.94	0.22	80.50	1.00	1.00	—	—	41.87	1.00	1.00	—	—
2nd	48.74	43.69	53.04	11.34	0.20	89.16	1.11	1.10	1.05	1.15	56.35	1.35	1.31	1.18	1.46
3rd	57.06	53.05	60.96	12.16	0.21	92.65	1.15	1.14	1.09	1.18	60.76	1.45	1.39	1.25	1.54
4th	65.37	60.96	70.14	13.38	0.21	94.08	1.17	1.15	1.10	1.19	70.18	1.68	1.55	1.41	1.72
5th	78.06	70.14	100.00	15.41[¥]	0.21	95.30	1.18[¥]	1.15[¥]	1.10	1.19	77.20	1.84[¥]	1.64[¥]	1.48	1.81

*PR=Prevalence ratios estimated using Poisson regression.

[¦]PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

[¥]Significant linear trend across all quintiles ($p \leq 0.001$).

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1, 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4, 5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	6,7,9
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8,9
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	8
Outcome data	15*	Report numbers of outcome events or summary measures	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12-16

		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18,19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19
Generalisability	21	Discuss the generalisability (external validity) of the study results	17,18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Secondary Subject Heading:	Epidemiology, Nutrition and metabolism
Keywords:	Food processing, Ultra-processed, Free sugar, United Kingdom

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Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study

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Word count: 3,599

ABSTRACT

Objectives: to describe dietary sources of free sugars in different age groups of the UK population considering food groups classified according to the NOVA system and to estimate the proportion of excessive free sugars that could potentially be avoided by reducing consumption of their main sources.

Design and setting: Cross-sectional data from the UK National Diet and Nutrition Survey (2008–14) were analysed. Food items collected using a four-day food diary were classified according to the NOVA system.

Participants: 9,364 individuals aged 1.5 years and above.

Main outcome measures: Average dietary content of free sugars and proportion of individuals consuming more than 10% of total energy from free sugars.

Data analysis: Poisson regression was used to estimate the associations between each of the NOVA food group and intake of free sugars. We estimated the percent reduction in prevalence of excessive free sugar intake from eliminating ultra-processed foods and table sugar. Analyses were stratified by age group and adjusted for age, sex, ethnicity, region, and equivalised household income (sterling pounds).

Results: Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Free sugars represent 12.4% of total energy intake and 61.3% of the sample exceeded the recommended limit of 10% energy from free sugars. This percentage was higher among children (74.9%) and adolescents (82.9%). Prevalence of excessive free sugar intake increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly. Eliminating ultra-processed foods could potentially reduce the prevalence of excessive free sugar intake by 47%.

Conclusion: Our findings suggest that actions to reduce the ultra-processed food consumption generally rich in free sugars could lead to substantial public health benefits.

Keywords: Food processing; Ultra-processed; Free sugar; United Kingdom.

ARTICLE SUMMARY

Strengths and limitations of this study

- Use of a large and nationally representative sample of the UK population, increasing generalisability.
- Use of data on free sugars rather than total sugars or sugar-sweetened beverages, which correspond to the guidelines relevant area of prioritisation.
- Use of NOVA system, which has been recognised as a valid tool for public health and nutrition research and policy by international organizations.
- Dietary data obtained by food diaries are subject to potential error and bias.
- UK national dietary survey collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items.

INTRODUCTION

Excessive consumption of free sugar is associated with obesity, type 2 diabetes, dental caries, and several other health outcomes [1-4]. To address this associated health burden, the World Health Organization (WHO) [5] recommends that free sugars should be reduced to less than 10% of total energy intake and also suggests a level below 5% to obtain additional health benefits, such as reduction of dental caries. Achievement of this ambitious target will require bold and systematic efforts to reduce sugar across a variety of food products in most settings.

As defined by the NOVA food classification system, ultra-processed foods are industrial formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed) [6]. In some high-income countries, including the UK, ultra-processed foods account for more than half of total dietary energy intake [7-9]. Importantly, national dietary surveys conducted in high- and middle-income countries [8-12] have shown a strong and positive association between consumption of ultra-processed foods and excessive dietary added (or free) sugar intake. Free sugars include sugars added to foods by the manufacturer, cook and consumer, plus sugars naturally present in honey, syrups and fruit juices [5], while added sugars captures all free sugars, but exclude naturally occurring sugars in fruit juices.

Free sugar intake in the UK is high, ranging from 11 to 15% of total energy intake [13]. To address this, the UK has implemented a number of measures including a sugar-sweetened beverage levy in 2018. However, action on sugar sweetened beverages alone is unlikely to reduce population level sugar intake to WHO recommended levels. In a more recent publication, the voluntary sugar reduction programme continues being endorsed by the government, but other measures such as restriction of advertising and in-store promotions of some sugary foods are also being considered as strategies to reduce childhood obesity [14]. A better understanding of the key sources of sugar intake in the UK diet is required to inform policy development. This study aims to describe the dietary sources of free sugars in different age groups of the UK population taking into account food groups classified according to the NOVA classification system and estimate the proportion of excessive free sugars that could be potentially avoided by reducing the consumption of their main dietary sources.

METHODS

Data source and collection

We used data from the National Diet and Nutrition Survey Rolling Programme (NDNS) years 1-6 (2008/09-2009/10, 2010/11-2011/12, 2012/13-2013/14) combined, which is a cross-sectional survey of people aged 1.5 years or older. The survey was designed to be representative of the UK population and provides comprehensive information on food intake. Details of the rationale, design, and methods of the survey have been described elsewhere [15]. Briefly, the sample was drawn from households randomly selected from the UK Postcode Address File, a list of all UK addresses. One adult (aged 19 years and older) and one child (aged 1.5–18 years), if available, were randomly selected from each household. Only a child was selected from some households to be part of a 'child boost' to ensure approximately equal numbers of children and adults. Participants (or in the case of children ≤11 years, their parent/carer) completed a four-day food diary and participated in an interview that included data on socio-demographic status.

Participants were asked to report all foods and drinks consumed both within and outside the home. Portion sizes were estimated using household measures or weights from packaging. Once completed, diaries were checked by interviewers with respondents and missing details added to improve completeness. Diary days were randomly selected to ensure balanced representation of all days of the week. All individuals who completed three or four days of dietary recording were eligible for inclusion in the study, giving a sample size of 9,374 (4,738 adults and 4,636 children) participants for years 1 to 6 (2008/09 to 2013/14) combined.

The food intake data from completed records were coded and edited using the software DINO (Diet In, Nutrients Out) and food and nutrient intakes estimated using nutrient composition data from the Department of Health's Nutrient Databank, updated for each survey year [16, 17]. Free sugars are defined as sugars added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups, fruit juices and fruit concentrates [5]. Intakes in the UK NDNS years 1-6 were expressed as non-milk extrinsic sugars (NMES). The term NMES captures all sugars defined by the term free sugars while also including half of the sugars present in dried, stewed or canned fruit. The NMES values could be slightly higher in some cases than the free sugar values, mostly in the non-ultra-processed food group since the term free sugar does not include sugars contributed by dried and processed fruits. Based on the assumption that those definitions are sufficiently similar for assessment and monitoring purposes [1,3], this study used the term free sugars.

Computerized raw data files and documentation from this survey were obtained under license from the UK Data Archive (http://www.esds.ac.uk). All relevant research ethics and governance committees approved the survey.

Food classification according to processing

We classified all recorded food items according to NOVA, a food classification system based on the nature, extent, and purpose of the industrial food processing [6]. This classification includes four groups: 1) unprocessed or minimally processed foods (e.g. fresh, dry or frozen fruits or vegetables; grains, flours and pasta; pasteurized or power plain milk, plain yogurt, fresh or frozen meat); 2) processed culinary ingredients (e.g. table sugar, oils, butter, and salt); 3) processed foods (e.g. vegetables in brine, cheese, simple breads, fruits in syrup, canned fish); and 4) ultra-processed foods (e.g. soft drinks, sweet or savoury packaged snacks, confectionery; packaged breads and buns; reconstituted meat products and pre-prepared frozen or shelf-stable dishes) (**see Suppl. Table S1**). The detailed description of NOVA classification can be found elsewhere [6, 18].

All foods in NDNS are coded as food number and grouped into subsidiary food groups (n = 155). When possible, subsidiary food groups were directly classified according to NOVA (**see Suppl. Table S2**). When foods within a subsidiary food group pertained to different NOVA groups (n = 52), it was the food codes instead of the group, which were individually classified. By doing so, we were able to classify each underlying ingredient of homemade dishes in its corresponding NOVA group. Subsidiary food groups as classified by NOVA are described in the Supplementary Table S2.

Although the NDNS database was provided with most food items systematically disaggregated into their individual components, about 4% of composite food codes were still mixed dishes compiled from two or more single-ingredient food code [19]. The method we adopted to disaggregate food codes has been described previously [19]. Using the core sample of years 1 to 4 (2008/09 to 2011/12) (n = 4,125), we estimated that composite food codes represented only 3% of total calories. In this case, dishes were categorised according to the main constituent ingredient. Dishes in which a main constituent ingredient was not clearly identified (e.g. chicken and vegetable soup) were classified as a specific subgroup of freshly prepared dishes based on one or more unprocessed or minimally processed food (group 1). Non-caloric supplements were not included in the analyses.

Covariates

Covariates included were age (years), sex, ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region (England North, England Central/Midlands, England South (including London), Scotland, Wales, and Northern Ireland), survey year (years 1-6), and equivalised household income (equivalised for different household sizes and composition using the McClements equivalence scale [15]). Due to the significant proportion of missing values for the equivalised household income (12.8%), we applied multiple imputation by chained equation method based on age, sex, ethnicity, excessive free sugars intake and ultra-processed food consumption. Multiple imputation was performed 20 times, and the Monte Carlo error analysis showed good statistical reproducibility of the results [20].

Data analysis

For each survey day and age group (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years), we defined extreme total energy intake outliers as values below the 1st and above the 99th percentiles [21]. Based on these criteria, we excluded ten individuals who had all days of food diary classified as outliers. In total, 9,364 (4,729 adults and 4,635 children) participants were eligible for inclusion in the analyses and more than 91% completed the four food diary days. We used the mean of all available days of food diary for each individual.

Food items were sorted into mutually exclusive food groups according to NOVA classification. We combined the group of unprocessed or minimally processed foods with the group of processed culinary ingredients, as foods belonging to these two groups are usually combined together in culinary preparations and, therefore, consumed together. Thus, we performed the analyses considering three groups of foods: unprocessed or minimally processed foods and processed culinary ingredients, processed foods, and ultra-processed foods.

First, we estimated the distribution of total energy and free sugars intake according to the food groups. Then, we calculated the mean free sugars intake of the overall diet and the prevalence of excessive intake of free sugars. We used the WHO recommendations [5] to assess the excessive intake of free sugars (≥10% of total energy). Analyses using the UK recommendations to further limit free sugars intake to less than 5% of total energy intake are presented in a supplementary table **(Suppl. Table S3)**. Analyses were carried out for the entire population and also stratified by age group.

Next, the prevalence of excessive intake of free sugars (≥10% of total energy) was compared across quintiles of the energy share provided by each of the three food groups. Poisson regression was used to estimate prevalence ratios (PR) and 95% confidence intervals for the associations between each of the three NOVA food group quintiles and prevalence of individuals consuming more than 10% of total energy from free sugars. Tests of linear trend were performed to evaluate the quintiles as a single continuous variable. All analyses were stratified by age group. Multiple regression models were also performed to adjust for age, sex, ethnicity, region, survey year, and equivalised household income (sterling pounds). Analyses using the entire population are presented in a supplementary table **(Suppl. Table S4)**. We also evaluated the extent to which the association between the exposure (dietary contribution of NOVA food groups) and the dietary content in free sugars changed according to the survey year, by including a multiplicative interaction term (survey year*dietary contribution of NOVA food groups) in the fully adjusted models.

Finally, we estimated the proportion of excessive free sugar intake that could be potentially avoided if exposure to the risk factors were eliminated (theoretical minimum risk exposure level scenarios) [22, 23]. The counterfactual scenarios were defined considering the main dietary sources of free sugars. The first counterfactual scenario assumed no consumption of ultra-processed food (potentially hidden sugars), while in the second scenario table sugar consumption was set to zero. Table sugar included honey, molasses, maple syrup (100%), and sugar added to coffee/juice and homemade dishes (potentially sugar that can be measured by the consumer). Examples of homemade dishes include: biscuits, fruit pies, buns cakes and pastries, cereal based milk puddings, and sponge pudding (**see Suppl. Table S2**).

In both scenarios, we first calculated the prevalence of excessive free sugar intake in the UK population ($P_{population}$). We then estimated the predicted prevalence of excessive free sugar intake that would be expected had the consumption of each of these main sources of free sugars being zero ($P_{nonexposed}$). Lastly, we calculated the proportion of excessive free sugar intake that could be potentially avoided in each scenario using the following formula: $(P_{population} - P_{nonexposed}) / P_{population}$. Prevalences were adjusted for sex, age, ethnicity, region, survey year, and household income.'

NDNS study weights were used in all analyses to account for sampling and non-response error. All statistical analyses were carried out using Stata Statistical Software version 14. The *p* values reported were two-tailed, and a threshold of <0.01 was considered for statistically significant associations.

Patient and public involvement

Patients and/or public were not involved in in the design or conduct of this study.

RESULTS

Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Unprocessed or minimally processed foods and processed culinary ingredients represented an additional 34.3% of total energy intake and 23.8% of free sugars, and processed foods the remaining 8.8% of total energy intake and 11.5% of free sugars. Ultra-processed foods accounted for a higher percentage of total energy intake among children (63.5%) and adolescents (68%). The average UK daily intake of free sugars was 12.4% (SE 0.1) of total energy intake and 61.3% of British exceeded the recommended limit of 10% energy from free sugars. This proportion was even higher among children (74.9%) and adolescents (82.9%) (**Table 1**).

Table 1. Dietary contribution of NOVA food groups and indicators of the dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

Age groups	Dietary contribution (% of total energy intake)						% of total energy intake from free sugars								Individuals with ≥10% of total energy intake from free sugars		
	Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Total		Overall diet		
	Mean	*SE*					*Mean*	*SE*							*%*	*95%CI*	
1.5 - 10 years	31.96	0.33	4.51	0.10	63.53	0.34	18.82	0.45	5.15	0.22	76.03	0.49	14.00	0.14	74.94	72.78	76.99
11 - 18 years	27.25	0.37	4.75	0.16	68.00	0.40	18.63	0.55	2.48	0.19	78.89	0.57	15.78	0.19	82.91	80.72	84.90
19 - 64 years	34.75	0.32	10.37	0.19	54.89	0.35	24.68	0.50	12.96	0.38	62.36	0.56	11.93	0.14	56.59	54.47	58.68
≥65 years	38.57	0.49	8.45	0.29	52.98	0.52	26.77	0.96	15.38	0.69	57.86	1.01	11.36	0.23	56.83	52.98	60.59
Total	**34.35**	**0.22**	**8.83**	**0.13**	**56.82**	**0.24**	**23.78**	**0.36**	**11.46**	**0.27**	**64.75**	**0.40**	**12.44**	**0.10**	**61.27**	**59.76**	**62.76**

No significant interaction was observed between the exposure and the survey year for the total energy intake from free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.254; processed foods: p = 0.538; ultra-processed foods: p = 0.137), nor for the prevalence of excessive intake of free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.609; processed foods: p = 0.262; ultra-processed foods: p = 0.258). Even so, we included variable survey year (1-6) in the adjusted model.

Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups stratified by age groups are shown in **Tables 2 to 5** (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years, respectively). The dietary contents of free sugars increased linearly across quintiles of ultra-processed food consumption for children (from 10.4% in the lowest quintile to 15.3% in the highest quintile), adolescents (from 12.7% to 17.4%, respectively) and adults (from 9.6% to 15.2%, respectively), whereas the increase for elderly was not significant (from 10.6% to 11.7%, respectively). The prevalence of excessive free sugar intake also increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly group. Children in the highest quintiles of ultra-processed food consumption had a prevalence of excessive free sugar intake 60% higher (PRadj 1.6; 95% CI 1.3 to 1.9) than those in the lowest quintile group. The same trend was observed for adolescents (PRadj 1.6 95% IC 1.2 – 1.9) and adults (PRadj 1.7 95% IC 1.5 – 1. 9), while no difference in prevalence was observed for elderly (PRadj 1.1 95% IC 0.8 – 1.4).

Opposite trends were observed for the group of unprocessed or minimally processed foods and processed culinary ingredients, where the prevalence of excessive free sugars intake decreased from the first to the last quintile of these food groups in all age groups. The prevalence of excessive free sugars intake also decreased from the first to the last quintile of processed foods, but only in adolescents and adults.

Table 2. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 - 10 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*[¦]	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.36	0.00	20.92	15.80	0.33	82.99	1.00	1.00	–	–
2nd	24.86	20.93	28.41	14.60	0.30	79.62	0.96	0.95	0.89	1.02
3rd	31.57	28.46	34.96	14.37	0.28	81.68	0.98	0.99	0.93	1.06
4th	39.30	34.98	43.86	13.66	0.36	73.40	0.88	0.91	0.84	0.99
5th	52.46	43.97	79.93	11.13[¥]	0.26	53.87	0.65[¥]	0.69[¥]	0.61	0.78
Processed foods										
1st	0.41	0.00	1.33	13.93	0.29	72.58	1.00	1.00	–	–
2nd	2.56	1.34	3.79	14.82	0.30	80.23	1.11	1.11	1.03	1.19
3rd	5.18	3.79	6.82	13.77	0.25	73.85	1.02	1.04	0.95	1.13
4th	8.96	6.83	11.95	13.37	0.31	73.23	1.01	1.02	0.93	1.12
5th	16.05	12.04	41.71	13.16	0.52	69.20	0.95	0.99	0.86	1.14
Ultra-processed foods										
1st	36.38	15.11	43.67	10.35	0.38	46.41	1.00	1.00	–	–
2nd	49.00	43.72	53.03	12.37	0.30	66.78	1.44	1.39	1.15	1.70
3rd	57.17	53.06	60.95	13.84	0.37	74.22	1.60	1.50	1.24	1.81
4th	65.58	60.96	70.14	14.48	0.26	80.95	1.74	1.62	1.35	1.95
5th	78.05	70.15	100	15.32[¥]	0.25	81.41	1.75[¥]	1.62[¥]	1.35	1.95

*PR=Prevalence ratios estimated using Poisson regression.

[¦]PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

[¥]Significant linear trend across all quintiles (p≤0.001).

Table 3. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 11 - 18 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	14.43	0.00	20.89	17.28	0.36	88.89	1.00	1.00	–	–
2nd	24.61	20.92	28.43	15.87	0.35	84.30	0.95	0.95	0.89	1.01
3rd	31.46	28.44	34.93	15.50	0.37	81.82	0.92	0.92	0.86	0.99
4th	39.24	34.98	43.84	13.96	0.43	78.15	0.88	0.89	0.82	0.96
5th	52.96	43.88	79.86	13.60[¥]	0.80	66.92	0.75[¥]	0.77[¥]	0.66	0.88
Processed foods										
1st	0.29	0.00	1.33	17.18	0.41	85.11	1.00	1.00	–	–
2nd	2.56	1.34	3.79	15.81	0.35	81.74	0.96	0.96	0.90	1.03
3rd	5.16	3.80	6.81	15.62	0.35	86.87	1.02	1.02	0.96	1.09
4th	8.94	6.82	11.95	14.52	0.43	79.40	0.93	0.93	0.86	1.01
5th	17.53	12.05	41.62	13.68[¥]	0.57	74.89	0.88[¥]	0.87[¥]	0.78	0.99
Ultra-processed foods										
1st	35.29	18.40	42.94	12.72	1.39	56.18	1.00	1.00	–	–
2nd	49.35	43.70	53.03	13.65	0.56	75.73	1.35	1.34	1.03	1.74
3rd	56.91	53.08	60.96	14.19	0.40	79.24	1.41	1.40	1.09	1.80
4th	65.63	60.96	70.13	14.99	0.32	80.76	1.44	1.42	1.11	1.82
5th	79.05	70.14	100	17.37[¥]	0.29	89.04	1.58[¥]	1.56[¥]	1.23	1.99

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.001).

Table 4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 19 - 64 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.06	0.00	20.92	15.11	0.36	35.87	1.00	–	–	
2nd	24.93	20.95	28.41	12.87	0.31	31.12	0.85	0.87	0.79	0.96
3rd	31.65	28.43	34.96	11.97	0.31	30.87	0.79	0.85	0.77	0.94
4th	38.95	34.97	43.88	11.01	0.28	28.45	0.66	0.72	0.64	0.80
5th	54.24	43.93	91.90	9.89¥	0.25	25.28	0.57¥	0.62¥	0.55	0.71
Processed foods										
1st	0.28	0.00	1.32	13.09	0.50	59.14	1.00	1.00	–	–
2nd	2.60	1.34	3.79	12.82	0.41	60.65	1.03	1.04	0.92	1.19
3rd	5.35	3.79	6.82	12.17	0.30	61.42	1.04	1.04	0.92	1.18
4th	9.36	6.82	12.03	11.62	0.26	55.92	0.95	0.98	0.87	1.11
5th	19.80	12.04	65.22	11.27¥	0.22	52.47	0.89¥	0.92¥	0.82	1.03
Ultra-processed foods										
1st	34.45	1.82	43.67	9.62	0.27	39.42	1.00	1.00	–	–
2nd	48.70	43.69	53.04	11.11	0.25	53.34	1.35	1.30	1.13	1.50
3rd	57.08	53.06	60.96	11.83	0.29	56.84	1.44	1.37	1.19	1.57
4th	65.34	60.96	70.14	13.09	0.32	66.31	1.68	1.57	1.37	1.79
5th	78.04	70.15	100	15.21¥	0.38	74.30	1.88¥	1.67¥	1.46	1.92

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles (p≤0.001).

Table 5. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 65 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	16.63	6.34	20.82	11.67	0.87	56.16	1.00	1.00	–	–
2nd	25.04	20.95	28.36	12.83	0.61	67.39	1.20	1.19	0.90	1.57
3rd	32.06	28.44	34.90	11.98	0.48	64.37	1.15	1.15	0.87	1.52
4th	39.30	34.98	43.85	10.93	0.44	53.96	0.96	0.97	0.73	1.28
5th	52.26	43.89	78.36	10.70	0.42	50.94	0.91¥	0.91¥	0.69	1.21
Processed foods										
1st	0.38	0.00	1.32	9.70	0.72	43.52	1.00	1.00	–	–
2nd	2.42	1.34	3.78	12.13	0.56	64.30	1.48	1.49	1.14	1.96
3rd	5.23	3.79	6.81	12.16	0.45	65.00	1.49	1.52	1.17	1.98
4th	9.27	6.82	12.02	11.10	0.47	54.46	1.25	1.27	0.96	1.67
5th	19.10	12.04	50.86	11.23	0.46	53.62	1.23	1.29	0.97	1.69
Ultra-processed foods										
1st	35.98	7.79	43.69	10.63	0.49	47.63	1.00	1.00	–	–
2nd	48.67	43.74	53.02	11.30	0.48	58.67	1.23	1.20	0.97	1.47
3rd	56.97	53.05	60.91	11.61	0.45	59.89	1.26	1.21	0.98	1.50
4th	64.99	61.01	70.08	12.01	0.54	65.53	1.38	1.35	1.09	1.66
5th	75.66	70.17	92.30	11.67	0.70	53.75	1.13	1.06	0.81	1.40

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles (p≤0.001).

In our counterfactual scenarios, we calculated the percentage of excessive free sugar intake avoided if the consumption of ultra-processed foods and table sugar were zero (**Figure 1**). We estimated that about 47% of the prevalence of excessive free sugars intake in the UK population could be potentially avoided if the consumption of ultra-processed foods was eliminated. Eliminating table sugar could potentially avoid 9.4% of the prevalence of excessive free sugars intake. This greater reduction in the percentage of excessive free sugar intake due to elimination of ultra-processed foods, relative to table sugar, was observed in all age groups, except in the elderly group where both scenar100-47ios had similar impacts on total free sugar intake.

DISCUSSION

In this large, nationally representative sample of the UK population, higher consumption of ultra-processed food was associated with greater dietary content of free sugars in children, adolescents, and adults. Using theoretical minimum risk exposure level scenarios, we also showed that by eliminating ultra-processed food consumption, the prevalence of excessive free sugar intake (10% or more of total energy intake) could be potentially reduced from 60% to 31%. In children and adolescents, the potential reduction could be from 74% to 45% and from 83% to 53%, respectively.

Our findings confirm an excessive consumption of free sugars in the UK diet [13] and show that ultra-processed foods contributed nearly 65% of all free sugars in all age groups and nearly 80% in children and adolescents. Unprocessed or minimally processed foods (mostly fresh juice) and processed culinary ingredients (mostly table sugar) contributed between 19% and 27% of the dietary content of free sugars, while processed foods provided the lowest contribution in all age groups.

Our findings are similar to previous studies conducted in high- and middle-income countries that have shown strong associations between the intake of ultra-processed foods and the dietary content of free sugars [8-11]. A previous study conducted in Chile similarly showed that the association between ultra-processed food consumption and the dietary content of added sugars is more pronounced among children and adolescents [12]. In our study there was no association between ultra-processed food consumption and dietary content of free sugars among the elderly, probably due to differences in the type of ultra-processed foods consumed in this age group, with salted products more likely to be consumed than the sweetened products.

There is strong evidence that the high consumption of free sugars contributes to excess obesity, type 2 diabetes, dyslipidaemia, hypertension and coronary heart disease [2-4]. Consequently, most dietary recommendations now advise limiting free sugar intake, but more focused efforts are needed to put this recommendation into practice. Changing personal behaviour and choice alone is not an effective or realistic option as our findings confirm that the majority of free sugar is added to food before it is marketed and sold. Voluntary agreements between industry and government have been shown repeatedly to be ineffective in improving public health [24]. This is confirmed by recent UK experience where the early stages of the government's sugar reduction programme, which challenged the food industry to voluntarily cut sugar in some products, has produced only slow progress toward proposed targets [25]. Thus, more drastic measures that change the availability, price and marketing of these products is necessary.

The analyses presented here suggest that actions to reduce the consumption of ultra-processed foods often rich in free sugars could lead to larger public health benefits. Policies concerning the use of fiscal measures to reduce intake of free sugars and improve diet quality should consider extending beyond artificially sweetened beverages to include the main driver of excessive free sugar intake, including dairy drinks, cakes, biscuits and confectionery [13].

To our knowledge, this is the first study to examine the association between consumption of ultra-processed foods, as defined per NOVA [6], and dietary content of free sugar in different age groups of the UK population. The use of NOVA is a key strength of the study as it classified foods by their level of processing level using standardised and objective criteria. NOVA has been recognised as a valid tool for public health and nutrition research and policy by the Food and Agricultural Organization of the United Nations [26] and the Pan American Health Organization [27]. In addition, we used data from the NDNS - a large and nationally representative sample of the UK population, applying weighting to reduce any sampling and non-response bias. Unlike household budget data, food diaries employed in the NDNS take food wastage into account, include food eaten out of home, and do not assume that all individuals within a household consume the same diet. Importantly, the dietary data also allowed for the disaggregation of dishes into their constituents and classification of the underlying ingredients, which enabled the calculation of more precise estimates of intakes of each NOVA group and reduced misclassification.

Potential limitations should be considered. The dietary data we used were self-reported and may be subject to misclassification. A constant limitation of dietary assessment methods is underreporting of some foods (particularly unhealthy foods), though food diaries are recognised to be one of the most comprehensive methods for assessing dietary intake. Possible underreporting of unhealthy foods may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of free sugars, but may less likely affect the association between these variables. Nevertheless, accurate and valid NDNS data were achieved through optimal methods for collecting dietary intake [28] which helped to minimise missing information. NDNS collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items. This bias is more likely for a small number of specific food items such as pizza where there is insufficient information for classification purposes (see **Suppl. Table S2**). In those cases, the most frequently consumed alternative (culinary preparation or manufactured product) was chosen. Finally, our theoretical minimum risk exposure models estimate the potential impact of eliminating each of the main sources of free sugars on excessive free sugar intake, ignoring substitutions that may occur in the consumption of other foods. Although our findings suggest that greater reduction in excessive free sugar intake could be achieved by eliminating ultra-processed food consumption, guidance to the public about reducing the consumption of table sugar remains an important component of any public health guidance.

Conclusions

Almost half of excessive intake of free sugars in the UK can be attributed to ultra-processed foods. Policies to reduce sugar consumption should focus on minimizing consumption of ultra-processed foods and replacing them with unprocessed or minimally processed foods alternatives. The study adds to a growing body of evidence that ultra-processed foods are a major contributor to growth of diet related non-communicable diseases globally.

Author contributions: CAM, EMS, FR, MLdCL, and RBL designed the research. FR and RBL undertook data management and analysis. CAM, CM, EMS, FR, LFMR, MLdCL, and RBL interpreted the data. FR wrote the first draft of the manuscript. All authors read, edited and approved the final manuscript.

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Competing interests: None declared.

Data sharing statement: This study is based on open data of the UK population that is available in the UK Data Archive website (http://www.esds.ac.uk).

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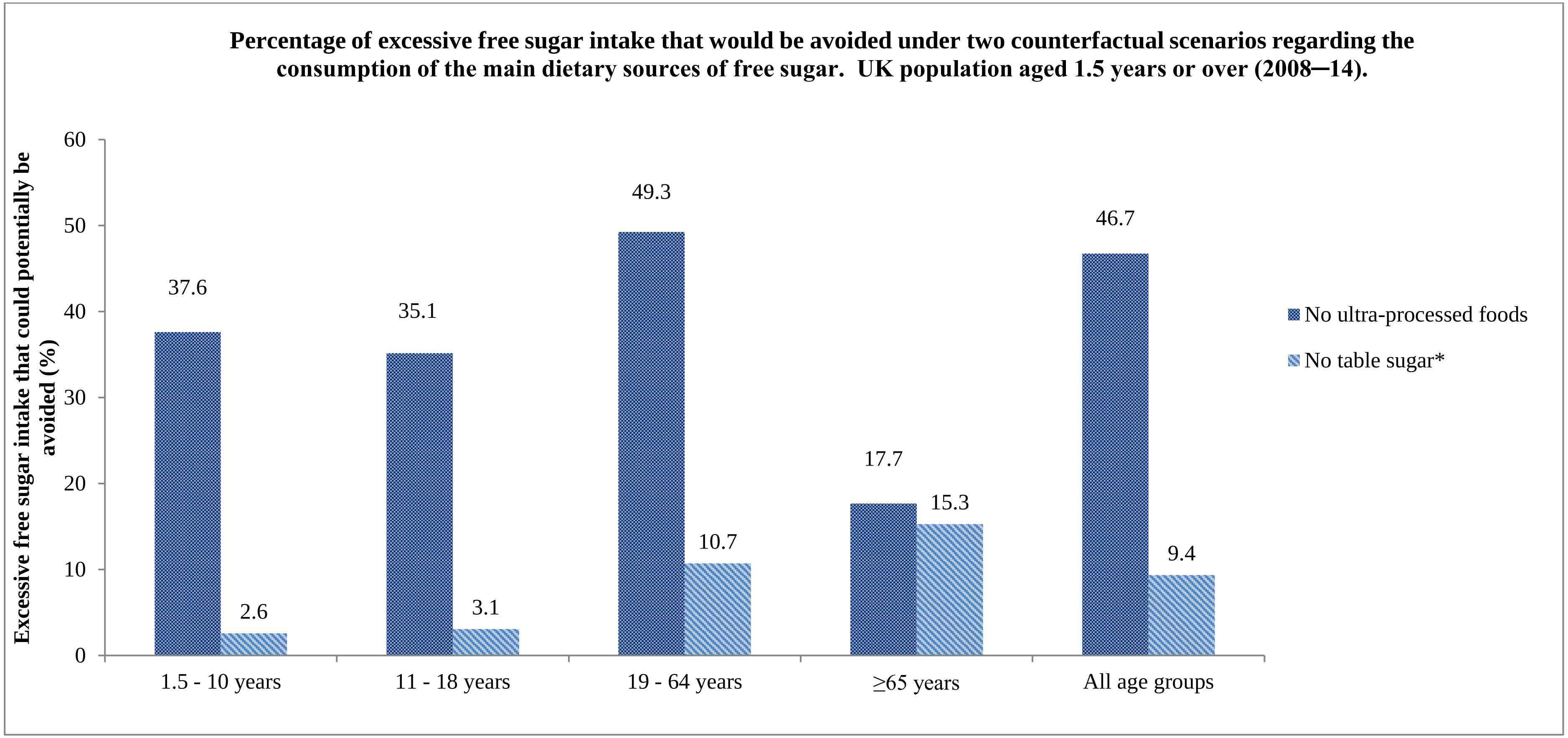
Figure 1. Percentage of excessive free sugar intake that would be avoided under two counterfactual scenarios regarding the consumption of the main dietary sources of free sugar. UK population aged 1.5 years or over (2008–14).

Figure 1.



*Including honey, molasses, maple syrup (100%).

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study.

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Supplementary table S1. The Nova food classification system*

Food groups	Examples
1) Unprocessed foods or minimally processed foods Natural foods altered by methods such as freezing, pasteurization, fermentation, removal of inedible or unwanted parts, grinding, and other methods that do not include the addition of substances such as salt, sugar and/or oils or fats.	Fresh, dry or frozen fruits or vegetables; legumes; grains, roots and tubers, flours and pasta; pasteurized or power plain milk and plain yogurt; fresh or frozen meat (fish, poultry and red meat); eggs; nuts and seeds; fungi; fresh or pasteurised fruit or vegetable juices without added sugar, sweeteners or flavours; tea, coffee and drinking water.
2) Processed culinary ingredients Substances obtained directly from group 1 foods or from nature by processes that include pressing, refining, grinding, milling, and drying, and consumed in combination with group 1 foods in freshly prepared dishes or drinks.	Salt; sugar, honey and molasses; vegetable oils; butter and lard; starches extracted from corn and other plants.
3) Processed foods Products manufactured with the addition of group 2 substances (e.g. salt, sugar, oil, and fats) to group 1 foods and alcoholic drinks produced by fermentation of group 1 foods such as beer, cider and wine.	Canned or bottled vegetables, fruits and legumes; salted or sugared nuts and seeds; salted, cured, or smoked meats; canned fish; fruits in syrup; cheeses and unpackaged freshly made breads.
4) Ultra-processed foods Food and drink formulations made from several ingredients. Such ingredients include salt, sugar, oils, and fats but also other substances derived from foods but not commonly used as culinary ingredients (such as protein isolates, hydrogenated oils, modified starches) and additives used to imitate sensory quality of natural foods and freshly prepared dishes or to disguise unpalatable aspects of the final product (such as flavours, colours, sweeteners, emulsifiers). Alcoholic drinks produced by fermentation of group 1 foods followed by distillation of the resulting alcohol, such as whisky, gin, rum, vodka, are classified in group 4.	Carbonated drinks; sweet or savoury packaged snacks; confectionery; mass-produced packaged breads and buns; margarines and spreads; biscuits, pastries, cakes, and cake mixes; breakfast ‘cereals’, ‘cereal’ and ‘energy’ bars; ‘energy’ drinks; milk drinks, ‘fruit’ yoghurts and ‘fruit’ drinks; cocoa drinks; meat and chicken extracts and ‘instant’ sauces; ready to heat products including pre-prepared pies and pasta and pizza dishes; poultry and fish ‘nuggets’ and ‘sticks’, sausages, burgers, hot dogs, and other reconstituted meat products, and powdered and packaged ‘instant’ soups, noodles and desserts.

Adapted from Monteiro et al. (2016 and 2018).

Monteiro CA, Cannon G, Moubarac JC et al. (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr 21, 5-17.
Monteiro CA, Cannon G, Levy RB, et al. NOVA. The star shines bright. World Nutrition. 2016;7(1-3):28-38.

Supplementary Table S2. Coding of subsidiary food groups from National Diet and Nutrition Survey according to NOVA classification.

Subsidiary food group code	Subsidiary food group name	NOVA food group†
1C	Pizza	4
1D	Pasta (manufactured products and ready meals	4
1E	Pasta (other, including homemade dishes)	*
1F	Rice (manufactured products and ready meals)	4
1G	Rice (other, including homemade dishes)	*
1R	Other cereals	*
2R	White bread (not high fibre, not multiseed bread)	4
3R	Wholemeal bread	4
4R	Other bread	4
5R	High fibre breakfast cereals	4
6R	Other breakfast cereals (not high fibre)	4
7A	Biscuits(manufactured/retail)	4
7B	Biscuits (homemade)	*
8B	Fruit pies (manufactured)	4
8C	Fruit pies (homemade)	*
8D	Buns cakes and pastries (manufactured)	4
8E	Buns cakes and pastries (homemade)	*
9C	Cereal based milk puddings (manufactured)	4
9D	Cereal based milk puddings (homemade)	*
9E	Sponge puddings (manufactured)	4
9F	Sponge puddings (homemade)	*
9G	Other cereal based puddings (manufactured)	4
9H	Other cereal based puddings (homemade)	*
10R	Whole milk	1
11R	Semi-skimmed milk	1
12R	Skimmed milk	1
13A	Infant formula	4
13B	Cream (including imitation cream)	*
13R	Other milk	*
14A	Cottage cheese	3
14B	Cheddar cheese	3
14R	Other cheese	*
15B	Yogurt	*
15C	Fromage frais and other dairy desserts (manufactured)	4
15D	Dairy desserts (homemade)	*
16C	Manufactured egg products, including ready meals	4
16D	Other eggs and egg dishes, including homemade	*
17R	Butter	2
18A	Polyunsaturated margarine	4
18B	Polyunsaturated oils	2
19A	Polyunsaturated low fat spread	4
19R	Low fat spread not polyunsaturated	4
20A	Block margarine	4
20B	Soft margarine not polyunsaturated	4
20C	Other cooking fats and oils not polyunsaturated	2
21A	Reduced fat spread (polyunsaturated)	4
21B	Reduced fat spread (not polyunsaturated)	4
22A	Ready meals/meal centres based on bacon and ham	4
22B	Other bacon and ham (including homemade dishes)	*
23A	Manufactured beef products (including ready meals)	4
23B	Other beef & veal (including homemade recipe dishes)	*
24A	Manufactured lamb products (including ready meals)	4
24B	Other lamb (including homemade recipe dishes)	*
25A	Manufactured pork products(including ready meals)	4
25B	Other pork (including homemade recipe dishes)	*
26A	Manufactured coated chicken/turkey products	4
27A	Manufactured chicken products (including ready meals)	4
27B	Other chicken/turkey (including homemade recipe dishes)	*
28R	Liver and dishes	*
29R	Burgers and kebabs purchased	4
30A	Ready meals based on sausages	4
30B	Other sausages (including homemade dishes)	*
31A	Meat pies and pastries (manufactured)	4
31B	Meat pies and pastries (homemade)	*
32A	Other meat products (manufactured including ready meals)	4
32B	Other meat (including homemade recipe dishes)	*

33R	White fish coated or fried	*
34C	Manufactured white fish products (including ready meals)	4
34D	Other white fish (including homemade dishes)	*
34E	Manufactured shellfish products (including ready meals)	4
34F	Other shellfish (including homemade dishes)	*
34G	Manufactured canned tuna products (including ready meals)	*
34H	Other canned tuna (including homemade dishes)	*
35A	Manufactured oily fish products (including ready meals)	4
35B	Other oily fish (including homemade dishes)	*
36A	Carrots (raw)	1
36B	Salad and other raw vegetables	*
36C	Tomatoes raw	1
37A	Peas not raw	*
37B	Green beans not raw	*
37C	Baked beans	4
37D	Leafy green vegetables not raw	*
37E	Carrots not raw	*
37F	Tomatoes not raw	*
37I	Beans and pulses (including ready meal & homemade dishes)	*
37K	Meat alternatives (including ready meals and homemade dishes)	4
37L	Other manufactured vegetable products (including ready meals)	4
37M	Other vegetables (including homemade dishes)	*
38A	Chips purchased including takeaway	4
38C	Other manufactured potato products fried/baked	4
38D	Other fried/roast potatoes (including homemade dishes)	*
39A	Other potato products and dishes(manufactured)	4
39B	Other potatoes (including homemade dishes)	*
40A	Apples and pears not canned	*
40B	Citrus fruit not canned	*
40C	Bananas	*
40D	Canned fruit in juice	*
40E	Canned fruit in syrup	3
40R	Other fruit not canned	*
41A	Sugar	*
41B	Preserves	3
41R	Sweet spreads fillings and icing	4
42R	Crisps and savoury snacks	4
43R	Sugar confectionery	4
44R	Chocolate confectionery	4
45R	Fruit juice	*
47A	Liqueurs	4
47B	Spirits	4
48A	Wine	3
48B	Fortified wine	4
48C	Low alcohol and alcohol free wine	3
49A	Beers and lagers	3
49B	Low alcohol & alcohol free beer & lager	3
49C	Cider and Perry	4
49D	Low alcohol & alcohol free cider & Perry	4
49E	Alcoholic soft drinks (Alcopops)	4
50A	Beverages dry weight	4
50C	Soup (manufactured/retail)	4
50D	Soup (homemade)	*
50E	Nutrition powders and drinks	4
50R	Savoury sauces pickles gravies & condiments	4
51A	Coffee (made up weight)	*
51B	Tea (made up)	*
51C	Herbal tea (made up)	1
51D	Bottled water still or carbonated	*
51R	Tap water only	1
52A	Commercial toddlers drinks	3
52R	Commercial toddlers foods	3
53R	Ice cream	4
54A	Cod liver oil and other fish oils	**
54B	Evening primrose oil and other plant oils	**
54C	Single vitamins/minerals not Folic acid, iron, calcium	**
54D	Folic acid	**
54E	Iron only or with vitamin C	**
54F	Calcium only or with vitamin D	**
54G	Vitamins (two or more including multivitamins) no minerals	**
54H	Minerals (two or more including multimineral) no vitamins	**
54I	Vitamins and minerals (including multivitamins & minerals)	**
54J	Non-nutrient supplements (including herbal)	**

54K	Other nutrient supplements	**
54L	Vitamin C	**
54M	Single vitamins/minerals not Folic acid, iron, calcium or vitamin C	**
54N	Cod liver oil and other fish oils (including with vitamins A, D, E)	**
54P	Multivitamins and/or minerals with omega ultra-processed	**
55R	Artificial sweeteners	4
56R	Nuts and seeds	*
57A	Soft drinks not low calorie concentrated	4
57B	Soft drinks not low calorie carbonated	4
57C	Soft drinks not low calorie, ready to drink, still	4
58A	Soft drinks low calorie concentrated	4
58B	Soft drinks low calorie carbonated	4
58C	Soft drinks low calorie, ready to drink, still	4
59R	Brown, granary and wheat germ bread	4
60R	1% Milk	1
61R	Smoothies	1

† NOVA food groups defined as 1) unprocessed or minimally processed foods; 2) processed culinary ingredients; 3) processed foods; and 4) ultra-processed foods.
* All foods within this subsidiary food group were individually coded (by food name).
** Supplements were not included in any of the NOVA food groups.
Source: Rauber F, Louzada MLC, Steele EM, Millett C, Monteiro CA, Levy RB. Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). Nutrients 2018, 10, 587; doi:10.3390/nu10050587.

Supplementary table S3. Dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

Age groups	% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars		
	mean	SE	%	95%CI	
1.5 - 10 years	14.00	0.14	97.16	96.29	97.84
11 - 18 years	15.78	0.19	96.77	95.62	97.62
19 - 64 years	11.93	0.14	88.82	87.48	90.04
≥65 years	11.36	0.23	87.62	84.88	89.93
All age groups	**12.44**	**0.10**	**90.34**	**89.39**	**91.21**

Supplementary table S4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars					Individuals with ≥10% of total energy intake from free sugars				
Quintile	**mean**	**min**	**max**	**mean**	**SE**	**%**	**PR***	**PRadj¦**	**95%CI**		**%**	**PR***	**PRadj¦**	**95%CI**	
Unprocessed or minimally processed foods + Processed culinary ingredients															
1st	15.10	0.00	20.92	15.36	0.24	95.94	1.00	1.00	—	—	77.42	1.00	1.00	—	—
2nd	24.90	20.92	28.43	13.44	0.22	94.28	0.98	0.99	0.97	1.01	68.55	0.89	0.92	0.86	0.97
3rd	31.68	28.43	34.96	12.62	0.21	91.92	0.96	0.97	0.95	1.00	65.09	0.84	0.89	0.84	0.95
4th	39.08	34.97	43.88	11.46	0.21	89.70	0.93	0.96	0.93	0.98	55.09	0.71	0.77	0.72	0.83
5th	53.57	43.88	91.90	10.32¥	0.19	82.41	0.86	0.89	0.86	0.92	46.36	0.60¥	0.67¥	0.61	0.73
Processed foods															
1st	0.32	0.00	1.33	13.53	0.29	87.19	1.00	1.00	—	—	64.14	1.00	1.00	—	—
2nd	2.55	1.34	3.79	13.48	0.24	92.34	1.06	1.06	1.03	1.10	67.93	1.06	1.08	1.01	1.16
3rd	5.28	3.79	6.82	12.83	0.19	92.39	1.06	1.07	1.03	1.10	67.10	1.05	1.08	1.00	1.16
4th	9.28	6.82	12.03	11.89	0.20	90.61	1.04	1.06	1.02	1.09	58.87	0.92	0.98	0.91	1.06
5th	19.54	12.04	65.22	11.38¥	0.19	89.40	1.03	1.04	1.01	1.08	53.70	0.84¥	0.91¥	0.84	0.98
Ultra-processed foods															
1st	34.89	1.82	43.69	9.94	0.22	80.50	1.00	1.00	—	—	41.87	1.00	1.00	—	—
2nd	48.74	43.69	53.04	11.34	0.20	89.16	1.11	1.10	1.05	1.15	56.35	1.35	1.31	1.18	1.46
3rd	57.06	53.05	60.96	12.16	0.21	92.65	1.15	1.14	1.09	1.18	60.76	1.45	1.39	1.25	1.54
4th	65.37	60.96	70.14	13.38	0.21	94.08	1.17	1.15	1.10	1.19	70.18	1.68	1.55	1.41	1.72
5th	78.06	70.14	100.00	15.41¥	0.21	95.30	1.18¥	1.15¥	1.10	1.19	77.20	1.84¥	1.64¥	1.48	1.81

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.001).

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1, 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4, 5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	6,7,9
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8,9
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	8
Outcome data	15*	Report numbers of outcome events or summary measures	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12-16

		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18,19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19
Generalisability	21	Discuss the generalisability (external validity) of the study results	17,18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study

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Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Nutrition and metabolism
Keywords:	Food processing, Ultra-processed, Free sugar, United Kingdom

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study

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Word count: 3,877

ABSTRACT

Objectives: to describe dietary sources of free sugars in different age groups of the UK population considering food groups classified according to the NOVA system and to estimate the proportion of excessive free sugars that could potentially be avoided by reducing consumption of their main sources.

Design and setting: Cross-sectional data from the UK National Diet and Nutrition Survey (2008–14) were analysed. Food items collected using a four-day food diary were classified according to the NOVA system.

Participants: 9,364 individuals aged 1.5 years and above.

Main outcome measures: Average dietary content of free sugars and proportion of individuals consuming more than 10% of total energy from free sugars.

Data analysis: Poisson regression was used to estimate the associations between each of the NOVA food group and intake of free sugars. We estimated the percent reduction in prevalence of excessive free sugar intake from eliminating ultra-processed foods and table sugar. Analyses were stratified by age group and adjusted for age, sex, ethnicity, region, and equivalised household income (sterling pounds).

Results: Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Free sugars represent 12.4% of total energy intake and 61.3% of the sample exceeded the recommended limit of 10% energy from free sugars. This percentage was higher among children (74.9%) and adolescents (82.9%). Prevalence of excessive free sugar intake increased linearly across quintiles of ultra-processed food consumption for all age groups, except among the elderly. Eliminating ultra-processed foods could potentially reduce the prevalence of excessive free sugar intake by 47%.

Conclusion: Our findings suggest that actions to reduce the ultra-processed food consumption generally rich in free sugars could lead to substantial public health benefits.

Keywords: Food processing; Ultra-processed; Free sugar; United Kingdom.

ARTICLE SUMMARY

Strengths and limitations of this study

- Use of a large and nationally representative sample of the UK population, increasing generalisability.
- Use of data on free sugars rather than total sugars or sugar-sweetened beverages, which correspond to the guidelines relevant area of prioritisation.
- Use of NOVA system, which has been recognised as a valid tool for public health and nutrition research and policy by international organizations.
- Dietary data obtained by food diaries are subject to potential error and bias.
- UK national dietary survey collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items.

INTRODUCTION

Excessive consumption of free sugar is associated with obesity, type 2 diabetes, dental caries, and several other health outcomes [1-4]. To address this associated health burden, the World Health Organization (WHO) [5] recommends that free sugars should be reduced to less than 10% of total energy intake and also suggests a level below 5% to obtain additional health benefits, such as reduction of dental caries. Achievement of this ambitious target will require bold and systematic efforts to reduce sugar across a variety of food products in most settings.

As defined by the NOVA food classification system, ultra-processed foods are industrial formulations of many ingredients, mostly of exclusive industrial use, that result from a sequence of industrial processes (hence ultra-processed) [6]. In some high-income countries, including the UK, ultra-processed foods account for more than half of total dietary energy intake [7-9]. Importantly, national dietary surveys conducted in high- and middle-income countries [8-12] have shown a strong and positive association between consumption of ultra-processed foods and excessive dietary added (or free) sugar intake. Free sugars include sugars added to foods by the manufacturer, cook and consumer, plus sugars naturally present in honey, syrups and fruit juices [5], while added sugars captures all free sugars, but exclude naturally occurring sugars in fruit juices.

Free sugar intake in the UK is high, ranging from 11 to 15% of total energy intake [13]. To address this, the UK has implemented a number of measures including a sugar-sweetened beverage levy in 2018. However, action on sugar sweetened beverages alone is unlikely to reduce population level sugar intake to WHO recommended levels. In a more recent publication, the voluntary sugar reduction programme continues being endorsed by the government, but other measures such as restriction of advertising and in-store promotions of some sugary foods are also being considered as strategies to reduce childhood obesity [14]. A better understanding of the key sources of sugar intake in the UK diet is required to inform policy development. This study aims to describe the dietary sources of free sugars in different age groups of the UK population taking into account food groups classified according to the NOVA classification system and estimate the proportion of excessive free sugars that could be potentially avoided by reducing the consumption of their main dietary sources.

METHODS

Data source and collection

We used data from the National Diet and Nutrition Survey Rolling Programme (NDNS) years 1-6 (2008/09-2009/10, 2010/11-2011/12, 2012/13-2013/14) combined, which is a cross-sectional survey of people aged 1.5 years or older. The survey was designed to be representative of the UK population and provides comprehensive information on food intake. Details of the rationale, design, and methods of the survey have been described elsewhere [15]. Briefly, the sample was drawn from households randomly selected from the UK Postcode Address File, a list of all UK addresses. One adult (aged 19 years and older) and one child (aged 1.5–18 years), if available, were randomly selected from each household. Only a child was selected from some households to be part of a 'child boost' to ensure approximately equal numbers of children and adults. Participants (or in the case of children ≤11 years, their parent/carer) completed a four-day food diary and participated in an interview that included data on socio-demographic status.

Participants were asked to report all foods and drinks consumed both within and outside the home. Portion sizes were estimated using household measures or weights from packaging. Once completed, diaries were checked by interviewers with respondents and missing details added to improve completeness. Diary days were randomly selected to ensure balanced representation of all days of the week. All individuals who completed three or four days of dietary recording were eligible for inclusion in the study, giving a sample size of 9,374 (4,738 adults and 4,636 children) participants for years 1 to 6 (2008/09 to 2013/14) combined.

The food intake data from completed records were coded and edited using the software DINO (Diet In, Nutrients Out) and food and nutrient intakes estimated using nutrient composition data from the Department of Health's Nutrient Databank, updated for each survey year [16, 17]. Free sugars are defined as sugars added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups, fruit juices and fruit concentrates [5]. Intakes in the UK NDNS years 1-6 were expressed as non-milk extrinsic sugars (NMES). The term NMES captures all sugars defined by the term free sugars while also including half of the sugars present in dried, stewed or canned fruit. The NMES values could be slightly higher in some cases than the free sugar values, mostly in the non-ultra-processed food group since the term free sugar does not include sugars contributed by dried and processed fruits. Based on the assumption that those definitions are sufficiently similar for assessment and monitoring purposes [1,3], this study used the term free sugars.

Computerized raw data files and documentation from this survey were obtained under license from the UK Data Archive (http://www.esds.ac.uk). All relevant research ethics and governance committees approved the survey.

Food classification according to processing

We classified all recorded food items according to NOVA, a food classification system based on the nature, extent, and purpose of the industrial food processing [6]. This classification includes four groups: 1) unprocessed or minimally processed foods (e.g. fresh, dry or frozen fruits or vegetables; grains, flours and pasta; pasteurized or power plain milk, plain yogurt, fresh or frozen meat); 2) processed culinary ingredients (e.g. table sugar, oils, butter, and salt); 3) processed foods (e.g. vegetables in brine, cheese, simple breads, fruits in syrup, canned fish); and 4) ultra-processed foods (e.g. soft drinks, sweet or savoury packaged snacks, confectionery; packaged breads and buns; reconstituted meat products and pre-prepared frozen or shelf-stable dishes) (**see Suppl. Table S1**). The detailed description of NOVA classification can be found elsewhere [6, 18].

All foods in NDNS are coded as food number and grouped into subsidiary food groups (n = 155). When possible, subsidiary food groups were directly classified according to NOVA (**see Suppl. Table S2**). When foods within a subsidiary food group pertained to different NOVA groups (n = 52), it was the food codes instead of the group, which were individually classified. By doing so, we were able to classify each underlying ingredient of homemade dishes in its corresponding NOVA group. Subsidiary food groups as classified by NOVA are described in the Supplementary Table S2.

Although the NDNS database was provided with most food items systematically disaggregated into their individual components, about 4% of composite food codes were still mixed dishes compiled from two or more single-ingredient food code [19]. The method we adopted to disaggregate food codes has been described previously [19]. Using the core sample of years 1 to 4 (2008/09 to 2011/12) (n = 4,125), we estimated that composite food codes represented only 3% of total calories. In this case, dishes were categorised according to the main constituent ingredient. Dishes in which a main constituent ingredient was not clearly identified (e.g. chicken and vegetable soup) were classified as a specific subgroup of freshly prepared dishes based on one or more unprocessed or minimally processed food (group 1). Non-caloric supplements were not included in the analyses.

Covariates

Covariates included were age (years), sex, ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region (England North, England Central/Midlands, England South (including London), Scotland, Wales, and Northern Ireland), survey year (years 1-6), and equivalised household income (equivalised for different household sizes and composition using the McClements equivalence scale [15]). Due to the significant proportion of missing values for the equivalised household income (12.8%), we applied multiple imputation by chained equation method based on age, sex, ethnicity, excessive free sugars intake and ultra-processed food consumption. Multiple imputation was performed 20 times, and the Monte Carlo error analysis showed good statistical reproducibility of the results [20]. We used the average of estimates from each imputed dataset. Sensitivity analysis was conducted comparing findings from imputed data and complete case analysis.

Data analysis

For each survey day and age group (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years), we defined extreme total energy intake outliers as values below the 1st and above the 99th percentiles [21] **(see Suppl. Figure S1)**. Based on these criteria, we excluded ten individuals who had all days of food diary classified as outliers. In total, 9,364 (4,729 adults and 4,635 children) participants were eligible for inclusion in the analyses and more than 91% completed the four food diary days. We used the mean of all available days of food diary for each individual.

Food items were sorted into mutually exclusive food groups according to NOVA classification. We combined the group of unprocessed or minimally processed foods with the group of processed culinary ingredients, as foods belonging to these two groups are usually mixed together in culinary preparations and, therefore, consumed together. Thus, we performed the analyses considering three groups of foods: unprocessed or minimally processed foods and processed culinary ingredients (individuals are able to determine the amount of table sugars they add), processed foods (sugar added by the food industry), and ultra-processed foods (sugar added by the food industry).

First, we estimated the distribution of total energy and free sugars intake according to the food groups. Then, we calculated the mean free sugars intake of the overall diet and the prevalence of excessive intake of free sugars. We used the WHO recommendations [5] to assess the excessive intake of free sugars (≥10% of total energy). Analyses using the UK recommendations to further limit free sugars intake to less than 5% of total energy intake are presented in a supplementary table **(Suppl.**

Table S3). Analyses were carried out for the entire population and also stratified by age group.

Next, the prevalence of excessive intake of free sugars (≥10% of total energy) was compared across quintiles of the energy share provided by each of the three food groups. Poisson regression was used to estimate prevalence ratios (PR) and 95% confidence intervals for the associations between each of the three NOVA food group quintiles and prevalence of individuals consuming more than 10% of total energy from free sugars. Tests of linear trend were performed to evaluate the quintiles as a single continuous variable. All analyses were stratified by age group. Multiple regression models were also performed to adjust for age, sex, ethnicity, region, survey year, and equivalised household income (sterling pounds). Analyses using the entire population are presented in a supplementary table **(Suppl. Table S4)**. We also evaluated the extent to which the association between the exposure (dietary contribution of NOVA food groups) and the dietary content in free sugars changed according to the survey year, by including a multiplicative interaction term (survey year*dietary contribution of NOVA food groups) in the fully adjusted models.

Finally, we estimated the proportion of excessive free sugar intake that could be potentially avoided if exposure to the risk factors were eliminated (theoretical minimum risk exposure level scenarios) [22, 23]. The counterfactual scenarios were defined considering the main dietary sources of free sugars. The first counterfactual scenario assumed no consumption of ultra-processed food (potentially hidden sugars), while in the second scenario table sugar consumption was set to zero. Table sugar included honey, molasses, maple syrup (100%), and sugar added to coffee/juice and homemade dishes (potentially sugar that can be measured by the consumer). Examples of homemade dishes include: biscuits, fruit pies, buns cakes and pastries, cereal based milk puddings, and sponge pudding (**see Suppl. Table S2**).

In both scenarios, we first calculated the prevalence of excessive free sugar intake in the UK population ($P_{population}$). We then estimated the predicted prevalence of excessive free sugar intake that would be expected had the consumption of each of these main sources of free sugars being zero ($P_{nonexposed}$). Lastly, we calculated the proportion of excessive free sugar intake that could be potentially avoided in each scenario using the following formula: ($P_{population}$ - $P_{nonexposed}$) / $P_{population}$. Prevalences were adjusted for sex, age, ethnicity, region, survey year, and household income.' To test more feasible scenarios, we also estimated the percent reduction in prevalence of excessive free sugar intake from reducing the consumption of ultra-processed foods and table sugar by 50% (**see Suppl. Figure S2**).

NDNS study weights were used in all analyses to account for sampling and non-response error. All statistical analyses were carried out using Stata Statistical Software version 14. The *p* values reported were two-tailed, and a threshold of <0.05 was considered for statistically significant associations.

Patient and public involvement

Patients and/or public were not involved in in the design or conduct of this study.

RESULTS

Ultra-processed foods account for 56.8% of total energy intake and 64.7% of total free sugars in the UK diet. Unprocessed or minimally processed foods and processed culinary ingredients represented an additional 34.3% of total energy intake and 23.8% of free sugars, and processed foods the remaining 8.8% of total energy intake and 11.5% of free sugars. Ultra-processed foods accounted for a higher percentage of total energy intake among children (63.5%) and adolescents (68%). The average UK daily intake of free sugars was 12.4% (SE 0.1) of total energy intake and 61.3% of British exceeded the recommended limit of 10% energy from free sugars. This proportion was even higher among children (74.9%) and adolescents (82.9%) (**Table 1**).

Table 1. Dietary contribution of NOVA food groups and indicators of the dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

Age groups	Dietary contribution (% of total energy intake)						% of total energy intake from free sugars								Individuals with ≥10% of total energy intake from free sugars		
	Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Unprocessed or minimally processed foods + Processed culinary ingredients		Processed foods		Ultra-processed foods		Total		Overall diet		
	Mean	*SE*					*Mean*	*SE*							*%*	*95%CI*	
1.5 - 10 years	31.96	0.33	4.51	0.10	63.53	0.34	18.82	0.45	5.15	0.22	76.03	0.49	14.00	0.14	74.94	72.78	76.99
11 - 18 years	27.25	0.37	4.75	0.16	68.00	0.40	18.63	0.55	2.48	0.19	78.89	0.57	15.78	0.19	82.91	80.72	84.90
19 - 64 years	34.75	0.32	10.37	0.19	54.89	0.35	24.68	0.50	12.96	0.38	62.36	0.56	11.93	0.14	56.59	54.47	58.68
≥65 years	38.57	0.49	8.45	0.29	52.98	0.52	26.77	0.96	15.38	0.69	57.86	1.01	11.36	0.23	56.83	52.98	60.59
Total	**34.35**	**0.22**	**8.83**	**0.13**	**56.82**	**0.24**	**23.78**	**0.36**	**11.46**	**0.27**	**64.75**	**0.40**	**12.44**	**0.10**	**61.27**	**59.76**	**62.76**

No significant interaction was observed between the exposure and the survey year for the total energy intake from free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.254; processed foods: p = 0.538; ultra-processed foods: p = 0.137), nor for the prevalence of excessive intake of free sugars (unprocessed or minimally processed foods + processed culinary ingredients: p = 0.609; processed foods: p = 0.262; ultra-processed foods: p = 0.258). Even so, we included variable survey year (1-6) in the adjusted model.

Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups stratified by age groups are shown in **Tables 2 to 5** (1.5 – 10 years, 11 – 18 years, 19 – 64 years, and ≥64 years, respectively). The dietary contents of free sugars increased linearly across quintiles of ultra-processed food consumption for children (from 10.4% in the lowest quintile to 15.3% in the highest quintile), adolescents (from 12.7% to 17.4%, respectively) and adults (from 9.6% to 15.2%, respectively), whereas the increase for elderly was not significant (from 10.6% to 11.7%, respectively). The prevalence of excessive free sugar intake also increased linearly across quintiles of ultra-processed food consumption for children, adolescents and adults. Children in the highest quintiles of ultra-processed food consumption had a prevalence of excessive free sugar intake 60% higher (PRadj 1.6; 95% CI 1.3 to 1.9) than those in the lowest quintile group. The same trend was observed for adolescents (PRadj 1.6 95% IC 1.2 – 1.9) and adults (PRadj 1.7 95% IC 1.5 – 1. 9). Although no linear trend was found between quintiles of ultra-processed food consumption and excessive free sugars intake among elderly (p>0.05), the fourth quintile group had a prevalence of excessive free sugar intake 35% higher (PRadj 1.3; 95% CI 1.1 to 1.7) than those in the lowest quintile group.

Opposite trends were observed for the group of unprocessed or minimally processed foods and processed culinary ingredients, where the prevalence of excessive free sugars intake decreased from the first to the last quintile of these food groups in all age groups. The prevalence of excessive free sugars intake also decreased from the first to the last quintile of processed foods, but only in adolescents and adults.

Sensitivity analysis performed by considering complete cases only indicated that the results of the multiple imputations did not differ significantly from the complete case analysis (data not shown).

Table 2. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 - 10 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*[¦]	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.36	0.00	20.92	15.80	0.33	82.99	1.00	1.00	–	–
2nd	24.86	20.93	28.41	14.60	0.30	79.62	0.96	0.95	0.89	1.02
3rd	31.57	28.46	34.96	14.37	0.28	81.68	0.98	0.99	0.93	1.06
4th	39.30	34.98	43.86	13.66	0.36	73.40	0.88	0.91	0.84	0.99
5th	52.46	43.97	79.93	11.13[¥]	0.26	53.87	0.65[¥]	0.69[¥]	0.61	0.78
Processed foods										
1st	0.41	0.00	1.33	13.93	0.29	72.58	1.00	1.00	–	–
2nd	2.56	1.34	3.79	14.82	0.30	80.23	1.11	1.11	1.03	1.19
3rd	5.18	3.79	6.82	13.77	0.25	73.85	1.02	1.04	0.95	1.13
4th	8.96	6.83	11.95	13.37	0.31	73.23	1.01	1.02	0.93	1.12
5th	16.05	12.04	41.71	13.16	0.52	69.20	0.95	0.99	0.86	1.14
Ultra-processed foods										
1st	36.38	15.11	43.67	10.35	0.38	46.41	1.00	1.00	–	–
2nd	49.00	43.72	53.03	12.37	0.30	66.78	1.44	1.39	1.15	1.70
3rd	57.17	53.06	60.95	13.84	0.37	74.22	1.60	1.50	1.24	1.81
4th	65.58	60.96	70.14	14.48	0.26	80.95	1.74	1.62	1.35	1.95
5th	78.05	70.15	100	15.32[¥]	0.25	81.41	1.75[¥]	1.62[¥]	1.35	1.95

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.01).

Table 3. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 11 - 18 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	14.43	0.00	20.89	17.28	0.36	88.89	1.00	1.00	–	–
2nd	24.61	20.92	28.43	15.87	0.35	84.30	0.95	0.95	0.89	1.01
3rd	31.46	28.44	34.93	15.50	0.37	81.82	0.92	0.92	0.86	0.99
4th	39.24	34.98	43.84	13.96	0.43	78.15	0.88	0.89	0.82	0.96
5th	52.96	43.88	79.86	13.60¥	0.80	66.92	0.75¥	0.77¥	0.66	0.88
Processed foods										
1st	0.29	0.00	1.33	17.18	0.41	85.11	1.00	1.00	–	–
2nd	2.56	1.34	3.79	15.81	0.35	81.74	0.96	0.96	0.90	1.03
3rd	5.16	3.80	6.81	15.62	0.35	86.87	1.02	1.02	0.96	1.09
4th	8.94	6.82	11.95	14.52	0.43	79.40	0.93	0.93	0.86	1.01
5th	17.53	12.05	41.62	13.68¥	0.57	74.89	0.88£	0.87£	0.78	0.99
Ultra-processed foods										
1st	35.29	18.40	42.94	12.72	1.39	56.18	1.00	1.00	–	–
2nd	49.35	43.70	53.03	13.65	0.56	75.73	1.35	1.34	1.03	1.74
3rd	56.91	53.08	60.96	14.19	0.40	79.24	1.41	1.40	1.09	1.80
4th	65.63	60.96	70.13	14.99	0.32	80.76	1.44	1.42	1.11	1.82
5th	79.05	70.14	100	17.37¥	0.29	89.04	1.58¥	1.56¥	1.23	1.99

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles (p≤0.01).
£Significant linear trend across all quintiles (p≤0.05).

Table 4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 19 - 64 years (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj¦*	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	15.06	0.00	20.92	15.11	0.36	35.87	1.00	–	–	
2nd	24.93	20.95	28.41	12.87	0.31	31.12	0.85	0.87	0.79	0.96
3rd	31.65	28.43	34.96	11.97	0.31	30.87	0.79	0.85	0.77	0.94
4th	38.95	34.97	43.88	11.01	0.28	28.45	0.66	0.72	0.64	0.80
5th	54.24	43.93	91.90	9.89¥	0.25	25.28	0.57¥	0.62¥	0.55	0.71
Processed foods										
1st	0.28	0.00	1.32	13.09	0.50	59.14	1.00	1.00	–	–
2nd	2.60	1.34	3.79	12.82	0.41	60.65	1.03	1.04	0.92	1.19
3rd	5.35	3.79	6.82	12.17	0.30	61.42	1.04	1.04	0.92	1.18
4th	9.36	6.82	12.03	11.62	0.26	55.92	0.95	0.98	0.87	1.11
5th	19.80	12.04	65.22	11.27¥	0.22	52.47	0.89¥	0.92¥	0.82	1.03
Ultra-processed foods										
1st	34.45	1.82	43.67	9.62	0.27	39.42	1.00	1.00	–	–
2nd	48.70	43.69	53.04	11.11	0.25	53.34	1.35	1.30	1.13	1.50
3rd	57.08	53.06	60.96	11.83	0.29	56.84	1.44	1.37	1.19	1.57
4th	65.34	60.96	70.14	13.09	0.32	66.31	1.68	1.57	1.37	1.79
5th	78.04	70.15	100	15.21¥	0.38	74.30	1.88¥	1.67¥	1.46	1.92

*PR=Prevalence ratios estimated using Poisson regression.
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.
¥Significant linear trend across all quintiles (p≤0.01).

Table 5. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 65 years or over (2008-14).

Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥10% of total energy intake from free sugars				
Quintile	*mean*	*min*	*max*	*mean*	*SE*	*%*	*PR**	*PRadj*¦	*95%CI*	
Unprocessed or minimally processed foods + Processed culinary ingredients										
1st	16.63	6.34	20.82	11.67	0.87	56.16	1.00	1.00	–	–
2nd	25.04	20.95	28.36	12.83	0.61	67.39	1.20	1.19	0.90	1.57
3rd	32.06	28.44	34.90	11.98	0.48	64.37	1.15	1.15	0.87	1.52
4th	39.30	34.98	43.85	10.93	0.44	53.96	0.96	0.97	0.73	1.28
5th	52.26	43.89	78.36	10.70	0.42	50.94	0.91£	0.91£	0.69	1.21
Processed foods										
1st	0.38	0.00	1.32	9.70	0.72	43.52	1.00	1.00	–	–
2nd	2.42	1.34	3.78	12.13	0.56	64.30	1.48	1.49	1.14	1.96
3rd	5.23	3.79	6.81	12.16	0.45	65.00	1.49	1.52	1.17	1.98
4th	9.27	6.82	12.02	11.10	0.47	54.46	1.25	1.27	0.96	1.67
5th	19.10	12.04	50.86	11.23	0.46	53.62	1.23	1.29	0.97	1.69
Ultra-processed foods										
1st	35.98	7.79	43.69	10.63	0.49	47.63	1.00	1.00	–	–
2nd	48.67	43.74	53.02	11.30	0.48	58.67	1.23	1.20	0.97	1.47
3rd	56.97	53.05	60.91	11.61	0.45	59.89	1.26	1.21	0.98	1.50
4th	64.99	61.01	70.08	12.01	0.54	65.53	1.38	1.35	1.09	1.66
5th	75.66	70.17	92.30	11.67	0.70	53.75	1.13	1.06	0.81	1.40

*PR=Prevalence ratios estimated using Poisson regression.

¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.01).

£Significant linear trend across all quintiles (p≤0.05).

In our counterfactual scenarios, we calculated the percentage of excessive free sugar intake avoided if the consumption of ultra-processed foods and table sugar were zero (**Figure 1**). We estimated that about 47% of the prevalence of excessive free sugars intake in the UK population could be potentially avoided if the consumption of ultra-processed foods was eliminated. Eliminating table sugar could potentially avoid 9.4% of the prevalence of excessive free sugars intake. This greater reduction in the percentage of excessive free sugar intake due to elimination of ultra-processed foods, relative to table sugar, was observed in all age groups, except in the elderly group where both scenarios had similar impacts on total free sugar intake. For the more feasible scenario, we found a similar trend where a greater reduction in the percentage of excessive free sugar intake due to a 50% reduction of ultra-processed foods, relative to table sugar, was observed in all age groups, except in the elderly group (**see Suppl. Figure S2**).

DISCUSSION

In this large, nationally representative sample of the UK population, higher consumption of ultra-processed food was associated with greater dietary content of free sugars in children, adolescents, and adults. Using theoretical minimum risk exposure level scenarios, we also showed that by eliminating ultra-processed food consumption, the prevalence of excessive free sugar intake (10% or more of total energy intake) could be potentially reduced from 60% to 31%. In children and adolescents, the potential reduction could be from 74% to 45% and from 83% to 53%, respectively.

Our findings confirm an excessive consumption of free sugars in the UK diet [13] and show that ultra-processed foods contributed nearly 65% of all free sugars in all age groups and nearly 80% in children and adolescents. Unprocessed or minimally processed foods (mostly fresh juice) and processed culinary ingredients (mostly table sugar) contributed between 19% and 27% of the dietary content of free sugars, while processed foods provided the lowest contribution in all age groups.

Our findings are similar to previous studies conducted in high- and middle-income countries that have shown strong associations between the intake of ultra-processed foods and the dietary content of free sugars [8-11]. A previous study conducted in Chile similarly showed that the association between ultra-processed food consumption and the dietary content of added sugars is more pronounced among children and adolescents [12]. In our study, there was no linear association between ultra-processed food consumption and dietary content of free sugars among the elderly. Although the prevalence of excessive free sugar intake was higher in the fourth in regards to the first quintile of ultra-processed food consumption, the prevalence in the highest quintile group was not different from the first. A possible explanation for this finding could be changes in the composition of different types of ultra-processed across quintiles in the elderly. Actually, while in the overall population, ultra-processed sweetened products such as soft/fruit drinks, confectionary, milk-based drinks, and biscuits monotonically increased across quintiles (from 18% to 23% of the total calories from ultra-processed foods), in the elderly a drop in consumption was observed between the fourth and fifth quintiles (from 18 to 15%) (data no shown).

There is strong evidence that the high consumption of free sugars contributes to excess obesity, type 2 diabetes, dyslipidaemia, hypertension and coronary heart disease [2-4]. Consequently, most dietary recommendations now advise limiting free sugar intake, but more focused efforts are needed to put this recommendation into practice. Changing personal behaviour and choice alone is not an effective or realistic option as our findings confirm that the majority of free sugar is added to food before it is marketed and sold. Voluntary agreements between industry and government have been shown repeatedly to be ineffective in improving public health [24]. This is confirmed by recent UK experience where the early stages of the government's sugar reduction programme, which challenged the food industry to voluntarily cut sugar in some products, has produced only slow progress toward proposed targets [25]. Thus, more drastic measures that change the availability, price and marketing of these products is necessary.

The analyses presented here suggest that actions to reduce the consumption of ultra-processed foods often rich in free sugars could lead to larger public health benefits. Policies concerning the use of fiscal measures to reduce intake of free sugars and improve diet quality should consider extending beyond artificially sweetened beverages to include the main driver of excessive free sugar intake, including dairy drinks, cakes, biscuits and confectionery [13].

To our knowledge, this is the first study to examine the association between consumption of ultra-processed foods, as defined per NOVA [6], and dietary content of free sugar in different age groups of the UK population. The use of NOVA is a key strength of the study as it classified foods by their level of processing level using standardised and objective criteria. NOVA has been recognised as a valid tool for public health and nutrition research and policy by the Food and Agricultural Organization of the United Nations [26] and the Pan American Health Organization [27]. In addition, we used data from the NDNS - a large and nationally representative sample of the UK population, applying weighting to reduce any sampling and non-response bias. Unlike household budget data, food diaries employed in the NDNS take food wastage into account, include food eaten out of home, and do not assume that all individuals within a household consume the same diet. Importantly, the dietary data also allowed for the disaggregation of dishes into their constituents and classification of the underlying ingredients, which enabled the calculation of more precise estimates of intakes of each NOVA group and reduced misclassification.

Potential limitations should be considered. The dietary data we used were self-reported and may be subject to misclassification. A constant limitation of dietary assessment methods is underreporting of some foods (particularly unhealthy foods), though food diaries are recognised to be one of the most comprehensive methods for assessing dietary intake. Possible underreporting of unhealthy foods may lead to an underestimation of the dietary contribution of ultra-processed foods and the overall intake of free sugars, but may less likely affect the association between these variables. Nevertheless, accurate and valid NDNS data were achieved through optimal methods for collecting dietary intake [28] which helped to minimise missing information. NDNS collects limited information indicative of food processing (for example, place of meals and product brands), which may lead to misclassification of food items. This bias is more likely for a small number of specific food items such as pizza where there is insufficient information for classification purposes (see **Suppl. Table S2**). In those cases, the most frequently consumed alternative (culinary preparation or manufactured product) was chosen. Finally, our theoretical minimum risk exposure models estimate the potential impact of eliminating each of the main sources of free sugars on excessive free sugar intake, ignoring substitutions that may occur in the consumption of other foods. Although our findings suggest that greater reduction in excessive free sugar intake could be achieved by eliminating ultra-processed food consumption, guidance to the public about reducing the consumption of table sugar remains an important component of any public health guidance.

Conclusions

Almost half of excessive intake of free sugars in the UK can be attributed to ultra-processed foods. Policies to reduce sugar consumption should focus on minimizing consumption of ultra-processed foods and replacing them with unprocessed or minimally processed foods alternatives. The study adds to a growing body of evidence that ultra-processed foods are a major contributor to growth of diet related non-communicable diseases globally.

Author contributions: CAM, EMS, FR, MLdCL, and RBL designed the research. FR and RBL undertook data management and analysis. CAM, CM, EMS, FR, LFMR, MLdCL, and RBL interpreted the data. FR wrote the first draft of the manuscript. All authors read, edited and approved the final manuscript.

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Competing interests: None declared.

Data sharing statement: This study is based on open data of the UK population that is available in the UK Data Archive website (http://www.esds.ac.uk).

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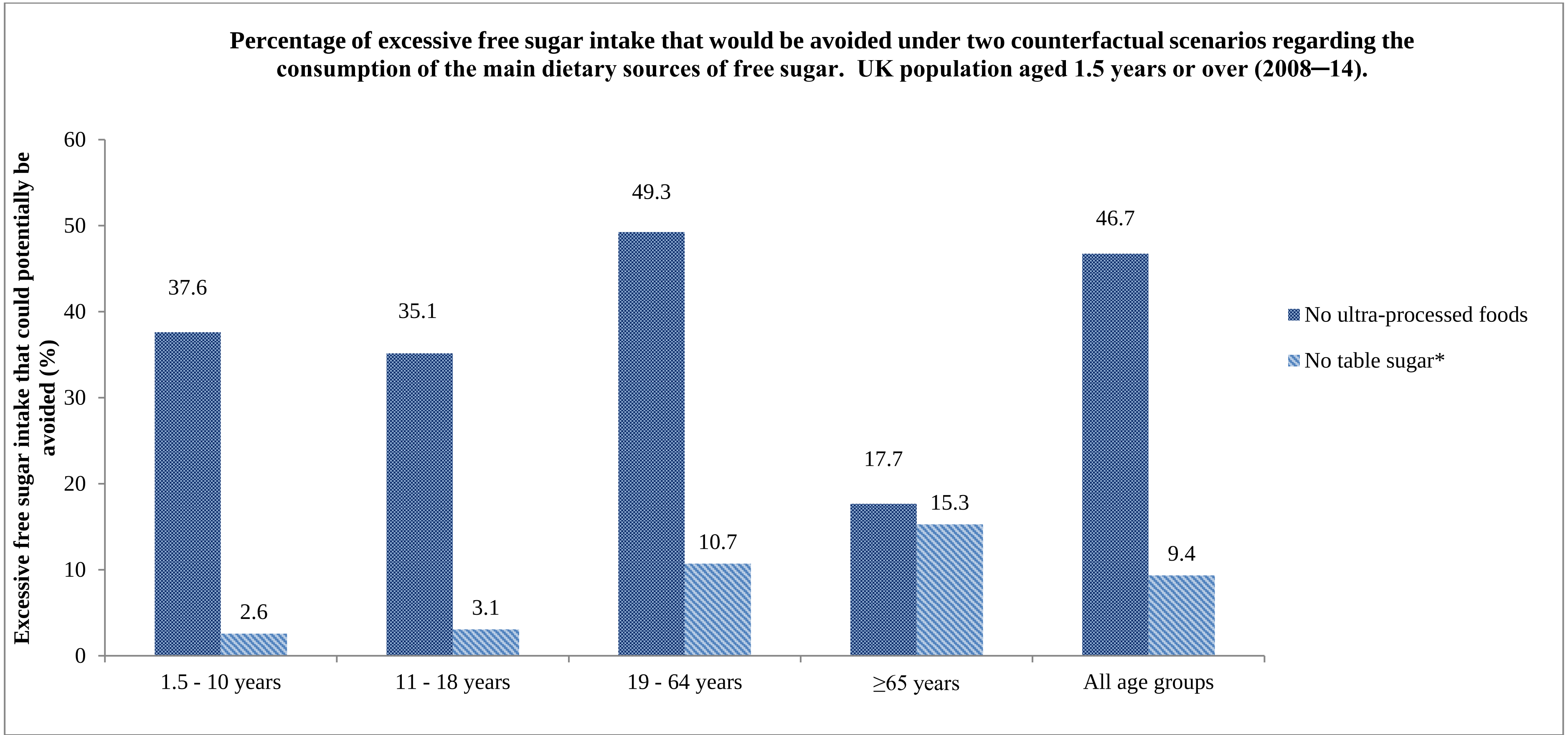
Figure 1. Percentage of excessive free sugar intake that would be avoided under two counterfactual scenarios regarding the consumption of the main dietary sources of free sugar. UK population aged 1.5 years or over (2008–14).

Figure 1.



*Including honey, molasses, maple syrup (100%).

Ultra-processed foods and excessive free sugar intake in the United Kingdom: a nationally representative cross-sectional study.

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Supplementary table S1. The Nova food classification system*

Food groups	Examples
1) Unprocessed foods or minimally processed foods Natural foods altered by methods such as freezing, pasteurization, fermentation, removal of inedible or unwanted parts, grinding, and other methods that do not include the addition of substances such as salt, sugar and/or oils or fats.	Fresh, dry or frozen fruits or vegetables; legumes; grains, roots and tubers, flours and pasta; pasteurized or power plain milk and plain yogurt; fresh or frozen meat (fish, poultry and red meat); eggs; nuts and seeds; fungi; fresh or pasteurised fruit or vegetable juices without added sugar, sweeteners or flavours; tea, coffee and drinking water.
2) Processed culinary ingredients Substances obtained directly from group 1 foods or from nature by processes that include pressing, refining, grinding, milling, and drying, and consumed in combination with group 1 foods in freshly prepared dishes or drinks.	Salt; sugar, honey and molasses; vegetable oils; butter and lard; starches extracted from corn and other plants.
3) Processed foods Products manufactured with the addition of group 2 substances (e.g. salt, sugar, oil, and fats) to group 1 foods and alcoholic drinks produced by fermentation of group 1 foods such as beer, cider and wine.	Canned or bottled vegetables, fruits and legumes; salted or sugared nuts and seeds; salted, cured, or smoked meats; canned fish; fruits in syrup; cheeses and unpackaged freshly made breads.
4) Ultra-processed foods Food and drink formulations made from several ingredients. Such ingredients include salt, sugar, oils, and fats but also other substances derived from foods but not commonly used as culinary ingredients (such as protein isolates, hydrogenated oils, modified starches) and additives used to imitate sensory quality of natural foods and freshly prepared dishes or to disguise unpalatable aspects of the final product (such as flavours, colours, sweeteners, emulsifiers). Alcoholic drinks produced by fermentation of group 1 foods followed by distillation of the resulting alcohol, such as whisky, gin, rum, vodka, are classified in group 4.	Carbonated drinks; sweet or savoury packaged snacks; confectionery; mass-produced packaged breads and buns; margarines and spreads; biscuits, pastries, cakes, and cake mixes; breakfast 'cereals', 'cereal' and 'energy' bars; 'energy' drinks; milk drinks, 'fruit' yoghurts and 'fruit' drinks; cocoa drinks; meat and chicken extracts and 'instant' sauces; ready to heat products including pre-prepared pies and pasta and pizza dishes; poultry and fish 'nuggets' and 'sticks', sausages, burgers, hot dogs, and other reconstituted meat products, and powdered and packaged 'instant' soups, noodles and desserts.

Adapted from Monteiro et al. (2016 and 2018).

Monteiro CA, Cannon G, Moubarac JC et al. (2018) The UN Decade of Nutrition, the NOVA food classification and the trouble with ultra-processing. Public Health Nutr 21, 5-17.
Monteiro CA, Cannon G, Levy RB, et al. NOVA. The star shines bright. World Nutrition. 2016;7(1-3):28-38.

Supplementary Table S2. Coding of subsidiary food groups from National Diet and Nutrition Survey according to NOVA classification.

Subsidiary food group code	Subsidiary food group name	NOVA food group†
1C	Pizza	4
1D	Pasta (manufactured products and ready meals	4
1E	Pasta (other, including homemade dishes)	*
1F	Rice (manufactured products and ready meals)	4
1G	Rice (other, including homemade dishes)	*
1R	Other cereals	*
2R	White bread (not high fibre, not multiseed bread)	4
3R	Wholemeal bread	4
4R	Other bread	4
5R	High fibre breakfast cereals	4
6R	Other breakfast cereals (not high fibre)	4
7A	Biscuits(manufactured/retail)	4
7B	Biscuits (homemade)	*
8B	Fruit pies (manufactured)	4
8C	Fruit pies (homemade)	*
8D	Buns cakes and pastries (manufactured)	4
8E	Buns cakes and pastries (homemade)	*
9C	Cereal based milk puddings (manufactured)	4
9D	Cereal based milk puddings (homemade)	*
9E	Sponge puddings (manufactured)	4
9F	Sponge puddings (homemade)	*
9G	Other cereal based puddings (manufactured)	4
9H	Other cereal based puddings (homemade)	*
10R	Whole milk	1
11R	Semi-skimmed milk	1
12R	Skimmed milk	1
13A	Infant formula	4
13B	Cream (including imitation cream)	*
13R	Other milk	*
14A	Cottage cheese	3
14B	Cheddar cheese	3
14R	Other cheese	*
15B	Yogurt	*
15C	Fromage frais and other dairy desserts (manufactured)	4
15D	Dairy desserts (homemade)	*
16C	Manufactured egg products, including ready meals	4
16D	Other eggs and egg dishes, including homemade	*
17R	Butter	2
18A	Polyunsaturated margarine	4
18B	Polyunsaturated oils	2
19A	Polyunsaturated low fat spread	4
19R	Low fat spread not polyunsaturated	4
20A	Block margarine	4
20B	Soft margarine not polyunsaturated	4
20C	Other cooking fats and oils not polyunsaturated	2
21A	Reduced fat spread (polyunsaturated)	4
21B	Reduced fat spread (not polyunsaturated)	4
22A	Ready meals/meal centres based on bacon and ham	4
22B	Other bacon and ham (including homemade dishes)	*
23A	Manufactured beef products (including ready meals)	4
23B	Other beef & veal (including homemade recipe dishes)	*
24A	Manufactured lamb products (including ready meals)	4
24B	Other lamb (including homemade recipe dishes)	*
25A	Manufactured pork products(including ready meals)	4
25B	Other pork (including homemade recipe dishes)	*
26A	Manufactured coated chicken/turkey products	4
27A	Manufactured chicken products (including ready meals)	4
27B	Other chicken/turkey (including homemade recipe dishes)	*
28R	Liver and dishes	*
29R	Burgers and kebabs purchased	4
30A	Ready meals based on sausages	4
30B	Other sausages (including homemade dishes)	*
31A	Meat pies and pastries (manufactured)	4
31B	Meat pies and pastries (homemade)	*

32A	Other meat products (manufactured including ready meals)	4
32B	Other meat (including homemade recipe dishes)	*
33R	White fish coated or fried	*
34C	Manufactured white fish products (including ready meals)	4
34D	Other white fish (including homemade dishes)	*
34E	Manufactured shellfish products (including ready meals)	4
34F	Other shellfish (including homemade dishes)	*
34G	Manufactured canned tuna products (including ready meals)	*
34H	Other canned tuna (including homemade dishes)	*
35A	Manufactured oily fish products (including ready meals)	4
35B	Other oily fish (including homemade dishes)	*
36A	Carrots (raw)	1
36B	Salad and other raw vegetables	*
36C	Tomatoes raw	1
37A	Peas not raw	*
37B	Green beans not raw	*
37C	Baked beans	4
37D	Leafy green vegetables not raw	*
37E	Carrots not raw	*
37F	Tomatoes not raw	*
37I	Beans and pulses (including ready meal & homemade dishes)	*
37K	Meat alternatives (including ready meals and homemade dishes)	4
37L	Other manufactured vegetable products (including ready meals)	4
37M	Other vegetables (including homemade dishes)	*
38A	Chips purchased including takeaway	4
38C	Other manufactured potato products fried/baked	4
38D	Other fried/roast potatoes (including homemade dishes)	*
39A	Other potato products and dishes(manufactured)	4
39B	Other potatoes (including homemade dishes)	*
40A	Apples and pears not canned	*
40B	Citrus fruit not canned	*
40C	Bananas	*
40D	Canned fruit in juice	*
40E	Canned fruit in syrup	3
40R	Other fruit not canned	*
41A	Sugar	*
41B	Preserves	3
41R	Sweet spreads fillings and icing	4
42R	Crisps and savoury snacks	4
43R	Sugar confectionery	4
44R	Chocolate confectionery	4
45R	Fruit juice	*
47A	Liqueurs	4
47B	Spirits	4
48A	Wine	3
48B	Fortified wine	4
48C	Low alcohol and alcohol free wine	3
49A	Beers and lagers	3
49B	Low alcohol & alcohol free beer & lager	3
49C	Cider and Perry	4
49D	Low alcohol & alcohol free cider & Perry	4
49E	Alcoholic soft drinks (Alcopops)	4
50A	Beverages dry weight	4
50C	Soup (manufactured/retail)	4
50D	Soup (homemade)	*
50E	Nutrition powders and drinks	4
50R	Savoury sauces pickles gravies & condiments	4
51A	Coffee (made up weight)	*
51B	Tea (made up)	*
51C	Herbal tea (made up)	1
51D	Bottled water still or carbonated	*
51R	Tap water only	1
52A	Commercial toddlers drinks	3
52R	Commercial toddlers foods	3
53R	Ice cream	4
54A	Cod liver oil and other fish oils	**
54B	Evening primrose oil and other plant oils	**
54C	Single vitamins/minerals not Folic acid, iron, calcium	**

54D	Folic acid	**
54E	Iron only or with vitamin C	**
54F	Calcium only or with vitamin D	**
54G	Vitamins (two or more including multivitamins) no minerals	**
54H	Minerals (two or more including multimineral) no vitamins	**
54I	Vitamins and minerals (including multivitamins & minerals)	**
54J	Non-nutrient supplements (including herbal)	**
54K	Other nutrient supplements	**
54L	Vitamin C	**
54M	Single vitamins/minerals not Folic acid, iron, calcium or vitamin C	**
54N	Cod liver oil and other fish oils (including with vitamins A, D, E)	**
54P	Multivitamins and/or minerals with omega ultra-processed	**
55R	Artificial sweeteners	4
56R	Nuts and seeds	*
57A	Soft drinks not low calorie concentrated	4
57B	Soft drinks not low calorie carbonated	4
57C	Soft drinks not low calorie, ready to drink, still	4
58A	Soft drinks low calorie concentrated	4
58B	Soft drinks low calorie carbonated	4
58C	Soft drinks low calorie, ready to drink, still	4
59R	Brown, granary and wheat germ bread	4
60R	1% Milk	1
61R	Smoothies	1

† NOVA food groups defined as 1) unprocessed or minimally processed foods; 2) processed culinary ingredients; 3) processed foods; and 4) ultra-processed foods.
* All foods within this subsidiary food group were individually coded (by food name).
** Supplements were not included in any of the NOVA food groups.
Source: Rauber F, Louzada MLC, Steele EM, Millett C, Monteiro CA, Levy RB. Ultra-Processed Food Consumption and Chronic Non-Communicable Diseases-Related Dietary Nutrient Profile in the UK (2008–2014). Nutrients 2018, 10, 587; doi:10.3390/nu10050587.

Supplementary table S3. Dietary content in free sugars according to age groups. UK population aged 1.5 years or over (2008–14).

Age groups	% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars		
	mean	**SE**	*%*	*95%CI*	
1.5 - 10 years	14.00	0.14	97.16	96.29	97.84
11 - 18 years	15.78	0.19	96.77	95.62	97.62
19 - 64 years	11.93	0.14	88.82	87.48	90.04
≥65 years	11.36	0.23	87.62	84.88	89.93
All age groups	**12.44**	**0.10**	**90.34**	**89.39**	**91.21**

Supplementary table S4. Indicators of the dietary content in free sugars according to quintiles of the dietary contribution of NOVA food groups in the UK population aged 1.5 years or over (2008-14).

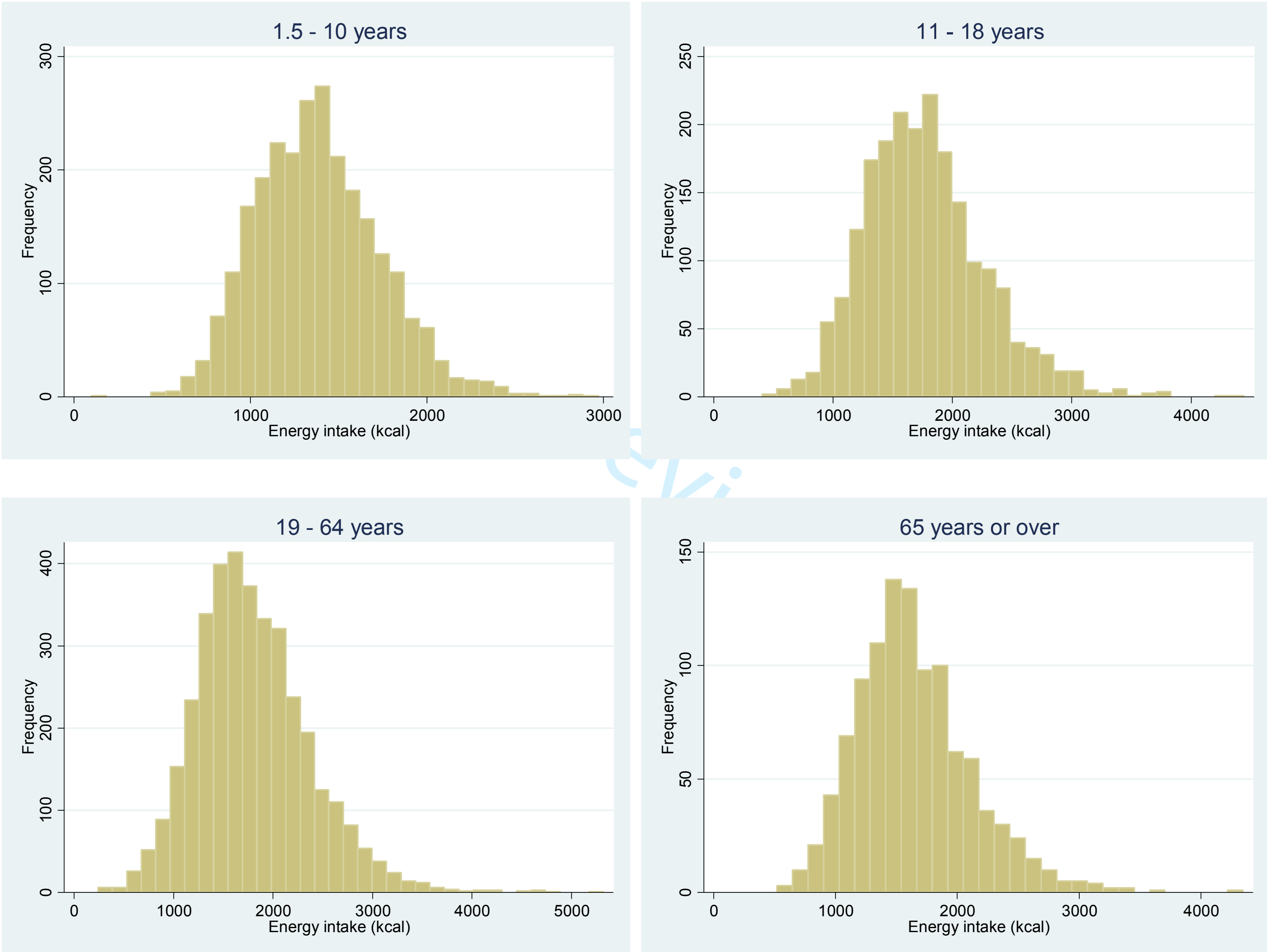
Dietary contribution (% of total energy intake)				% of total energy intake from free sugars		Individuals with ≥5% of total energy intake from free sugars					Individuals with ≥10% of total energy intake from free sugars				
Quintile	**mean**	**min**	**max**	**mean**	**SE**	**%**	**PR***	**PRadj¦**	**95%CI**		**%**	**PR***	**PRadj¦**	**95%CI**	
Unprocessed or minimally processed foods + Processed culinary ingredients															
1st	15.10	0.00	20.92	15.36	0.24	95.94	1.00	1.00	–	–	77.42	1.00	1.00	–	–
2nd	24.90	20.92	28.43	13.44	0.22	94.28	0.98	0.99	0.97	1.01	68.55	0.89	0.92	0.86	0.97
3rd	31.68	28.43	34.96	12.62	0.21	91.92	0.96	0.97	0.95	1.00	65.09	0.84	0.89	0.84	0.95
4th	39.08	34.97	43.88	11.46	0.21	89.70	0.93	0.96	0.93	0.98	55.09	0.71	0.77	0.72	0.83
5th	53.57	43.88	91.90	10.32¥	0.19	82.41	0.86	0.89	0.86	0.92	46.36	0.60¥	0.67¥	0.61	0.73
Processed foods															
1st	0.32	0.00	1.33	13.53	0.29	87.19	1.00	1.00	–	–	64.14	1.00	1.00	–	–
2nd	2.55	1.34	3.79	13.48	0.24	92.34	1.06	1.06	1.03	1.10	67.93	1.06	1.08	1.01	1.16
3rd	5.28	3.79	6.82	12.83	0.19	92.39	1.06	1.07	1.03	1.10	67.10	1.05	1.08	1.00	1.16
4th	9.28	6.82	12.03	11.89	0.20	90.61	1.04	1.06	1.02	1.09	58.87	0.92	0.98	0.91	1.06
5th	19.54	12.04	65.22	11.38¥	0.19	89.40	1.03	1.04	1.01	1.08	53.70	0.84¥	0.91¥	0.84	0.98
Ultra-processed foods															
1st	34.89	1.82	43.69	9.94	0.22	80.50	1.00	1.00	–	–	41.87	1.00	1.00	–	–
2nd	48.74	43.69	53.04	11.34	0.20	89.16	1.11	1.10	1.05	1.15	56.35	1.35	1.31	1.18	1.46
3rd	57.06	53.05	60.96	12.16	0.21	92.65	1.15	1.14	1.09	1.18	60.76	1.45	1.39	1.25	1.54
4th	65.37	60.96	70.14	13.38	0.21	94.08	1.17	1.15	1.10	1.19	70.18	1.68	1.55	1.41	1.72
5th	78.06	70.14	100.00	15.41¥	0.21	95.30	1.18¥	1.15¥	1.10	1.19	77.20	1.84¥	1.64¥	1.48	1.81

*PR=Prevalence ratios estimated using Poisson regression.

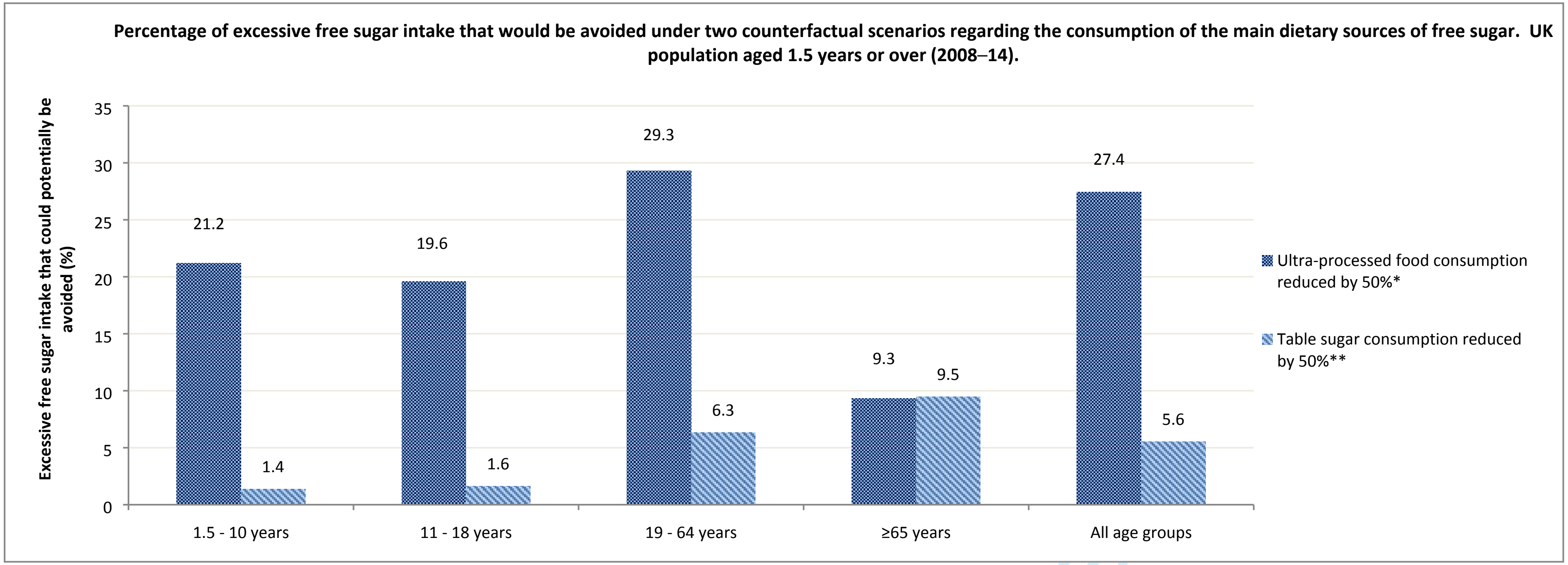
¦PRadj=Prevalence ratios adjusted for sex, age, race/ethnicity (White, Mixed ethnic group, Black or Black British, Asian or Asian British and Other race), region, survey year, and household income.

¥Significant linear trend across all quintiles (p≤0.01).

Supplementary figure S1. Distribution of total energy intake by age groups, including outliers. UK population (2008-14).



Supplementary figure S2. Percentage of excessive free sugar intake that would be avoided under two possible scenarios regarding the consumption of the main dietary sources of free sugar. UK population aged 1.5 years or over (2008–14).



* The consumption of ultra-processed food was reduced by 50% of the average intake for each age group (1.5-10y: from 63.5 to 28.4% of total energy intake; 11-18y: from 68 to 34%; 19-64y: from 54.8 to 27.4; ≥65y: from 52.9 to 26.4%; all age groups: from 56.8 to 28.4%).

** The consumption of table sugar (including honey, molasses, maple syrup) was reduced by 50% of the average intake for each age group (1.5-10y: from 0.48 to 0.24% of total energy intake; 11-18y: from 1.0 to 0.5%; 19-64y: from 1.8 to 0.9; ≥65y: from 1.9 to 0.9%; all age groups: from 1.6 to 0.8%).

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1, 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	1, 2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4, 5
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	5
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-9
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-9
Bias	9	Describe any efforts to address potential sources of bias	6,7,9
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7,8
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	8-9
		(*b*) Describe any methods used to examine subgroups and interactions	8,9
		(*c*) Explain how missing data were addressed	8
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	9
		(*e*) Describe any sensitivity analyses	NA
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8
		(b) Give reasons for non-participation at each stage	NA
		(c) Consider use of a flow diagram	NA
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	NA
		(b) Indicate number of participants with missing data for each variable of interest	8
Outcome data	15*	Report numbers of outcome events or summary measures	10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	12-16

		(*b*) Report category boundaries when continuous variables were categorized	
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	NA
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	12
Discussion			
Key results	18	Summarise key results with reference to study objectives	17
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	18,19
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	19
Generalisability	21	Discuss the generalisability (external validity) of the study results	17,18
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	20

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.