Adiposity among 132,479 UK Biobank participants; contribution of sugar intake versus other macronutrients.

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Abstract

Background

Policy-makers are being encouraged to specifically target sugar intake in order to combat obesity. We examined the extent to which sugar, relative to other macronutrients, was associated with adiposity.

Methods

We used baseline data from UK Biobank to examine the associations between energy intake (total and individual macronutrients) and adiposity (body mass index (BMI), percentage body fat and waist circumference). Linear regression models were conducted univariately and adjusted for age, sex, ethnicity and physical activity.

Results

Among 132,479 participants, 66.3% of men and 51.8% of women were overweight/obese. There was a weak correlation (r=0.24) between energy from sugar and fat. Thirteen percent of those in the highest quintile for sugar were in the lowest for fat, and vice versa. Compared with normal BMI, obese participants had 11.5% higher total energy intake and 14.6%, 13.8%, 9.5% and 4.7% higher intake from fat, protein, starch and sugar respectively. Hence, the proportion of energy derived from fat was higher (34.3% vs 33.4%, p<0.001) but from sugar was lower (22.0% vs 23.4%, p<0.001). BMI was more strongly associated with total energy (coefficient 2.47, 95% CI 2.36-2.55) and energy from fat (coefficient 1.96, 95% CI 1.91-2.06) than sugar (coefficient 0.48, 95% CI 0.41-0.55). The latter became negative after adjustment for total energy.

Conclusions

Fat is the largest contributor to overall energy. The proportion of energy from fat, but not sugar, is higher among overweight/obese individuals. Focusing public health messages on sugar may mislead on the need to reduce fat, and overall, energy consumption.

Key messages

- Adiposity is associated with higher intake of sugar; but the association is stronger for fat intake and strongest for total energy intake.
- Fat is the largest contributor to overall energy intake.
- There is only a weak correlation between absolute energy derived from sugar and from fat. Therefore, targeting high sugar consumers will not necessarily target high customers of fat and overall energy.
- Focusing public health messages on sugar consumption may mislead the public on the need to reduce fat intake and overall energy intake.

Introduction

The global prevalence of overweight and obesity has nearly doubled over three decades,[1] with recent health surveys reporting that more than half the adult population in Europe,[2] and two-thirds in the USA,[3] are now overweight or obese. Sugar consumption has been implicated as a major contributor to obesity. There is a correlation between the sugar consumption in a country and its prevalence of obesity.[4] The last three decades of the twentieth century saw rapid increases in both sugar consumption and obesity; however, obesity continued to increase beyond 2000 in spite of reported falls in sugar consumption.[5] Sugar has little nutritional value beyond energy provision; often referred to as "empty calories". Furthermore, sugar-sweetened beverages provide energy but contribute little to satiety.[6] Therefore, there has been increasing pressure on policy-makers to adopt interventions targeted specifically at sugar intake,[7] such as imposition of a "sugar-tax".[8,9]

However, the association between sugar intake and obesity is due to the contribution of sugar to overall energy consumption, rather than a specific effect of sugar. All macronutrients, other than fibre, contribute to overall energy intake and researchers have suggested there may be a "sugar-fat seesaw" whereby individuals who are free to choose their diets compensate for a change in the consumption of one by a reciprocal change in the other. Therefore, focusing on sugar, in isolation, may not be the best approach to reducing overall energy intake.[5,10] The aim of this study was to explore the relationships between macronutrients, including sugar, and several adiposity measures in the general population.

Methods

UK Biobank is a very large, general population cohort study. Between 2007 and 2010, 502,682 participants, aged 40-69 years, were recruited and underwent baseline assessments at 22 centres across England, Scotland, and Wales. Detailed information was obtained via a self-completed, touch-screen questionnaire and a face to face interview, and trained staff undertook a series of measurements using standard operating procedures. Following completion of the baseline assessment, participants were invited to complete an online dietary questionnaire on four occasions: February, June and October 2011, and April 2012.

The duration of light, moderate and vigorous physical activity undertaken over the previous 24 hours was self-reported using the Oxford WebQ.[11] These were converted into metabolic equivalents (MET-hours/week), by applying weights of 2.5, 4 and 8 respectively, and then summated to derive overall daily energy expenditure from physical activity. Ethnicity was self-reported and categorised into: white, South Asian, black, Chinese, other and mixed. Smoking status was self-reported and classified as: never, former and current. Participants reported physician-diagnoses of previous and current medical conditions. Height was measured, to the nearest centimetre (cm), using a Seca 202 height measure and a Tanita BC-418 body composition analyser was used to measure weight, to the nearest 0.1 kilogram (kg), and body fat, to the nearest 1 gram (g), by bio-impedance. The measurements were used to derive three measures of adiposity: body mass index (BMI), percentage body fat and waist circumference. BMI was derived from weight (kg) / (height (m) x height (m)) and categorised according to the World Health Organisation definitions into: underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), and obese (≥30.0 kg/m^2). Obese was further categorised into: obese 1 (30.0-34.9 kg/m^2), obese 2 (35.0-39.9 kg/m^2) and obese 3 (≥40.0 kg/m^2).

Dietary information was collected via the Oxford WebQ; a web-based 24-hour recall questionnaire which was developed specifically for use in large population studies and has been validated against an interviewer-administered 24-hour recall questionnaire.[11] The Oxford WebQ derives energy intake (total and from specific macronutrients) from the information recorded in McCance and Widdowson's "The composition of food. 5th edition".[11] The macronutrients studied were: fat, sugar, starch, protein and fibre. For participants who completed more than one on-line dietary questionnaire, mean values were calculated from all of the information provided.

We defined as ineligible for inclusion those individuals: who might have unintentional weight loss (current smokers and history of myocardial infarction, heart failure, cancer, chronic obstructive pulmonary disease, emphysema, pulmonary fibrosis and rheumatoid arthritis); whose energy intake was suggestive of current dieting or under-reporting (overall energy intake <1.1 x basal metabolic rate (BMR),[12] with BMR calculated using the Oxford equations[13]); or with implausible outlier values (BMI <14.9 kg/m^2 or >60 kg/m^2, waist circumference or percentage body fat more than four standard deviations from the mean values or overall energy intake >18,828 KJ[14]).

We compared men and women in terms of anthropometric measurements, level of physical activity, total energy intake, absolute energy derived from each macronutrient, and percentage of total energy derived from each macronutrient. The same comparisons of energy intake were then applied to the BMI groups. The latter analyses were undertaken for men and women separately and combined. P-values were obtained using χ^2 tests and χ^2 tests for trend for categorical and ordinal data respectively and Kruskal-Wallis tests and t tests for non-parametric and parametric continuous data respectively. Pearson correlation coefficients were used to examine the extent to which higher intake of one macronutrient was associated with higher intake of another. These were calculated for both absolute energy derived for each macronutrient and percentage contribution to total energy intake.

The adiposity measures (BMI, percentage body fat and waist circumference) were treated as continuous, dependent variables in a series of multivariable, linear regression models undertaken for men and women separately and then combined. Overall and sex-specific quintiles were derived for overall energy intake, absolute energy derived for each macronutrient and for the percentage of total energy derived from each macronutrient. The quintile representing the lowest level of consumption was treated as the referent category. The models were adjusted for age and ethnic group, as well as sex in the analyses of men and women combined, with subsequent additional adjustment for level of physical activity. All statistical analyses were performed using Stata version 13 (Stata Corporation, College Station, Texas, USA).

This study was performed under generic ethical approval obtained by UK Biobank from the NHS National Research Ethics Service (approval letter ref 11/NW/0382, dated 17th June 2011). There was no external grant funding for the study and all authors had final responsibility for submission for publication.

Results

Of the 502,682 UK Biobank participants, 211,066 (42.0%) had completed at least one of the online 24-hour dietary recall questionnaires. Of these, 78,587 were excluded: 37,514 were current smokers or had comorbid conditions commonly associated with unintentional weight loss; 39,673 had energy intake values <1.1 x BMR suggestive of weight reduction diets or under-reporting; 1,007 reported implausibly high values for energy intake and 393 had missing data required for the calculation of BMR. The remaining 132,479 participants comprised the study population (Supplementary Figure 1). They had a mean age of 56.1 years, 53,720 (40.5%) were male and 127,228 (96.0%) were white (Table 1). Men had a higher overall energy intake than women (mean 10,556 kJ/day vs 8,793 kJ/day). Compared with men, women derived a lower percentage of their energy intake from starch (23.0% vs 23.9%, p<0.001)), and a higher percentage from all other macronutrients, including sugar (23.7% vs 22.0%, p<0.001). Fat provided the largest contribution to total energy intake in both men and women. The minimum and maximum values for quintiles of absolute energy intake, and percentage of total energy intake by macronutrient, are contained in Supplementary Table 1.

Due to missing or extreme values, we excluded 1,594 (1.2%), 1,676 (1.3%) and 114 (0.1%) participants from the analyses of BMI, percentage body fat and waist circumference respectively. Based on BMI, 35,222 (66.3%) men and 40,273 (51.8%) women were either overweight or obese (p<0.001) (Table 2). Fat was the largest contributor to total energy intake in all BMI categories (Table 2). Compared with participants with a normal BMI, those who were obese had 11.5% higher energy intake overall (Table 2). Their absolute energy intake was higher for every macronutrient. Their absolute energy intakes from fat, protein and starch were 14.6%, 13.8% and 9.5% higher respectively; but their sugar intake was only 4.7% higher. Therefore, compared with participants with a normal BMI, the proportion of energy they obtained from fat was higher (34.3% vs 33.4%, p<0.001) but from sugar was lower (22.0% vs 23.4%, p<0.001). There were weak correlations between the absolute energy derived from sugar and the energy derived from starch (r=0.16), fat (r=0.24) and protein (0.28) (Supplementary Table 2); 13.2% of participants in the highest quintile for absolute energy intake from sugar were in the lowest quintile for absolute energy intake from fat and 13.3% of those in the lowest quintile for absolute energy intake from sugar were in the highest quintile for absolute energy intake from fat (Supplementary Table 3).

Figures 1-3 show the results of the multivariable linear regression models for BMI, percentage body fat and waist circumference, respectively. When adjusted for age, sex and ethnicity, there were clear dose relationships, across all quintiles, whereby BMI, percentage body fat and waist circumference where all higher in those with the highest consumption of starch, fat and protein. The patterns persisted after including physical activity in the models. In contrast, BMI and waist circumference were only higher in those participants whose sugar intake was in the highest two quintiles.

For fat and protein consumption, there was a positive association between the percentage of energy intake derived from these macronutrients and all three measures of adiposity (Figures 1-3). In contrast, there was a negative association with both sugar and starch. Higher adiposity was associated with lower percentage contributions from these macronutrients after taking account of potential demographic confounders and level of physical activity. There was no clear relationship between intake of fibre and BMI, and a negative association with percentage body fat.

Total energy intake was strongly associated with BMI (highest quintile adjusted coefficient 2.47, 95% CI 2.39-2.55, $p<0.001$). The magnitude of the association was greater than for any individual macronutrient (Supplementary Table 4). Of the macronutrients, the association was strongest for fat (highest quintile adjusted coefficient 1.98, 95% CI 1.91-2.06, $p<0.001$) and weakest for sugar (highest quintile adjusted coefficient 0.48, 95% CI 0.41-0.55, $p<0.001$). After adjusting for total energy intake, the association remained positive for fat (highest quintile adjusted coefficient 0.70, 95% CI 0.63-

0.77, p<0.001) but became negative for sugar (highest quintile adjusted coefficient -0.93, 95% CI -1.00 to -0.86, p<0.001).

Discussion

Obesity was more strongly associated with total energy intake than the amount of energy derived from any individual macronutrients. The association between obesity and absolute energy derived from sugar was less strong than all other macronutrients. The strongest association was with energy derived from fat. There was a positive, but weak, correlation between absolute energy derived from sugar and from other macronutrients, including fat. Fat made a greater contribution to overall energy intake than sugar in all BMI groups, but especially in the obese group. Finally, on adjusting for total energy intake, fat remained positively associated with obesity, whereas sugar was negatively associated. This implies that whilst obese participants had a higher absolute intake of sugar; obesity was actually associated with a lower percentage of energy intake derived from sugar.

The association between sugar intake and obesity is due to the contribution of sugar to overall energy consumption, rather than a specific effect of sugar. A meta-analysis of cohort studies showed an overall association between higher sugar consumption and higher weight, but not in the sub-group of studies that adjusted for overall energy consumption.[15] Similarly, two recent systematic reviews of trials in which sugar intake was increased within the context of isocalorific diets, showed no effect on body weight.[16,17] Therefore, reduction of sugar intake will be effective at reducing obesity only if associated with a reduction in overall energy intake. However, researchers have suggested there may be a "sugar-fat seesaw" whereby individuals free to choose their diets compensate for a change in the consumption of one by a reciprocal change in the other.

Sadler et al.'s recent systematic review of observational studies demonstrated a strong, consistent inverse association between the percentage of total energy derived from sugar and the percentage derived from fat; corroborating the "sugar-fat seesaw" hypothesis in terms of percentage contribution to energy intake.[18] However, only two of the studies examined the relationship in terms of the absolute energy intake derived from sugar and from fat, and both studies showed a positive association.[19,20] The correlation demonstrated (r=0.37) was relatively weak;[20] consistent with our findings.

Intervention studies have examined either weight loss interventions or dietary supplements. Of three meta-analyses published in 2013 on trials of reduced sugar intake in children, two concluded there was no impact on weight,[16, 21] and one reported a reduction in the fixed effects model,[22] but not the random effects model. A meta-analysis of five trials, conducted in adults, reported a reduction in weight, but highlighted the high heterogeneity between studies and the high risk of bias in three of the five studies; there was no reduction when these three studies were removed. The recent meta-analysis by Tobias et al. only compared low-carbohydrate diets with low-fat diets.[23] Focusing weight loss interventions on one macronutrient may be counterproductive. Drummond and Kirk demonstrated that advising overweight men to reduce both dietary fat and dietary sugar resulted in a reduction in total energy consumed,[24] whereas advising them only to reduce fat resulted in a compensatory increase in sugar consumption without a net change in overall energy intake.

Most intervention studies of dietary supplements suggested that increased consumption of one macronutrient led to a compensatory reduction in the absolute amount of other macronutrients consumed, but this was usually insufficient to obviate a net increase in overall energy intake. Reid et al. demonstrated that women given sugar-sweetened drinks compensated by a reduction in the absolute intake of both fat and protein, but nonetheless increased their overall energy intake.[25] The effects were apparent irrespective of whether the drinks were labelled correctly or mislabelled as diet drinks. Conversely, women who consumed diet drinks did not modify their consumption of proteins, fats or starch, and had reduced overall energy consumption, irrespective of labelling. Raben et al. reported similar results from a study of overweight men and women.[26]

UK Biobank is representative of the general population in terms of age, sex, ethnicity and socioeconomic status but is unrepresentative in terms of lifestyle. Therefore, caution should be heeded in generalising summary statistics, such as the prevalence of obesity, to the general population. This does not detract from the ability to generalise estimates of the magnitude of associations. Our study benefitted from a very large number of participants, recruited from the general population across the whole UK. We had sufficient power to undertake sub-group analyses by sex. We conducted a cross-sectional study and, therefore, cannot demonstrate a temporal relationship between diet and adiposity. Therefore, our results may underestimate the association between sugar/fat and obesity since obese people are more likely to be on weight reduction diets. However, the proportion of people on diets at any given time is likely to be modest and most are likely to have been excluded by removing from the analyses participants with energy intake less than 1.1 x BMR. Energy expenditure is typically >1.35 x BMR for all activities other than bed rest.

Dietary intake was self-reported outside of the clinic which may encourage more truthful reporting, and was collected using a 24 hour recall questionnaire which produces more accurate results than a a food frequency questionnaire; the usual approach adopted in large-scale studies.[14] Accuracy was further improved by administering the questionnaire on four occasions and deriving mean values.[33] In addition, online administration of the questionnaires is expected to minimise any reporting bias due to social desirability. Since social desirability tends to result in under-reporting of energy intake, we excluded from the analyses extreme outliers. We excluded 37% of participants; this is consistent with similar studies which have excluded 21-67%.[27,28] Reports of energy intake 10-40% below physiologically plausible values are common.[29,30] Since under-reporting increases with body mass index,[31,32] their exclusion is essential to avoid systemic errors. For example, among the 54,578 participants we excluded due to under-/over-reporting of dietary intake or smoking, obese people reported having slightly lower energy intake than people with a normal BMI (7,307 vs 7,315 kJ/day);

this is likely to be due to either systematic errors in self-reporting or obese individuals being systematically more likely to consume atypical diets at the time of assessment due to energy restriction diets. A third of our participants completed only one questionnaire but sensitivity analysis demonstrated no change in the findings when these participants were excluded. Most studies of diet and adiposity are based on only BMI which does not differentiate between lean and fat body mass, whereas we could demonstrate consistent findings across several measures of adiposity; all obtained objectively via standardised techniqes. We repeated all the analyses excluding the 4,153 eligible participants who had prevalent diabetes, and the findings were not substantially altered.

In conclusion, our findings suggest that, whilst obesity is associated with higher sugar intake, the association is less strong than with other macronutrients especially fat. Focusing public health interventions and messages on sugar may detract from the need to reduce overall energy consumption and could, paradoxically, increase fat consumption.

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Conflicts of interest

The authors of this study have no competing interests to report.

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Table 1 Characteristics of study participants by sex

		Men N=53,720	**Women** N=78,759	**Overall** N=132,479
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Age (years)		56.7 (8.1)	55.7 (7.9)	56.1 (8.0)
		N (%)	**N (%)**	**N (%)**
Ethnicity	White	51,752 (96.8)	75,476 (96.1)	127, 228 (96.0)
	South Asian	690 (1.3)	845 (1.1)	1,535 (1.2)
	Black	417 (0.8)	890 (1.1)	1,277 (1.0)
	Chinese	125 (0.2)	280 (0.4)	405 (0.3)
	Other	280 (0.5)	583 (0.7)	863 (0.7)
	Mixed	225 (0.4)	513 (0.7)	738 (0.6)
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
Anthropometric measurements	Body mass index (kg/m^2)	26.7 (3.6)	26.0 (4.6)	26.3 (4.2)
	% Body fat	23.7 (5.5)	35.1 (6.7)	30.5 (8.4)
	Waist circumference (cm)	94.0 (10.1)	82.1 (11.4)	86.9 (12.4)
		Mean (SD)	**Mean (SD)**	**Mean (SD)**
24hr energy intake	Sugar (kJ/day)	2,316 (813)	2,078 (749)	2,175 (784)
	Starch (kJ/day)	2,508 (754)	2,012 (650)	2,213 (735)
	Fat (kJ/day)	3,522 (1,057)	2,964 (945)	3,190 (1,029)
	Protein (kJ/day)	1,578 (407)	1,382 (354)	1,461 (389)
	Fibre (g/day)	18 (7)	17 (6)	18 (6)
	Total	10,556 (2,112)	8,793 (1,935)	9,508 (2,187)
24hr energy intake		**%**	**%**	**%**
	Sugar	22.0	23.7	23.0
	Starch	23.9	23.0	23.4
	Fat	33.2	33.5	33.3
	Protein	15.0	15.9	15.5
		Median (IQR)	**Median (IQR)**	**Median (IQR)**
Physical activity (METs/day)	Light	300 (75-330)	300 (188-450)	300 (150-425)
	Moderate	87 (20-220)	80 (20-180)	85 (20-190)
	Vigorous	40 (0-180)	13 (0-120)	20 (0-160)
	Total	500 (300-820)	515 (315-792)	511 (305-807)

N number; SD standard deviation; IQR interquartile range; MET metabolic equivalents
All $p<0.001$

Table 2. Total and macronutrient energy intake by body mass index group

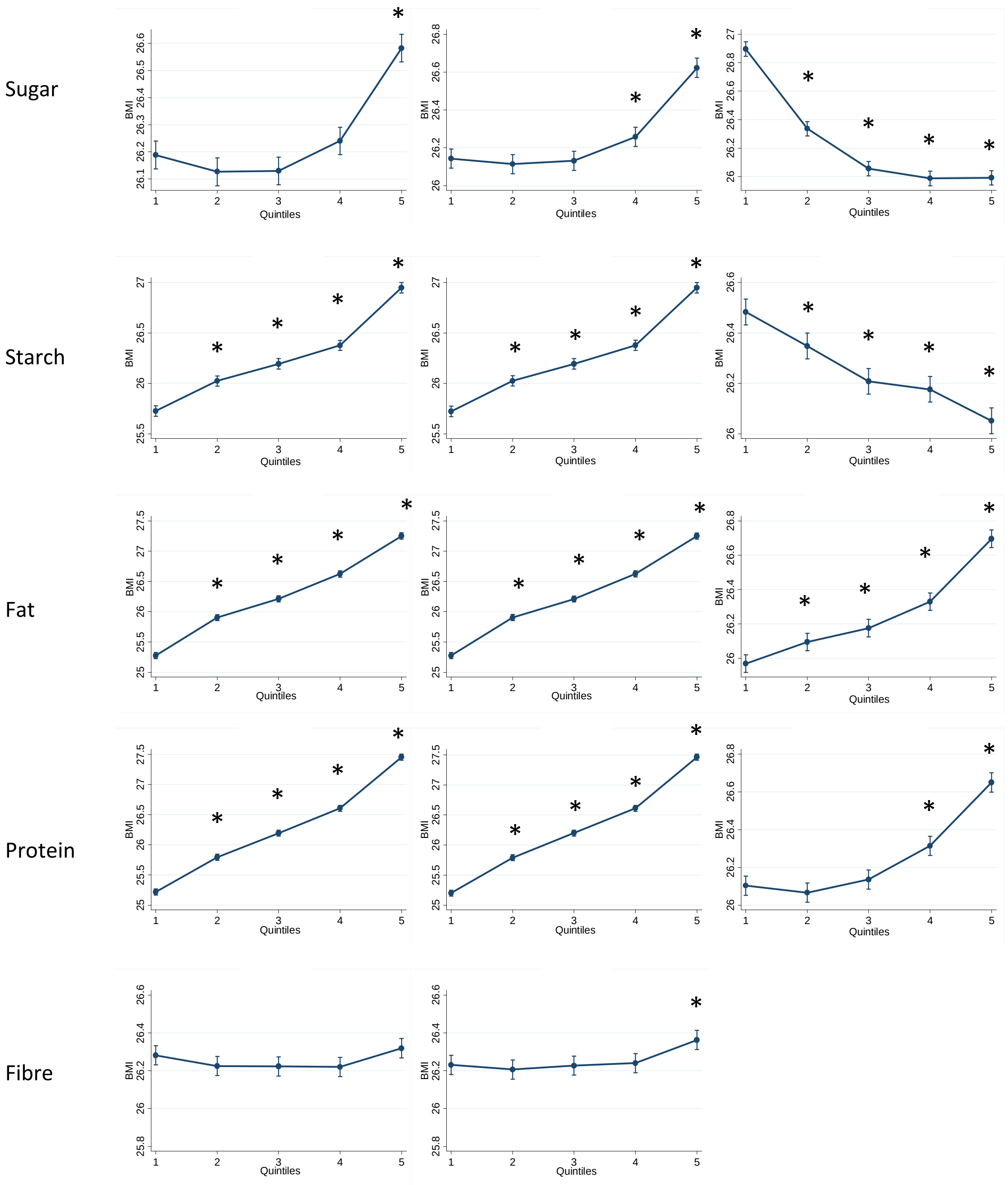
		Underweight Mean (kJ/day) (%)	Normal Mean (kJ/day) (%)	Overweight Mean (kJ/day) (%)	All Obese Mean (kJ/day) (%)	Obese1 Mean (kJ/day) (%)	Obese2 Mean (kJ/day) (%)	Obese3 Mean (kJ/day) (%)
		N=109	N=17,759	N=26,693	N=8,529	N=7,234	N=1,092	N=203
Men	Sugar	2,257 (22.9)	2,298 (22.6)	2,314 (21.9)	2,361 (20.8)	2,343 (20.9)	2,417 (20.1)	2,678 (20.4)
	Starch	2,537 (25.7)	2,495 (24.5)	2,479 (23.5)	2,627 (23.1)	2,599 (23.2)	2,754 (22.9)	2,968 (22.6)
	Fat	3,306 (33.5)	3,375 (33.1)	3,511 (33.3)	3,864 (34.0)	3,797 (33.9)	4,157 (34.6)	4,692 (35.8)
	Protein	1,410 (14.3)	1,510 (14.8)	1,577 (15.0)	1,721 (15.1)	1,694 (15.1)	1,839 (15.3)	2,044 (15.6)
	Total	9,876	10,189	10,545	11,362	11,215	12,009	13,107
		N=627	N= 36,895	N=27,401	N= 12,872	N= 9,200	N=2,723	N= 949
Women	Sugar	2,072 (24.4)	2,058 (23.9)	2,068 (23.6)	2,154 (23.0)	2,122 (23.1)	2,201 (22.8)	2,324 (22.3)
	Starch	2,029 (23.9)	1,975 (22.9)	1,992 (22.7)	2,161 (23.0)	2,110 (23.0)	2,237 (23.2)	2,432 (23.3)
	Fat	2,854 (33.7)	2,883 (33.5)	2,946 (33.6)	3,238 (34.5)	3,147 (34.3)	3,375 (35.0)	3,731 (35.8)
	Protein	1,296 (15.3)	1,336 (15.5)	1,391 (15.9)	1,495 (15.9)	1,466 (16.0)	1,536 (15.9)	1,654 (15.9)
	Total	8,478	8,608	8,771	9,379	9,187	9,657	10,434
		N=736	N= 54,654	N= 54,094	N= 21,401	N= 16,434	N= 3,815	N= 1,152
Overall	Sugar	2,100 (24.2)	2,136 (23.4)	2,189 (22.7)	2,236 (22.0)	2,219 (22.0)	2,263 (21.9)	2,387 (21.9)
	Starch	2,104 (24.2)	2,144 (23.5)	2,232 (23.1)	2,347 (23.1)	2,325 (23.1)	2,385 (23.1)	2,527 (23.2)
	Fat	2,921 (33.6)	3,043 (33.4)	3,225 (33.4)	3,488 (34.3)	3,433 (34.1)	3,599 (34.8)	3,900 (35.8)
	Protein	1,313 (15.1)	1,393 (15.3)	1,483 (15.4)	1,585 (15.6)	1,567 (15.6)	1,623 (15.7)	1,723 (15.8)
	Total	8,684	9,122	9,646	10,169	10,080	10,330	10,905

underweight (<18.5 kg/m^2), normal weight (18.5-24.9 kg/m^2), overweight (25.0-29.9 kg/m^2), all obese (≥30.0 kg/m^2), obese 1 (30.0-34.9 kg/m^2), obese 2(35.0-39.9 kg/m^2), obese 3 (≥40.0 kg/m^2),

All p<0.001

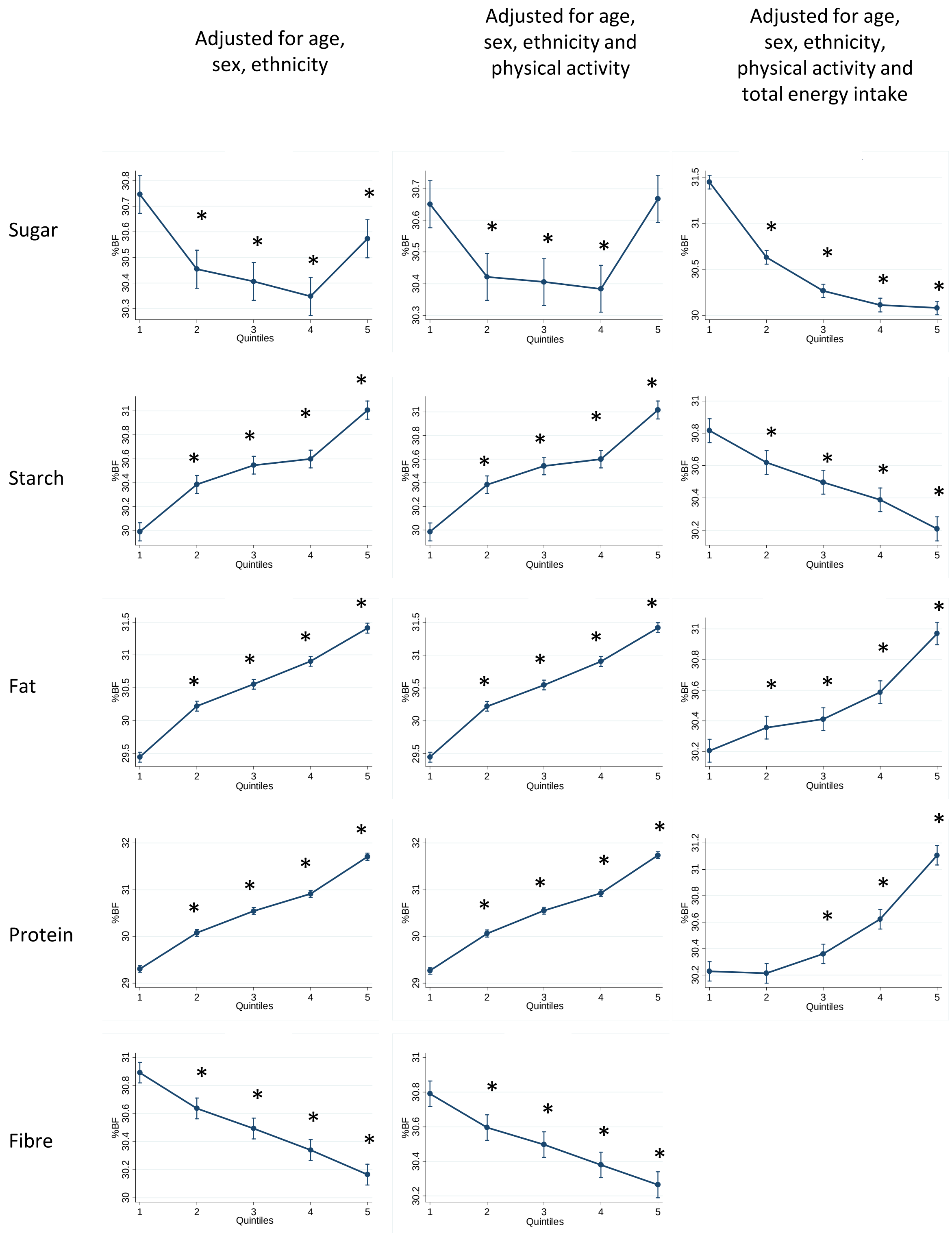
Figure 1. Body mass index by quintile of absolute energy obtained from macronutrient and quintile of percentage of total energy obtained from macronutrient

Adjusted for age, sex, ethnicity	Adjusted for age, sex, ethnicity and physical activity	Adjusted for age, sex, ethnicity, physical activity and total energy intake



*p<0.05 referent to quintile 1

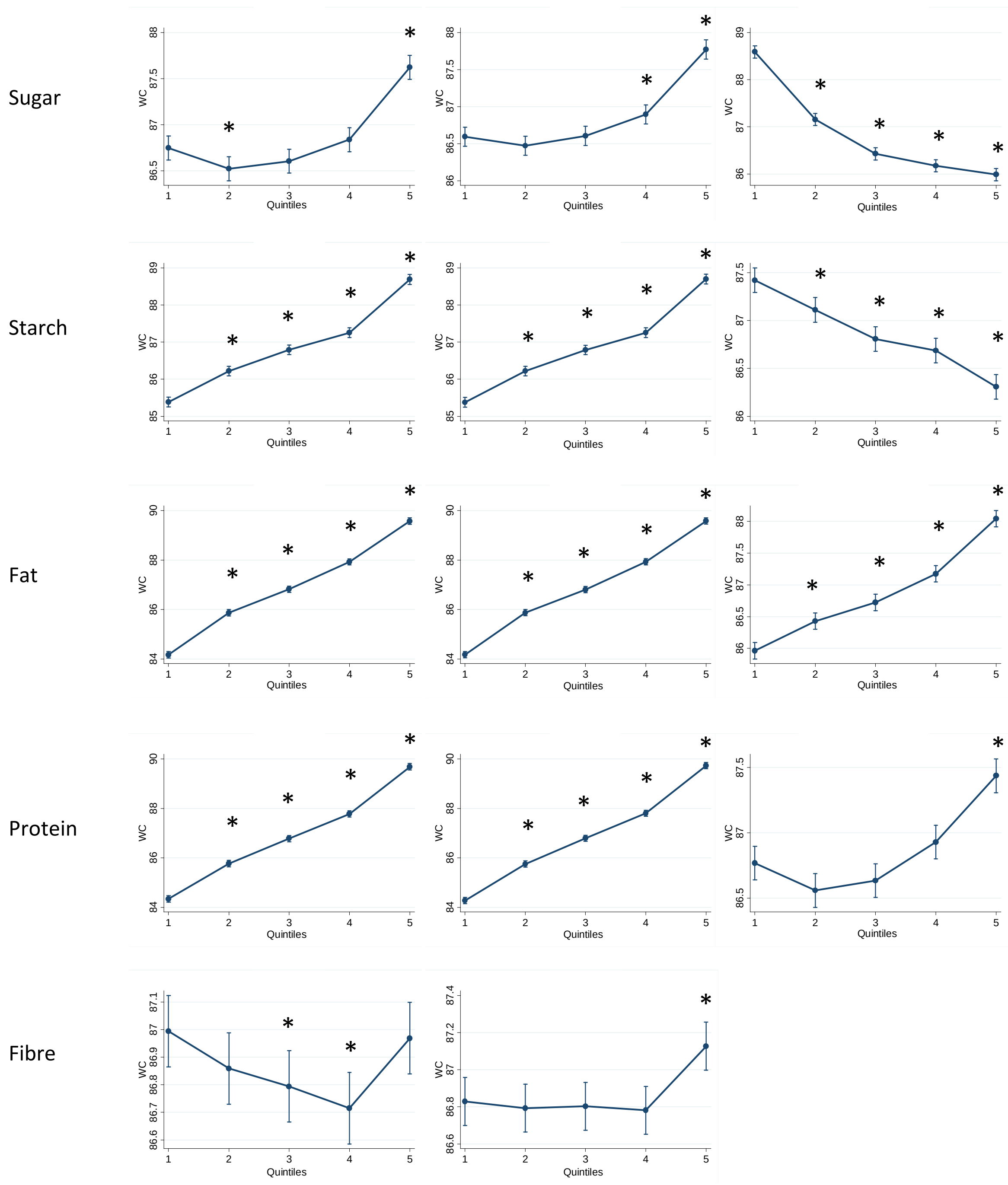
Figure 2. Percentage body fat by quintile of absolute energy obtained from macronutrient and quintile of percentage of total energy obtained from macronutrient



*p<0.05 referent to quintile 1

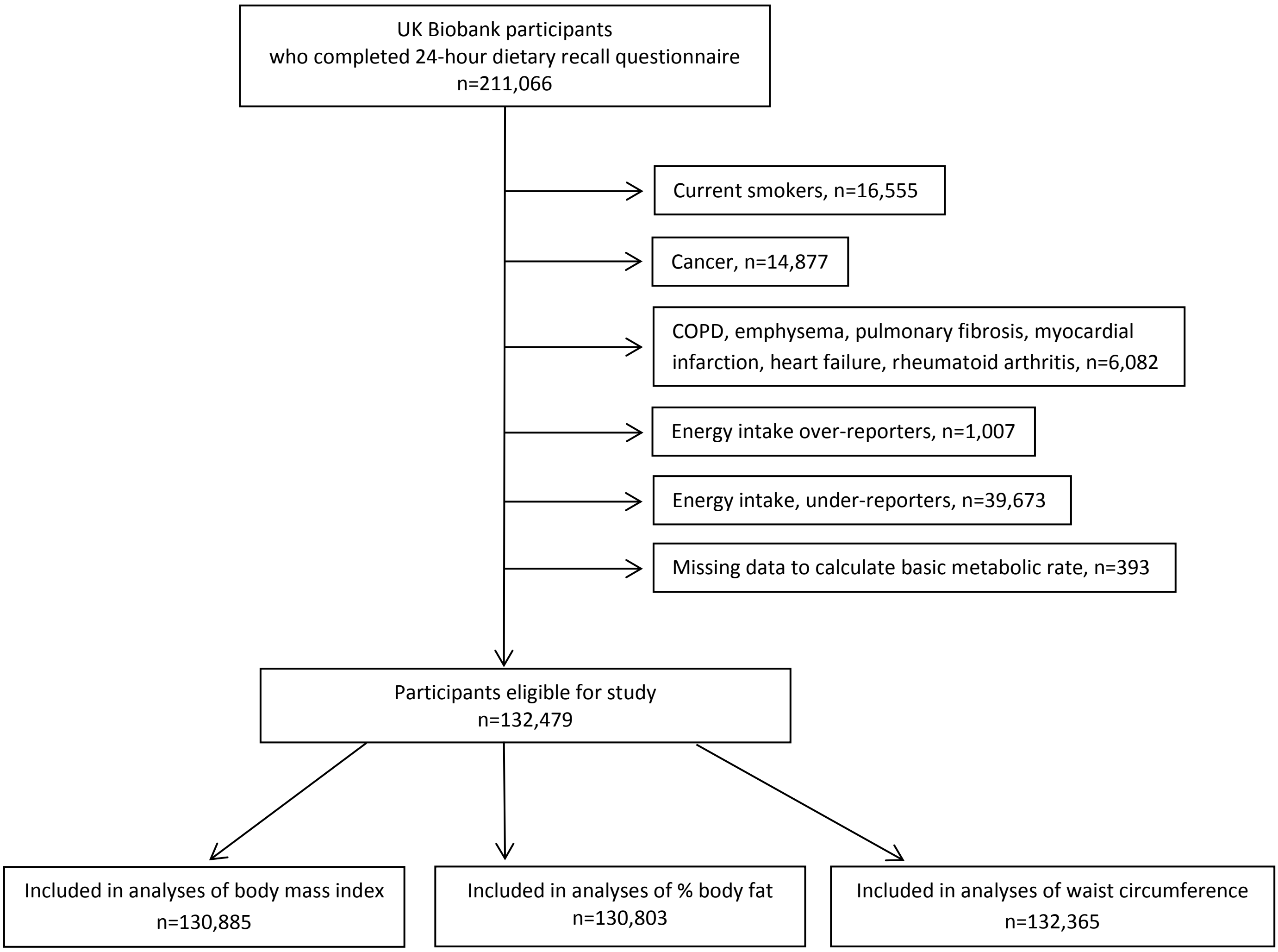
Figure 3. Waist circumference by quintile of absolute energy obtained from macronutrient and quintile of percentage of total energy obtained from macronutrient

Adjusted for age, sex, ethnicity	Adjusted for age, sex, ethnicity and physical activity	Adjusted for age, sex, ethnicity, physical activity and total energy intake



*p<0.05 referent to quintile 1

Supplementary Figure 1.



Supplementary Table 1. Minimum and maximum values for quintiles of absolute energy intake and percentage of total energy intake by macronutrient

All	Absolute energy intake		Percentage of total energy intake		
Sugar					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	29.6227	1,543.6171	1	0.35153	17.47209
2	1,543.6172	1,901.0422	2	17.47263	21.00791
3	1,901.0424	2,249.8200	3	21.00801	24.23357
4	2,249.8800	2,725.8900	4	24.23371	28.20806
5	2,725.9600	9,176.8520	5	28.20816	88.73127
Starch					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	0	1,622.053	1	0	18.67163
2	1,622.095	1,982.435	2	18.67167	22.01897
3	1,982.446	2,314.756	3	21.01899	24.76790
4	2,314.790	2,746.746	4	24.76810	27.99780
5	2,746.880	9,624.204	5	27.99840	57.18000
Fat					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	116.3570	2,338.4375	1	1.620000	28.115971
2	2,338.4377	2,820.8110	2	28.115973	31.778210
3	2,820.9360	3,297.7240	3	31.778230	34.897370
4	3,297.7870	3,949.8630	4	34.897610	38.522830
5	3,949.9260	9,823.3200	5	38.522930	75.99390
Protein					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	260.7469	1,153.0550	1	3.28000	13.00170
2	1,153.0690	1,334.8630	2	13.00192	14.59450
3	1,334.9190	1,502.8930	3	14.59456	16.04240
4	1,502.9350	1,731.5070	4	16.04242	17.87168
5	1,731.5070	6,093.0760	5	17.87170	47.46000
Fibre					
Quintile	Minimum (g)	Maximum (g)			
1	0	12.5533			
2	12.5540	15.4220			
3	15.4225	18.2500			
4	18.2525	22.1067			
5	22.1075	108.5700			

Women	Absolute energy intake		Percentage of total energy intake		
Sugar					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	78.827	1,543.617	1	0.7961	17.4721
2	1,543.645	1,901.042	2	17.4728	21.0079
3	1,901.098	2,249.820	3	21.0081	24.2335
4	2,249.988	2,725.848	4	24.2338	28.2081
5	2,725.960	8,742.720	5	28.2084	88.7313
Starch					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	0	1,622.053	1	0	18.67163
2	1,622.095	1,982.435	2	18.67167	22.01897
3	1,982.446	2,314.756	3	22.01899	24.76793
4	2,314.798	2,746.746	4	24.76814	27.99775
5	2,746.880	7,134.724	5	27.99853	57.18076
Fat					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	116.3570	2,338.4381	1	1.622834	28.115971
2	2,338.4382	2,820.8110	2	28.115972	31.778150
3	2,820.9360	3,297.7240	3	31.778230	34.897370
4	3,297.8180	3,949.8630	4	34.897610	38.522720
5	3,949.9260	9,346.9730	5	38.522960	75.993900
Protein					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	319.323	1,153.055	1	4.72486	13.00170
2	1,153.069	1,334.863	2	13.00192	14.59450
3	1,334.919	1,502.893	3	14.59456	16.04240
4	1,502.949	1,731.507	4	16.04273	17.87168
5	1,731.618	5,020.130	5	17.87173	45.65164
Fibre					
Quintile	Minimum (g)	Maximum (g)			
1	0	12.553			
2	12.554	15.422			
3	15.423	18.250			
4	18.253	22.107			
5	22.108	108.57			

Men	Absolute energy intake		Percentage of total energy intake		
Sugar					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	29.6227	1,543.6171	1	0.3515	17.4720
2	1,543.6172	1,901.0422	2	17.4726	21.0078
3	1,901.0424	2249.8200	3	21.0080	24.2336
4	2,249.8760	2,725.8930	4	24.2337	28.2080
5	2,726.1270	9,176.8520	5	28.2082	68.8674
Starch					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	0	1,621.97	1	0	18.6711
2	1,622.22	1,982.44	2	18.6719	22.0189
3	1,982.55	2,314.76	3	22.0190	24.7678
4	2,314.79	2,746.71	4	24.7682	27.9972
5	2,746.88	9,624.20	5	27.9984	56.8749
Fat					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	458.7	2,338.4	1	5.3780	28.1160
2	2,338.6	2,820.8	2	28.1171	31.7782
3	2,821.0	3,297.7	3	31.7786	34.8970
4	3,297.8	3,949.7	4	34.8980	38.5228
5	3,949.9	9,823.3	5	38.5229	68.5483
Protein					
Quintile	Minimum (KJ)	Maximum (KJ)	Quintile	Minimum (%)	Maximum (%)
1	260.74690	1,153.0270	1	3.2823	13.0015
2	1,153.0690	1,334.8630	2	13.0022	14.5943
3	1,334.9470	1,502.8930	3	14.5947	16.0423
4	1,502.9350	1,731.5071	4	16.0424	17.8715
5	1,731.5073	6,093.0760	5	17.8717	47.4611
Fibre					
Quintile	Minimum (g)	Maximum (g)			
1	0	12.553			
2	12.554	15.420			
3	15.423	18.250			
4	18.253	22.107			
5	22.110	98.530			

Supplementary Table 2. Pearson correlation coefficients between absolute energy obtained from macronutrients and between percentage of total energy obtained from macronutrients

All	Absolute energy intake				Percentage of total energy intake			
	Sugar	Starch	Fat	Protein	Sugar	Starch	Fat	Protein
Sugar	1.00				1.00			
Starch	0.16	1.00			-0.28	1.00		
Fat	0.24	0.45	1.00		-0.46	-0.16	1.00	
Protein	0.28	0.34	0.53	1.00	-0.14	-0.13	-0.07	1.00

Women	Absolute energy intake				Percentage of total energy intake			
	Sugar	Starch	Fat	Protein	Sugar	Starch	Fat	Protein
Sugar	1.00				1.00			
Starch	0.13	1.00			-0.30	1.00		
Fat	0.22	0.41	1.00		-0.51	-0.17	1.00	
Protein	0.28	0.28	0.49	1.00	-0.14	-0.14	-0.11	1.00

Men	Absolute energy intake				Percentage of total energy intake			
	Sugar	Starch	Fat	Protein	Sugar	Starch	Fat	Protein
Sugar	1.00				1.00			
Starch	0.11	1.00			-0.23	1.00		
Fat	0.20	0.38	1.00		-0.41	-0.14	1.00	
Protein	0.22	0.29	0.52	1.00	-0.18	-0.09	-0.008*	1.00

*p=0.0654, all other correlations p<0.001

Supplementary Table 3. Breakdown of participants by quintile energy derived from sugar versus quintile of energy derived from fat and protein for absolute energy and percentage of total energy

% contribution to total energy intake		Quintile of fat				
		1	2	3	4	5
Quintile of sugar	1	2,349 (8.9)	3,149 (11.9)	4,199 (15.9)	5,954 (22.5)	10,845 (40.9)
	2	2,951 (11.1)	4,256 (16.1)	5,459 (20.6)	6,792 (25.5)	7,068 (26.7)
	3	3,980 (15.0)	5,360 (20.2)	6,165 (23.3)	6,222 (23.5)	4,769 (18.0)
	4	5,692 (21.5)	6,711 (25.3)	6,345 (24.0)	5,004 (18.9)	2,744 (10.4)
	5	11,524 (43.5)	7,020 (26.5)	4,328 (16.3)	2,554 (9.6)	1,069 (4.0)
		Quintile of protein				
		1	2	3	4	5
Quintile of sugar	1	4,167 (15.7)	4,655 (17.6)	5,144 (19.4)	5,617 (21.2)	6,913 (26.1)
	2	4,661 (17.6)	5,299 (20.0)	5,513 (20.8)	5,580 (21.1)	5,443 (20.5)
	3	5,208 (19.7)	5,426 (20.5)	5,444 (20.6)	5,419 (20.5)	4,999 (18.9)
	4	5,496 (20.7)	5,714 (21.6)	5,472 (20.7)	5,219 (19.7)	4,595 (17.3)
	5	6,964 (26.3)	5,402 (20.4)	4,923 (18.6)	4,661 (17.6)	4,545 (17.2)

Absolute contribution to total energy intake		Quintile of fat				
		1	2	3	4	5
Quintile of sugar	1	6,517 (24.6)	6,298 (23.8)	5,543 (20.9)	4,626 (17.5)	3,513 (13.3)
	2	6,221 (23.5)	6,028 (22.8)	5,683 (21.5)	4,925 (18.6)	3,642 (13.7)
	3	5,487 (20.7)	5,686 (21.5)	5,565 (21.0)	5,352 (20.2)	4,406 (16.6)
	4	4,787 (18.1)	4,944 (18.7)	5,298 (20.0)	5,801 (21.9)	5,662 (21.4)
	5	3,487 (13.2)	3,548 (13.4)	4,397 (16.6)	5,792 (21.9)	9,271 (35.0)
		Quintile of protein				
		1	2	3	4	5
Quintile of sugar	1	7,477 (28.2)	6,194 (23.4)	5,023 (19.0)	4,320 (16.3)	3,483 (13.1)
	2	6,393 (24.1)	6,226 (23.5)	5,643 (21.3)	4,729 (17.9)	3,508 (13.2)
	3	5,371 (20.3)	5,787 (21.8)	5,771 (21.8)	5,355 (20.2)	4,212 (15.9)
	4	4,377 (16.5)	5,023 (19.0)	5,635 (21.3)	6,008 (22.7)	5,449 (20.6)
	5	2,879 (10.9)	3,278 (12.4)	4,414 (16.7)	6,082 (23.0)	9,842 (37.2)

Supplementary Table 4. Multivariate linear regression analyses of the associations between quintile of absolute energy intake, total and by macronutrient, and body mass index

	Adjusted for age, sex			Adjusted for age, sex, ethnicity			Adjusted for age, sex, ethnicity,		
	Coefficient (95% CI)	P value	P value	Coefficient (95% CI)	P value	P value	Coefficient (95% CI)	P value	P value
Total									
1									
2	0.99 (0.92, 1.06)	<0.001	<0.001	0.99 (0.92, 1.07)	<0.001	<0.001			
3	1.43 (1.36, 1.51)	<0.001		1.44 (1.37, 1.52)	<0.001				
4	1.86 (1.79, 1.94)	<0.001		1.88 (1.81, 1.96)	<0.001				
5	2.44 (2.36, 2.52)	<0.001		2.47 (2.39, 2.55)	<0.001				
Sugar									
1									
2	-0.06 (-0.13, 0.01)	0.090	<0.001	-0.03 (-0.10, 0.04)	0.406	<0.001	-0.56 (-0.63, -0.49)	<0.001	<0.001
3	-0.06 (-0.13, 0.02)	0.121		-0.01 (-0.08, 0.06)	0.781		-0.84 (-0.91, -0.77)	<0.001	
4	0.05 (0.02, 0.13)	0.150		0.12 (0.04, 0.19)	0.002		-0.93 (-1.00, -0.86)	<0.001	
5	0.40 (0.32, 0.47)	<0.001		0.48 (0.41, 0.55)	<0.001		-0.93 (-1.00, -0.86)	<0.001	
Starch									
1									
2	0.30 (0.23, 0.37)	<0.001	<0.001	0.30 (0.23, 0.37)	<0.001	<0.001	-0.14 (-0.21, -0.07)	<0.001	<0.001
3	0.47 (0.40, 0.54)	<0.001		0.47 (0.40, 0.54)	<0.001		-0.27 (-0.35, -0.20)	<0.001	
4	0.65 (0.58, 0.72)	<0.001		0.66 (0.58, 0.73)	<0.001		-0.31 (-0.39, -0.24)	<0.001	
5	1.22 (1.15, 1.30)	<0.001		1.23 (1.15, 1.30)	<0.001		-0.42 (-0.49, -0.34)	<0.001	
Fat									
1									
2	0.64 (0.57, 0.71)	<0.001	<0.001	0.64 (0.57, 0.71)	<0.001	<0.001	0.11 (0.04, 0.18)	0.002	<0.001
3	0.95 (0.87, 1.02)	<0.001		0.94 (0.87, 1.01)	<0.001		0.20 (0.13, 0.28)	<0.001	
4	1.36 (1.29, 1.43)	<0.001		1.36 (1.29, 1.43)	<0.001		0.33 (0.26, 0.41)	<0.001	

5	1.99 (1.91, 2.10)	<0.001		1.98 (1.91, 2.06)	<0.001		0.70 (0.63, 0.77)	<0.001	
Protein									
1									
2	0.57 (0.50, 0.65)	<0.001	<0.001	0.59 (0.52, 0.66)	<0.001	<0.001	-0.01 (-0.08, 0.06)	0.816	<0.001
3	0.98 (0.91, 1.05)	<0.001		1.00 (0.93, 1.07)	<0.001		0.07 (-0.0, 0.14)	0.051	
4	1.39 (1.32, 1.46)	<0.001		1.41 (1.34, 1.49)	<0.001		0.19 (0.12, 0.26)	<0.001	
5	2.24 (2.17, 2.31)	<0.001		2.27 (2.20, 2.34)	<0.001		0.53 (0.46, 0.60)	<0.001	