Sweetened beverage intake in association to energy and sugar consumption and cardiometabolic markers in children

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Abbreviations: SSBs: Sugar-sweetened beverages; ASBs: Artificially sweetened beverages; NDNS: National Diet and Nutrition Survey; BMI: Body Mass Index; TE: Total Energy; OLS: Ordinary Least Squares

What is already known about this subject

- Sugar-sweetened beverages (SSBs) are large contributors of sugar in children.
- Artificially sweetened beverages (ASBs) have been promoted as healthy SSB alternatives in order to reduce sugar intake.
- However, the effect of ASBs on energy and sugar intake and cardiometabolic health is uncertain.

What this study adds

- In this nationally representative study of UK children, SSBs were associated with higher sugar intake overall.
- ASBs were associated with higher sugar intake from solid foods but not with overall sugar.
- Both SSBs and ASBs were associated with higher blood glucose levels.

Abstract

Background

Artificially sweetened beverages (ASBs) are promoted as healthy alternatives to sugar-sweetened beverages (SSBs) in order to reduce sugar intake but their effects on weight control and glycemia have been debated. This study examines associations of SSBs and ASBs with energy and sugar intake and cardiometabolic measures.

Methods

1,687 children aged 4-18 participated in the National Diet and Nutrition Survey Rolling Program (2008/9-2011/12) in the UK. Linear regression was used to examine associations between SSBs and ASBs and energy and sugar, overall and from solid foods and beverages, and BMI, waist-to-hip ratio and blood analytes. Fixed effects linear regression examined within-person associations with energy and sugar.

Results

Compared to non-consumption, SSB consumption was associated with higher sugar intake overall (6.15%; 4.18, 8.12) and ASB consumption with higher sugar intake from solid foods (1.67%; 0.46, 2.88) but not overall, mainly among boys. On SSB consumption days energy and sugar intakes were higher (216 kcal; 163, 269 and 7.00%; 6.17, 7.83) and on ASB consumption days intake of sugar was lower (-0.98%, -1.81, -0.14) compared to non-consumption days. SSB and ASB intakes were associated with higher levels of blood glucose (SSB: 0.30 mmol/L; 0.11, 0.49; ASB: 0.24 mmol/L; 0.06, 0.43) and SSB intake with higher triglycerides (0.29 mmol/L; 0.13, 0.46). No associations were found with other outcomes.

Conclusion

SSB intake was associated with higher sugar intake and both SSBs and ASBs with a less healthy cardiometabolic profile. These findings add to evidence that health policy should discourage all sweetened beverage consumption.

Introduction

Sugar sweetened beverages (SBSs) are major contributors of sugar and energy intake, providing 39% of total sugar intake in the US population[1]. Sugar intake is especially high in children and adolescents[1, 2]. Data from observational studies and clinical trials have shown a causal association between SSB consumption and obesity[3] and diabetes[4]. There are also indications that SSBs are related to metabolic syndrome[5] and hypertension[6]. Thus, current guidelines from the World Health Organisation (WHO) recommend that daily sugar intake should ideally not exceed 5% of the total energy intake[7]. In order to achieve this goal, public health policies promoting SSB reduction have been growing. In response, the beverage industry has increasingly marketed artificially sweetened beverages (ASBs)[8], while ASBs have also been suggested as SSB alternatives by clinical guidelines[9] and national campaigns focusing on children[10]. As a result, ASB sales have been increasing over the last years in many countries, exceeding these of SSBs in the US[11].

The 2015-2020 Dietary Guidelines for Americans state that the long-term effectiveness of low-calorie sweeteners in weight management is still in question[1]. Trials in children have suggested that consumption of artificial sweeteners may result in complete caloric compensation from other sources[12], although a meta-analysis of short-term clinical trials has shown opposing results[13]. Additionally, clinical trials in mice and humans have indicated an association between artificial sweeteners and glucose intolerance[14]. There has been no previous examination of the associations between ASB consumption and energy or sugar intake from different sources, and glycemic markers in a nationally representative sample of children.

The objectives of this study are to examine associations between SSB and ASB consumption and (1) energy and sugar intake, overall and from solid foods and beverages separately, and

(2) cardiometabolic risk factors, including BMI, waist-to-hip ratio, blood glucose and blood lipids, in a nationally representative sample of UK children and adolescents.

Methods

Study design and population

Data from the National Diet and Nutrition Survey Rolling Programme (NDNS) years 1-4 (2008/2009-2011/2012)[15] were used. NDNS is a dietary survey of a nationally representative sample of UK adults and children carried out on behalf of Public Health England and the Food Standards Agency. 1,648 children aged 4-18 years were sampled.

Full details of the survey methodology are described elsewhere[2]. In short, the sample was randomly drawn from the UK Postcode Address File, a list of all UK addresses, and one child or one child and one adult were selected from each address. The overall response rate for the first stage of the survey was 56%. Each participant or their guardian took part in a computer assisted personal interview, completed a 4-day food diary, including weekends and weekdays, and had their weight and height measured. Two to four months after completion of this stage, participants had a visit from a trained nurse in order to collect more detailed physical measurements and blood samples. Ethical approval for the NDNS was provided by the *Oxfordshire A Research Ethics Committee*. For blood sample collection, written consent was taken from the participants aged 16 years and over and from the guardians of the participants aged 4-15 years.

Variables

Beverage consumption data were obtained from 4-day (n= 1,656) or 3-day (n=31) food diaries. In the NDNS, SSBs were defined as drinks not low calorie, including carbonated, ready to drink and concentrated soft drinks and squashes, and ASBs were defined as low calorie drinks without added sugar or sugar free, including carbonated, ready to drink and concentrated soft drinks and squashes. Water, unsweetened beverages, and fruit juices were not included in any of the sweetened beverages categories. We constructed categorical consumption variables as (1) Drinking neither SSBs nor ASBs (mean consumption of SSBs=0 g/day and ASBs=0 g/day), (2) Drinking only SSBs (mean consumption of SSBs>0 g/day and ASBs=0 g/day), (3) Drinking only ASBs (mean consumption of ASBs>0 g/day and SSBs=0 g/day), and (4) Drinking both SSBs and ASBs (mean consumption of SSBs>0 g/day and ASBs>0 g/day). More than 94% of sweetened beverage drinkers consumed at least 50 g/day of sweetened beverages, i.e. at least one can per week.

Energy and sugar intakes were calculated using nutrient composition data from the Department of Health's Nutrient Databank, updated for each survey year. Energy and sugar consumption were averaged across the diary days. Energy was measured in mean kcal per day and sugar was measured in mean percentage of total energy consumption (%TE) per day, in order to better reflect public health recommendations[7]. Sugar, referring to free or added sugars and defined by the NDNS as non-milk extrinsic sugars, comprised either sugars added or naturally present to foods, excluding extrinsic sugars in milk and milk products. Energy and sugar from solid foods and beverages separately were also calculated.

Body Mass Index (BMI) was calculated (in kg/m^2) from objective weight and height measurements, without shoes, socks, and heavy garments, collected by trained staff using a portable stadiometer and scales. Waist and hip circumferences were measured for children 11 years and older and fasting blood samples were collected for children 4 years and older by a qualified nurse.

Physical activity information was collected using a self-completion physical activity questionnaire (Recent Physical Activity Questionnaire - RPAQ) for children 16 years and older, whereas children aged 4-15 years were asked to wear an accelerometer (ActiGraph) for seven consecutive days. Demographic and lifestyle data, including age, sex, household income, ethnicity, and frequency of takeaway eating were also collected.

Some variables had incomplete data. The percentages of missing values for the variables used were: income (13%), physical activity (47%), BMI (4%), waist-to-hip ratio (62%), glucose (76%), HbA1c, triglycerides, total and HDL cholesterol (72%).

Statistical analyses

Characteristics of the participants were described across beverage consumption groups, with p-values for differences calculated using chi-square or Kruskal-Wallis tests. Two different models were applied to study associations between beverages and energy/sugar. First, an ordinary least squares (OLS) model was applied to study between-person associations among SSB and ASB consumers. Multivariable linear regression models were fitted, adjusting for several demographic and lifestyle characteristics. The models were tested for interactions with age, sex and BMI. Statistically significant interactions with age and sex were identified ($p<0.05$), so stratified analyses for age and sex subcategories were also performed as sensitivity analyses.

Second, as there was high within-person variation of beverage consumption, a fixed effects model was applied to study within-person associations when beverage consumption varied from day to day. Fixed effects models minimise confounding from differences between persons, and assess changes in outcome associated with substituting one beverage for another. For these models, dietary data were not averaged across diary days but each day was used as a separate observation. As there was a slightly higher completion of diaries on Fridays, Saturdays and Sundays in the NDNS[2] and beverage consumption was higher in these days compared to weekdays, the models were adjusted for day of the week that the diary was completed. These models were also sex and age stratified as sensitivity analyses.

Finally, associations between beverage consumption and cardiometabolic risk factors were examined using multivariable linear regression. First, models adjusted for age, sex, ethnic group, equivalised household income, frequency of eating takeaway, and physical activity were applied. As adjustment for age and sex was performed, BMI was chosen over BMI z-scores to investigate adiposity. Second, energy and energy adjusted dietary variables (g/1000 kcal) were added, to assess associations independent of other diet compounds. Finally, in the blood analytes models, BMI was added to investigate associations independent of adiposity. Age and sex interactions were not identified in these models (all $p>0.05$).

A further sensitivity analysis, excluding children on a weight loss diet or obese children (BMI>95th centile) (n=308), was performed to reduce likelihood of reverse causality bias. Sensitivity analyses were also performed to examine the effect of juice consumption as a mediator of the associations between sweetened beverages and energy and sugar intake, by adding juice intake (g/d) as a covariate in the models.

All analyses used survey weights to address sampling and non-response. Separate weights were used to account for different non-response to blood sample collection.

Results

Descriptive characteristics

Characteristics of the sample by beverage consumption group are presented in Table 1. The majority of the children consumed both SSBs and ASBs (43%) while only 10% of participants did not consume any sweetened beverages. 30% of the children were consuming only SSBs and 18% only ASBs. Mean consumption of SSBs among SSB drinkers was 311.9 g/day and of ASBs among ASB drinkers was 351.4 g/day. Compared to SSB consumers, ASB consumers were more likely to be younger, and white. Half of ASB consumers were females. Compared to all sweetened beverages consumers, non-consumers were of higher income and were consuming take-away meals less frequently. They were also eating more fruits and vegetables, less meat and they were drinking more juice and water, tea, and coffee.

Between-person associations with energy and sugar

Associations of beverage consumption with energy and sugar are shown in Table 2A. Consumption of SSBs was associated with higher intakes of energy from beverages (91 kcal; 95% Confidence Interval: 54, 129), overall sugar (6.2%; 4.2, 8.1) and sugar from beverages (5.4%; 3.8, 6.9) compared to non-consumers. ASB consumers did not have statistically significantly higher overall sugar intake (1.4%, -0.4, 3.3), but ASB consumption was associated with higher sugar from solid foods (1.7%; 0.5, 2.9).

Analyses stratified by age and sex (Appendix I; Table 1), found that positive associations between SSBs and energy, overall and from beverages, were apparent only among girls (e.g. overall energy 250 kcal; 70, 430). Associations between ASBs and sugar from solid foods were significant only among boys (3.4%; 1.7, 5.2). For younger boys, ASBs were also directly related with total sugar intake (3.5%; 1.0, 6.0). Sensitivity analyses excluding children obese or on a weight loss diet (Appendix II, Table 1A) attenuated the associations between ASBs and sugar from solid foods (1.3%; -0.11, 2.72), suggesting possible reverse causation.

Within-person associations with energy and sugar

Within-person associations with energy and sugar are presented in Table 2B. Shifting from a day of non-consumption to a day of SSB consumption was associated with higher intakes of energy from all sources (89 kcal; 163, 269 for solid foods and 127 kcal; 107, 146 for beverages) and higher intakes of sugar overall (7.0%; 6.2, 7.8) and from beverages (7.4%; 6.8, 7.8). Shifting from a day of non-consumption to a day of ASB consumption was associated with lower energy from beverages (-33 kcal; -54, -12), total sugar (-1.0%; -1.8, -

0.1), and sugar from beverages (-1.0%; -1.7, -0.3). Adjusting for juice consumption attenuated these associations (e.g. for total sugar: -0.4%; -1.1, 0.4).

Analyses stratified by age and sex (Appendix I; Table 2), found that the inverse associations between ASBs and energy and sugar were mostly evident in younger boys.

Associations with cardiometabolic risk factors

Associations between sweetened beverages consumption and BMI and cardiometabolic risk factors are reported in Table 3. Consumption of ASBs and both SSBs and ASBs was associated with higher BMI but these associations did not remain statistically significant after adjusting for demographic and lifestyle characteristics. SSB and ASB consumers had higher glucose levels compared to non-consumers. These associations remained statistically significant after correcting for energy and energy adjusted food groups and BMI (SSB: 0.30 mmol/L; 0.11, 0.49 and ASB: 0.24 mmol/L; 0.06, 0.43). Consumption of SSBs was also associated with triglyceride levels (0.29 mmol/L; 0.13, 0.46), although for ASB drinkers, associations were attenuated after adjustment for BMI (0.15 mmol/L; 0.00, 0.31). HbA1c, total cholesterol and HDL cholesterol were not associated with SSB or ASB consumption.

Discussion

This study examined the mean energy and sugar intakes of SSB and ASB consumers, and the impacts on daily energy and sugar intake of shifting from non-consumption to SSB or ASB consumption. It found that SSB consumers had increased overall sugar intake compared to non-consumers. Also, male ASB consumers had increased sugar intake from solid foods, while female ASB consumers did not differ from non-consumers of sweetened beverages. It also found that the days that SSBs were consumed, energy intake was more than 200 kcal higher and sugar intake was up to 7% higher compared to the days of non-consumption, but the days that ASBs were consumed, sugar intake was 1% lower compared to non-consumption days. This study also suggests a positive association between SSBs and blood glucose and triglycerides and between ASBs and blood glucose, after adjusting for dietary compounds and BMI.

Comparison with current literature

SSBs are the main contributors of sugar intake in UK children, but few observational studies have examined associations between ASBs and energy and sugar in children; together having uncertain results[16, 17]. A clinical trial in children found that total energy and sugar intake were reduced after replacing SSBs with non-sugary drinks for 2 years, but non-sugary drinks comprised varied unsweetened options including water, so definite conclusions concerning ASBs are hard to be drawn[18]. In contrast, our analyses reflect associations solely with ASBs, as unsweetened options were not included in the ASB comparison group.

Consumption of SSBs has been previously associated with higher blood glucose and triglycerides in Asian adolescents[19], and with impaired insulin resistance among overweight children[20]. There are insufficient studies examining possible associations between ASBs and blood metabolites in children. However, a clinical trial in adults have shown that a water but not an ASB consumption group reduced levels of fasting glucose compared to a control[21]. We found that ASBs were associated with higher fasting glucose levels compared to non-consumers. Further clinical trials in adults have shown that water and ASB groups had no difference in glucose, HbA1c, total cholesterol or HDL[22-24] but when insulin and 2h postprandial glucose levels were measured, the results favoured the water group[23].

Possible underlying mechanisms

Our findings indicate that boys who consumed ASBs had higher mean intake of sugar from solid foods compared to boys who consumed SSBs or no sweetened beverages, although ASBs were not associated with total sugar intake. ASBs have been associated with taste preferences because of their sweet taste[25]. Overexposure to sweet taste stimuli can alter taste preferences towards sweetness or reduce cephalic response to sweet taste[25] and thus increase consumption of sweet foods. In our sample, for example, children that consumed ASBs also consumed more confectionery compared to SSB and non-consumers.

We also found that shifting from non-consumption to ASB consumption was associated with slightly lower levels of overall sugar intake. Results from our sensitivity analysis indicate that this may be due to children consuming neither SSBs nor ASBs shifting towards juice consumption, which is an important source of sugar in children's diets, and a high contributor to overall sugar intake.

Statistically significant associations were identified between sweetened beverages and fasting glucose levels. SSBs have been associated with type 2 diabetes, due to their high sugar content, which can rapidly raise blood glucose and insulin levels, and their association with weight gain[26]. Moreover, their consumption can affect taste preferences towards sweet taste, which can also be stated for ASBs[26]. ASBs have also been associated with higher glucose levels through alterations in gut microbiota[14], interactions with sweet-taste receptors, or learned responses to sweet taste which can influence glucose metabolism[27, 28]. Our data raise concerns regarding the effect of ASBs in glucose metabolism and highlight the need of clinical trials and long term longitudinal studies, especially among children.

Strengths and limitations

This is the first nationally representative examination of associations between ASB and energy and sugar intake, disaggregated by source, as well as blood metabolites among UK children. NDNS benefits from a high q uality dietary assessment method, as the diary gives the flexibility to look into different dietary components in detail and the multiple days of assessment allows to take into account within-person day-to-day variability. However, there are some limitations that should be considered. As the data are cross-sectional, reverse causality cannot be ruled out. However, we did attempt to address this issue by excluding obese children and children on a weight loss diet. In addition, as the time elapsed between collection of diaries and blood samples is considerable (at least 8 weeks after the second NDNS year), comparisons between blood measurements and diet do not reflect a direct effect[2] but rather describe the metabolic profile of sweetened beverage consumers. Similarly, BMI reflects a long-term dietary pattern, which is not represented by these data. This could explain the lack of association between SSBs and BMI, contrary to the majority of the current literature. Moreover, although the sample was nationally representative, the population number was quite small in some of the analyses, due to missing values. This is especially the case for the blood measurements reported. However, non-response weights for blood measurements were used to reduce potential bias. Finally, physical activity measurement techniques were different between children 4-15 and 16-18 years old.

Policy implications

Our results confirm that reducing SSB consumption should be a priority in efforts to reach the sugar intake goal set by the WHO guidelines. The large effect size of the SSB and sugar intake association should urge policymakers to look beyond social marketing and education techniques and seek more effective interventions that will reach the whole population, such as product reformulation and fiscal measures.

Policies aiming to reduce SSB consumption may drive consumers towards ASBs. Our results indicate that ASB consumption is not associated with overall sugar intake in children, while within-person associations highlighted the modest benefits of ASBs to day-to-day sugar intake. However, we have found that ASB consumption is associated with a diet higher in sugar from solid foods compared to non-consumption in boys. Additionally, we identified that both SSBs and ASBs may induce an unhealthier glycemic profile in children, while previous studies have linked them with prevalence of diabetes[4]. Currently, marketing and distribution of sweetened drinks (either sugar- or artificially sweetened) is considerable among children, through the media[29] and school environments[30], and can influence food selection and eating habits which can continue to adulthood. Thus, it is crucial that future policy incorporates scrutiny of industry, child-focused advertising, and school availability of sweetened beverages, while their role in health remains disputed.

This nationally representative study of children aged 4 to 18 years old has found that SSBs contributed towards higher total sugar intake, while ASBs have not. However, both SSBs and ASBs were related to a less healthy cardiometabolic profile. Policy should focus on minimizing consumption of sweetened drinks and replacing them with unsweetened alternatives. The study adds to a growing evidence base that ASBs, like SSBs, may be linked to poorer cardiometabolic health in children.

Conflict of interest:

The authors have no conflicts of interest to disclose

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The authors' responsibilities were as follows: PS, CM, and AAL designed research; PS performed the statistical analysis; CM and AAL supervised the statistical analysis; PS drafted and revised the manuscript; CM, and AAL critically reviewed the manuscript; All authors approved the final manuscript as submitted.

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Tables

Table 1. Characteristics of sample by beverage use in UK children 4-18 years old, n (%) or mean (SD).

Characteristics	Neither[1]	SSBs[1]	ASBs[1]	Both[1]	p[2]
N	164 (9.7)	501 (29.7)	298 (17.7)	724 (42.9)	
Age (years)	10.7 (0.4)	11.7 (0.2)	9.7 (0.2)	10.9 (0.2)	<.001
Sex (% males)	75 (45.7)	265 (52.9)	149 (50.0)	370 (51.1)	.447
Ethnicity (% white)	120 (73.2)	396 (79.0)	277 (93.0)	660 (91.1)	<.001
Equivalised household income					.019
1st quintile – lowest	18 (14.0)	100 (23.4)	40 (15.3)	137 (21.0)	
2nd quintile	23 (17.8)	81 (19.0)	58 (22.1)	142 (21.8)	
3rd quintile	21 (16.3)	77 (18.0)	53 (20.2)	133 (20.4)	
4th quintile	27 (20.9)	94 (22.0)	53 (20.2)	128 (19.6)	
5th quintile – highest	40 (31.0)	75 (17.6)	58 (22.1)	113 (17.3)	
Eating take away meal					<.001
At least once a week	31 (18.9)	121 (24.2)	53 (17.8)	175 (24.2)	
1-2 times per month	48 (29.3)	214 (42.7)	130 (43.6)	345 (47.7)	
Rarely or never	85 (51.8)	166 (33.1)	115 (38.6)	204 (28.2)	
Physical activity[3] (%>median)	40 (44.9)	136 (51.3)	80 (45.7)	192 (52.0)	.394
BMI (Kg/m^2)	19.4 (4.3)	19.7 (4.3)	19.3 (4.5)	19.8 (0.4)	.181
Waist-to-hip ratio[4]	0.79 (0.06)	0.81 (0.06)	0.80 (0.07)	0.82 (0.07)	.002
SSBs (g/day)	0	311.9 (268.0)	0	250.5 (237.1)	
ASBs (g/day)	0	0	351.4 (300.8)	286.3 (248.5)	
Food groups (g/1000 kcal)					
Fruit	72.5 (66.7)	45.0 (51.3)	61.6 (58.9)	43.6 (48.0)	<.001
Vegetables	77.4 (51.4)	60.3 (37.7)	63.3 (42.3)	53.1 (33.1)	<.001
Meat	43.4 (31.1)	52.1 (28.8)	48.3 (27.6)	51.7 (25.5)	<.001
Confectionery	45.3 (33.9)	40.7 (27.2)	46.0 (31.0)	44.3 (26.6)	.042
Juices and smoothies	77.8 (112.0)	51.5 (75.3)	58.8 (87.5)	47.0 (64.7)	.452
Tea, coffee and water	432.8 (413.2)	254.0 (230.5)	221.6 (238.7)	168.6 (185.9)	<.001
Blood analytes					
Glucose (mmol/L)	4.6 (0.4)	4.8 (0.4)	4.7 (0.4)	4.8 (0.4)	.121
HbA1c (%)	5.3 (0.3)	5.3 (0.3)	5.2 (0.3)	5.3 (0.3)	.342
Triglycerides (mmol/L)	0.7 (0.4)	0.8 (0.4)	0.8 (0.4)	0.8 (0.5)	.307
Total cholesterol (mmol/L)	4.2 (0.9)	4.2 (0.8)	4.2 (0.7)	4.1 (0.7)	.698
HDL (mmol/L)	1.5 (0.4)	1.5 (0.3)	1.5 (0.4)	1.4 (0.3)	.384
Total energy (kcal)	1499 (499)	1699 (485)	1511 (372)	1729 (440)	<.001
Total sugar (% TE)	11.7 (5.4)	16.4 (6.1)	12.1 (5.1)	16.2 (5.6)	<.001

[1]Neither: mean consumption of SSBs=0 g/day & ASBs=0 g/day; SSBs: mean consumption of SSBs>0 g/day & ASBs=0 g/day; ASBs: mean consumption of ASBs>0 g/day & SSBs=0 g/day; Both: mean consumption of SSBs>0 g/day & ASBs>0 g/day
[2]p-value for chi-square or Kruskal–Wallis test
[3]Physical activity is measured as mean counts per minute using data from ActiGraph for children aged <16 and as hours spent at moderate or vigorous physical activities using data from RPAQ for children aged 16-18
[4]for children >11 years old

Table 2. Associations from OLS and fixed effects regression between energy and sugar intake, total and from solid foods and beverages, and SSBs or ASBs consumption compared to no consumption

Beverage consumed	Neither[1] (ref)	SSBs[1] Coeff. (95% CI)	ASBs[1] Coeff. (95% CI)	Both[1] Coeff. (95% CI)
A. OLS regression[2]				
Total Energy (kcal)		106 (-38, 250)	27 (-120, 174)	**162 (21, 303)**
Energy from solid foods (kcal)		15 (-118, 148)	37 (-99, 174)	108 (-22, 239)
Energy from beverages (kcal)		**91 (54, 129)**	-11 (-48, 27)	**54 (20, 88)**
Total sugar (% TE)		**6.2 (4.2, 8.1)**	1.4 (-0.4, 3.3)	**4.9 (3.1, 6.8)**
Sugar from solid foods (% TE)		0.8 (-0.5, 2.0)	**1.7 (0.5, 2.9)**	**1.2 (0.0, 2.3)**
Sugar from beverages (% TE)		**5.4 (3.8, 6.9)**	-0.2 (-1.6, 1.1)	**3.8 (2.4, 5.2)**
B. Fixed-effects regression[3]				
Total Energy (kcal)		**216 (163, 269)**	17 (-45, 79)	**217 (135, 299)**
Energy from solid foods (kcal)		**89 (41, 138)**	50 (-7, 106)	**154 (81, 226)**
Energy from beverages (kcal)		**127 (107, 146)**	**-33 (-54, -12)**	**64 (35, 92)**
Total sugar (%TE)		**7.0 (6.2, 7.8)**	**-1.0 (-1.8, -0.1)**	**4.5 (3.4, 5.5)**
Sugar from solid foods (% TE)		-0.4 (-1.0, 0.2)	0.0 (-0.6, 0.7)	-0.1 (-0.9, 0.6)
Sugar from beverages (% TE)		**7.4 (6.8, 8.1)**	**-1.0 (-1.7, -0.3)**	**4.6 (3.8, 5.4)**

[1]Neither: mean consumption of SSBs=0 g/day & ASBs=0 g/day; SSBs: mean consumption of SSBs>0 g/day & ASBs=0 g/day; ASBs: mean consumption of ASBs>0 g/day & SSBs=0 g/day; Both: mean consumption of SSBs>0 g/day & ASBs>0 g/day

[2]adjusted for: age, sex (male/female), BMI (kg/m^2), ethnic group (white, non-white), equivalised household income (quintiles), frequency of eating takeaway (once per week or more; 1-2 times per month; rarely-never) and physical activity (mean counts per minute for children aged <16 and hours spent at moderate or vigorous physical activities for children aged 16-18; above/below the median)

Unweighted sample size for OLS regression: n=785

[3]adjusted for: diary being collected on a Friday, Saturday, or Sunday

Table 3. Associations from OLS regression between cardiometabolic risk factors and SSBs or ASBs consumption compared to no consumption.[1]

Beverage consumed	Neither[2] (ref)	SSBs[2] Coeff. (95% CI)	ASBs[2] Coeff. (95% CI)	Both[2] Coeff. (95% CI)
BMI (Kg/m^2)				
Model 1		0.35 (-0.41, 1.11)	**1.13 (0.32, 1.94)**	**0.80 (0.10, 1.49)**
Model 2		-0.90 (-2.10, 0.31)	0.65 (-0.62, 1.91)	0.16 (-1.06, 1.37)
Model 3		-0.72 (-1.91, 0.48)	0.79 (-0.43, 2.00)	0.38 (-0.83, 1.60)
Waist-to-hip ratio[3]				
Model 1		0.013 (-0.004, 0.031)	0.008 (-0.013, 0.029)	**0.021 (0.003, 0.038)**
Model 2		-0.001 (-0.026, 0.025)	0.007 (-0.024, 0.039)	0.024 (-0.003, 0.050)
Model 3		-0.007 (-0.032, 0.018)	0.004 (-0.025, 0.033)	0.018 (-0.008, 0.044)
Glucose (mmol/L)				
Model 1		**0.21 (0.08, 0.34)**	**0.17 (0.02, 0.32)**	**0.17 (0.05, 0.30)**
Model 2		**0.22 (0.04, 0.41)**	**0.22 (0.02, 0.42)**	**0.23 (0.04, 0.43)**
Model 3		**0.30 (0.11, 0.50)**	**0.26 (0.06, 0.46)**	**0.30 (0.10, 0.50)**
Model 4		**0.30 (0.11, 0.49)**	**0.24 (0.06, 0.43)**	**0.28 (0.08, 0.47)**
HbA1c (%)				
Model 1		0.06 (-0.07, 0.19)	-0.03 (-0.18, 0.11)	0.01 (-0.12, 0.15)
Model 2		-0.06 (-0.26, 0.14)	-0.11 (-0.32, 0.10)	-0.05 (-0.25, 0.16)
Model 3		-0.09 (-0.25, 0.07)	-0.15 (-0.32, 0.02)	-0.09 (-0.26, 0.08)
Model 4		-0.08 (-0.24, 0.08)	-0.16 (-0.33, 0.01)	-0.09 (-0.25, 0.07)
Triglycerides (mmol/L)				
Model 1		**0.10 (0.01, 0.19)**	**0.13 (0.02, 0.25)**	**0.17 (0.08, 0.27)**
Model 2		0.14 (0.00, 0.29)	0.14 (-0.03, 0.32)	**0.21 (0.05, 0.36)**
Model 3		**0.22 (0.06, 0.38)**	**0.18 (0.01, 0.35)**	**0.29 (0.11, 0.47)**
Model 4		**0.29 (0.13, 0.46)**	0.15 (0.00, 0.31)	**0.29 (0.12, 0.47)**
Total cholesterol (mmol/L)				
Model 1		0.17 (-0.16, 0.50)	0.11 (-0.23, 0.46)	0.08 (-0.24, 0.4)
Model 2		0.17 (-0.32, 0.67)	0.25 (-0.26, 0.76)	0.11 (-0.38, 0.61)
Model 3		0.34 (-0.09, 0.77)	0.32 (-0.12, 0.76)	0.30 (-0.13, 0.72)
Model 4		0.38 (-0.06, 0.81)	0.31 (-0.13, 0.76)	0.30 (-0.13, 0.72)
HDL cholesterol (mmol/L)				
Model 1		0.03 (-0.12, 0.18)	0.00 (-0.16, 0.17)	-0.04 (-0.18, 0.11)
Model 2		0.08 (-0.12, 0.29)	0.08 (-0.14, 0.30)	0.03 (-0.17, 0.23)
Model 3		0.13 (-0.08, 0.34)	0.11 (-0.10, 0.33)	0.08 (-0.13, 0.29)
Model 4		0.08 (-0.12, 0.28)	0.12 (-0.08, 0.32)	0.07 (-0.13, 0.26)

[1]Model 1: age, sex; Model 2: Model 1 + ethnic group (white, non-white), equivalised household income (quintiles), frequency of eating takeaway (once per week or more; 1-2 times per month; rarely-never) and physical activity (mean counts per minute for children aged <16 and hours spent at moderate or vigorous physical activities for children aged 16-18; above/below the median); Model 3: Model 2 + Energy (kcal) and food groups (g/1000 kcal):

fruits and vegetables, meat, confectionery, juices, and tea-coffee-water; Model 4: Model 3 + BMI (kg/m^2)

[2]Neither: mean consumption of SSBs=0 g/day & ASBs=0 g/day; SSBs: mean consumption of SSBs>0 g/day & ASBs=0 g/day; ASBs: mean consumption of ASBs>0 g/day & SSBs=0 g/day; Both: mean consumption of SSBs>0 g/day & ASBs>0 g/day

[3]for children >11 years old

Unweighted sample sizes of final models: BMI: n= 785 (males: 47%, females: 53%), waist-to-hip ratio: n=291 (males: 46%, females: 54%), Glucose: n=208 (males: 51%, females 49%), HbA1c: n=476 (males: 50%, females: 50%), Triglycerides: n=253 (males: 52%, females: 48%), Total cholesterol: n= 255 (males: 52%, females: 48%). HDL: n=252 (males: 52%, females 48%).