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# Consumption frequency of added sugars and UK children's dental caries

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**Key words:** dental health survey, child dentistry, dental public health, caries preventions, biostatistics, fluoride, sucrose, sugars.

**Abstract**

Objectives: To examine the association between consumption frequency of foods and drinks with added sugar and dental caries experience in the permanent teeth of 12- and 15-year-old children in England, Wales and Northern Ireland, using the Children's Dental Health Survey 2013 (CDHS) data.

Methods: 4,950 children aged 12 and 15 have the following information available: daily consumption frequency of foods and drinks with added sugar, tooth-brushing frequency, dental attendance, and water-drinking frequency. The children's dental caries experience was available as a DMFT score (number of decayed (into dentine), missing, filled permanent teeth). A zero-inflated negative binomial model (ZINB) was used to fit the DMFT-score.

Results: Lower socio-economic status (SES), non-regular dental check-ups, and low water drinking frequency were associated with higher consumption frequency of added sugar (all $p < 0.05$). The consumption frequency of both drinks and foods with added sugar also differed by region ($p<0.001$), and children who more frequently consumed foods with added sugars also consumed drinks with added sugars more often ($p<0.001$). Using the Zero-Inflated Negative Binomial model, DMFT scores were not associated with consumption frequency of added sugars for children with caries (DMFT>0), but the chance of being free of obvious caries (DMFT=0) was lower for children with high frequency (>=4) of sugar-added foods than for children reported to have a sugar-free diet [OR = 0.5, 95% CI (0.3, 0.8)].

Conclusions: Consumption frequency of added sugars was associated with dental caries and a number of child demographic and lifestyle characteristics. Children who consume foods and drinks with added sugar more frequently are more likely to develop dental caries, but higher consumption frequency of drinking water in fluoridated areas might reduce dental caries. The findings add to the evidence for the association between children's dental caries and added sugar consumption.

## Introduction

High consumption of foods and drinks with added sugars is a great concern in many countries, and it has increased among children of all ages over the past few decades.[1,2,3] In the UK and the USA, sweetened soft drinks and sweetened dairy drinks and juices account for a large share of children's beverage consumption,[1] especially among adolescents.[1,2] Consuming sugars has negative effects on oral health as cariogenic bacteria metabolise monosaccharides to produce acids which are harmful to the teeth.[4,5] Currently, dental caries is the greatest global oral health burden with 60-90% of school children affected worldwide.[6] Dental caries has a negative impact on children's quality of life along with high treatment costs; it also has potential further adverse consequences.[7-11]

It is still a matter of debate whether it is the amount, timing, or frequency of added sugar consumption that plays the most important role in caries formation, and only a handful of high-quality publications have reviewed this issue.[4,12,13] For example, Ismail et al.[14] found a positive association between the frequencies of at- and between-meal consumption of soft drinks and dental caries among participants aged 9-29 years in the National Health and Nutrition Examination Survey (NHANES) I. By contrast, findings from NHANES III indicated that the association between frequency of consuming drinks with added sugars and caries experience could not be seen in persons under 25 years.[15] However, very few studies have investigated other modifiable factors that might attenuate the association between added sugars and dental caries in children. Modifiable factors include an individual's exposure to fluoride, behaviours, and socioeconomic status (SES).[4,16] One Australian study[17] reported that frequent consumption of drinks with added sugars was associated with caries in both primary and permanent teeth, and the association was ameliorated by high SES, fluoridated water exposure and frequent tooth-brushing.

The UK conducted its fifth decennial national Children's Dental Health Survey (CDHS) in 2013 and collected information on demographic characteristics (age, gender, region, SES), dental health behaviours (tooth-brushing, dental attendance) and self-reported diet (consumption frequency of various categories of drinks and foods, water-drinking frequency). As children's daily consumption of foods and drinks with added sugars (cakes, biscuits and sweets; soft drinks that contain sugar and energy/sports drinks) was collected only from 12- and 15-year-olds, this paper considers just these age groups. The survey reported prevalence of caries in the permanent dentition of 34% in 12-year-olds and 46% in

15-year-olds.[18] The 12- and 15-year-old groups are best among children for assessing the effects of exposures to oral and external environments on permanent teeth, because the teeth have been erupted, and exposed to the oral environment, for up to nine years.[19]

This paper aimed to investigate associations between the consumption frequency of foods and drinks with added sugars and the dental caries experience of children aged 12 and 15 years, using Children's Dental Health Survey 2013 data.

## Methods

***Database.*** Data for this study come from the 2013 United Kingdom's Children's Dental Health Survey (CDHS)[20]. The survey included 13,628 children aged 5, 8, 12 and 15 in 1,015 primary schools and 955 secondary schools across England (North East, North West, Yorkshire & the Humber, East Midlands, West Midlands, East of England, London, South East coast, South Central, and South West), Wales and Northern Ireland, using a multi-stage cluster sampling technique.[21]

Survey data were collected through clinical dental examinations, parent questionnaires and self-completed questionnaires (for children aged 12 and 15 years).[21] Information about the consumption frequency of sugar-added foods (cakes, biscuits and sweets) and sugar-added drinks (soft drinks and energy/sports drinks); tooth-brushing and water consumption was collected by self-completed questionnaires using a six-category frequency scale (rare or never, less than once, once, twice, three times, four or more times per day). Although the survey also collected information about daily juice consumption, there was no information on the exact nature of the juices consumed (natural or fruit-based juice, diluted from concentrate, sugar-free or not). Therefore, for the purposes of this paper, juice consumption was not included within the sugar-added drinks category in the main results, but we have included juice in a sensitivity analysis and present the results in Appendix Table S1 and Table S2, and in the discussion.

***Measures.*** Dental caries experience was measured by the number of decayed (into dentine), missing, and filled teeth (DMFT) of participants at age 12 and 15 as the dependent variable for this study.

Exposure measures included the children's age, gender and consumption frequency of both foods and drinks with added sugars. Mediators were SES, region, tooth-brushing frequency, water-drinking frequency and dental attendance pattern. Reference to 3 meals per day, frequency of sugar-added drinks consumption and frequency of water drinking were grouped into three categories: "rare/never", "once to three times per day usually", and "four times or more per day usually". Frequency of sugar-added foods consumption was categorized as "never to once per day usually", "twice to three times per day usually", and "four times or more per day usually". Tooth-brushing frequency was classified as "less than twice daily", and "twice or more daily". Pattern of dental attendance was defined as "regular check-ups", and “only when in trouble/never”. The SES of each child was identified by using the Index of Multiple Deprivation (IMD) relevant to each country. Participants were grouped into three categories: “more deprived” (rank 1-6496), “medium deprived” (rank 6497-12993), and “less deprived” (rank 25987-32482). Other independent variables were age (12 or 15 years) and gender (male or female). Region information of participants was included to identify the exposure to fluoridated water (information on the percentage of each population receiving a fluoridated water supply is presented in Appendix S4). A causal diagram, or directed acyclic graph (DAG), is used to describe the exposure measures and their relation to the outcome measure DMFT (Appendix S1).

Multicollinearity was examined for each variable using the variance inflation factor (VIF), and covariates with a VIF greater than 10 were considered as having high multicollinearity. No measures could be considered as a linear combination of other independent variables because each VIF was lower than 5 (age=2.7, gender=1.4, SES=3.3, tooth-brushing=1.9, dental attendance=1.3, sugar-added foods=2.6, sugar-added drinks=2.6, water=4.2). Region was not used as a risk factor in the ZINB model because it had already been adjusted for in the stratification.

***Statistical analysis.*** Analysis of variance (ANOVA) was performed to explore the unadjusted relationship between exposure/mediating measures and the DMFT score. Each variable was summarized with its mean estimates and 95% confidence interval (CI) after weighting. Caries prevalence in both 12- and 15-year-olds in the CDHS was below 50 percent,[18] resulting in a considerable number of ‘caries-free’ (no dentine caries) children. In order to allow for excess zeros in this count variable, we used the zero-inflated negative binomial (ZINB) model to assess the association between sugar-added drinks and foods intake frequency and caries count and the chance of being ‘caries-free’. ZINB modelling generated two separate models and then combined them: first, a logit model was generated for the ‘zero’ DMFT (‘caries-free’) cases, predicting whether or not a child was in the ‘caries-free’ group; second, a negative binomial model was generated, predicting the counts (DMFT index) for those children who were not ‘caries-free’; finally, the two models were combined. The model was sequentially adjusted for demographic features (age, gender, SES), then additionally for dental behaviour (tooth-brushing frequency and dental attendance), and then additionally for water consumption frequency. Finally, all covariates were adjusted for by including consumption frequencies for both drinks and foods with added sugars in the fully adjusted model. The Negative Binomial (NB) model was also used to compare it with the ZINB model with the same adjustment of variables. In order to explore the effects of excluding 'juice' drinking frequency in the main analysis, a sensitivity analysis which included the frequency of juice consumption within the sugar-added drinks category was also performed. This enabled examination of the robustness of the findings (Appendix S3). Prespecified subgroup analyses were performed to evaluate DMFT in children from regions with a fluoridated water scheme and regions without water fluoridation, according to spatial distribution of natural and artificial water fluoridation using information from the British Fluoridation Society.[22]

Data were weighted according to the primary sampling unit (PSU) and strata in the survey design. A significance level of 0.05 was used to determine statistical significance. The analysis was done using RStudio with Survey Package and StataSE 14.

## Results

The demographic characteristics, SES, oral health behaviour and frequency of sugar intake of the surveyed children aged 12 and 15 (n=4,950) were summarized in Table 1. SES and several behavioural variables were associated with diets with added sugar: children who consumed more drinks and foods with added sugars were from lower SES, brushed their teeth less often, attended a dentist only 'when in trouble or never', and drank water less frequently. Meanwhile, children who consumed foods with added sugars more frequently tended to consume drinks with added sugars more frequently too, and vice versa ($p<0.001$). Diet behaviour also varied in regions: children from East Midlands and North West reported consuming the highest frequencies of drinks with added sugars (2.4 and 2.0 times per day, respectively) and foods with added sugars (3.0 and 3.2 times per day, respectively).

Dental caries experience was measured using DMFT scores in the analysis (Table 1, last column). Nearly half (46%) of 15-year-olds and a third (34%) of 12-year-olds had clinical apparent decay experience in their permanent teeth, and the weighted mean DMFT score for 12- and 15-year-olds was 0.8 and 1.4 respectively.[18] The DMFT score was associated with almost all variables except gender: Caries experience was higher among children who were older, from lower SES, who brush their teeth less than twice a day, attend a dentist only 'when in trouble or never', drink water less than once a day, imbibe more drinks with added sugars, and eat foods with added sugars more than 4 times per day. Higher consumption frequency of drinks with added sugars is significantly associated with higher DMFT [$F(2, 4825)=31.9$, $p<0.001$], and so is eating foods with added sugars [$F(2, 4854)=51.4$, $p<0.001$]. Children's caries experience varied in regions: economically affluent regions such as East England, South East, and South West, had lower DMFT scores than less-affluent regions such as North East, North West, Wales and Northern Ireland, except the West Midlands.

The distribution of DMFT across regions is presented in Appendix Figure S2, demonstrating that West Midland, East England, South West and South East have a higher proportion of 'caries-free' children. Model selection has been performed and the ZINB model was used as the best fit for DMFT with the smallest residual (Appendix Figure S3). Among the children with caries (DMFT>0) in the negative binomial model part, we found no association between consumption frequency of foods and drinks with added sugars and DMFT when comparing none/low versus high consumption frequency of added sugars (Table 2); however, these associations were significant in the logit model part, indicating that the chance of being ‘caries-free’ (DMFT=0) was lower for children who consume foods or drinks with added sugars frequently than for those who don’t [OR=0.4, 95% CI (0.2, 0.8) for drinks with added sugars; OR=0.4, 95% CI (0.2, 0.7) for foods with added sugars, assessed separately; Table 2]. When including consumption of both drinks and foods with added sugars in the model, the odds of being ‘caries-free’ was 50% lower when consuming foods with added sugars at least four times daily than for consuming them once daily or less often. To summarize, this ZINB two-part model showed that children who consume drinks and foods with added sugars more frequently were less likely to be ‘caries-free’, but no significant difference was found in the magnitude of the DMFT score once the caries had developed.

On the other hand, when taking into consideration only the standard negative binomial regression model adjusting for age, gender, SES and oral health behaviour, frequent imbibition of drinks with added sugars (1-3 times or >4 times daily) was associated with higher caries experience [Incident Rate Ratio, IRR=1.3, 95% CI (1.1, 1.6), IRR=1.4, 95% CI (1.2, 1.7), respectively], while eating foods with added sugars more than four times daily was associated with higher DMFT [IRR=1.3, 95% CI (1.1, 1.5)] (Table 2).

When juice consumption was included within the drinks with added sugars category, the association between high frequency consumption of drinks with added sugars and dental caries experience still held (Appendix S3: Sensitivity analysis), but the effect was diluted for low frequency of drinks with added sugars (1-3 times daily).

80% of children surveyed as part of the CDHS 2013 lived in areas with limited access to fluoridated water, and around 5% of the children surveyed were from the West Midlands where the water fluoridation scheme results in 70% of its population having access to fluoridated domestic water supplies. This offered the opportunity for some subgroup analysis comparing the associations between caries and consumption frequency of foods and drinks with added sugars in non-fluoridated regions (London, South West, South East, Wales and Northern Ireland) and the fluoridated region such as West Midlands. Figure 1 illustrates the difference in DMFT when the consumption frequency of drinks and foods with added sugars was higher, separated by different frequency of drinking water while controlling other variables. The water drinking frequency was further grouped into ‘less than 3 times a day’ and ‘4 or more times a day’ to make the figure easier to read. In regions with no fluoridation scheme, there was no association between caries experience and frequency of drinking water [effect sizes=0.0, 95% CI (-0.5, 0.5) for both drink and food]. On the contrary, in the West

Midlands, where 70% of population had access to fluoridated water, the risk of having high DMFT scores was lower among children who reported drinking water four times or more daily [effect size = 0.8, 95% CI (0.1, 1.6) for drink; effect size = 0.7, 95% CI (0.1, 1.6) for food].

## Discussion

Our findings showed that the frequent consumption of foods and drinks with added sugars was associated with the presence of dental caries among 12- and 15-year-olds, but this association was not observed among caries-affected children. Consumption of drinks with added sugar was more frequent among children who were female, older, from a lower-SES background, attended dental check-ups irregularly, or who reported drinking water less frequently. Similar patterns were observed for the consumption of foods with added sugars. Moreover, our subgroup analysis found that frequent drinking of water helped to moderate the association between consumption frequency of foods and drinks with added sugars and caries experience in a region with wide coverage of fluoridated water.

A major strength of our study was the CDHS survey's use of a relatively large and representative sample of children, which ensured study results are likely to be generalizable across the UK children (except Scotland). Additionally, we fitted both zero-inflated negative binomial (ZINB) model and negative binominal regression model (NB) to allow for excess zeros in DMFT scoring. The limitations of this study are related closely to limitations in the methods of measuring dietary data and the cross-sectional nature of the data. Analyses based on a self-completed single frequency questionnaire can be subject to recall and social desirability biases, along with measurement error.[12,23] Likewise, recall at a single point in time may be an inadequate risk indicator for a disease that develops over many months. Because the CDHS used close-ended food frequency questionnaires (FFQs) to obtain information on food and drinks consumption, another limitation was the lack of detailed information about foods in those FFQs.[24] The CDHS collected information about consumption frequency of only cakes, biscuits, sweets, soft drinks and sports/energy drinks and juices, while information on other foods with added sugars (such as sweetened dairy products, jams and bread and cereals) was not captured. Hence, we grouped cakes, biscuits and sweets into 'foods with added sugars', and grouped soft drinks and sports/energy drinks into 'drinks with added sugars'. However, juice consumption was not included in the final model due to a lack of information on juice types to allow any meaningful assessment of potential harm due to free sugars. Another limitation of the current study is the potential bias from moderate level of multicollinearity of water drinking frequency with sugar consumption frequencies.

One also could argue that the information about children's previous addresses was not available, and so assumptions have been made that all surveyed children have been staying in the regions for the past few years and that their schools and homes were both in the same region. This might have had a confounding impact when we include a water drinking frequency in the analysis examining regions with fluoridated water versus regions without, due to the children's unknown history of fluoride exposure both at home and school.

Although dose-response associations between the consumption of drinks and foods with added sugars and caries experience (DMFT) has been reported in many studies,[12,14] our findings from the ZINB models indicate that daily consumption frequency of drinks and foods with added sugars was significantly associated with the presence of dental caries, rather than the actual DMFT score among caries-affected children. It was shown that 12- and 15-year-old children consuming drinks and foods with added sugars four times or more daily were less likely to be 'caries-free'. The findings using the NB model might be misleading because the model fitting was poor (Appendix Figure S3).

Our finding is consistent with a Belgian study which fitted ZINB models among 7-year-old children and indicated the excess of caries-free children was lower for the children who had drinks with added sugars between meals (twice or more daily).[25] From the perspective of caries aetiology, lower plaque pH values and a slower increase in pH after exposure to free sugar in caries-affected children could also explain such associations.[5] As in our study, a three-year longitudinal US study found that the frequency of added sugar consumption was poorly associated with caries increment in caries-prone children.[26] Although previous research implies that frequent consumption of drinks with added sugar is associated with caries experience,[17,27] these analyses did not use zero-inflated modelling, and few reported having done a model-fitting check. Burt et al.[26] suggested that the caries/frequency relationship might be stronger where sugar consumption was generally lower; however, consumption of products with added sugar in our study was high. 62.9% of children in the CDHS 2013 survey consumed drinks with added sugars at least daily, and 66.0% consumed foods with added sugars twice or more daily.

In the subgroup analysis using ZINB models, we found lower DMFT scores among children with caries in the fluoridated area (West Midlands) who drank water more than four times a day. However, the association between water-drinking frequency and DMFT was not found in non-fluoridated areas. The protective effects of water fluoridation against caries could explain these findings owing to the high proportion of the West Midland population having access to fluoridated water. This is consistent with studies in the UK,[28] the US[27] and Australia,[17] demonstrating that children in local authorities with water fluoridation schemes had less dental caries than those living without the scheme. However, due to data confidentiality, only the information of regions where each surveyed participant was from was publicly available rather than their residential location. Thus, this study can only provide a rough estimate of the preventive effect of water fluoridation using ecological variables. Further research could explore the association by analysing a dataset with detailed geographic information about fluoride exposures and residence history.

Our study also found that tooth-brushing frequency and dental attendance patterns were associated with caries experience. Such patterns have also been reported previously in the literature,[17,29] suggesting that tooth-brushing frequency and regular dental attendance are beneficial in reducing caries experience. We found considerable differences in DMFT and consumption frequency of sugar-added drinks and foods across all SES groups. Children from the more deprived families reported consuming drinks and foods with added sugars more frequently than did children from less deprived families. This finding is in line with findings from several other countries.[8,17]

In conclusion, consuming foods and drinks with added sugars more frequently was associated with being less likely to be ‘caries-free’ among children aged 12 and 15 years. Once caries has developed, however, the association between consumption frequency and caries is no longer apparent. Drinking water frequently helped ameliorate the apparent deleterious effect of sugar consumption on children’s dental caries experience in regions with wide coverage of fluoridated water, such as the West Midlands. The findings add to the evidence of the harmful effect of added sugars on children’s dental health and promote the implications of dietary advice from dental health professionals on reduction of free-sugar intakes.[30]

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# Tables

**Table 1.** Daily consumption frequency of sugar-added drinks and foods, and dental caries experience measured by DMFT for 12- and 15-year-olds by demographic characteristics, socioeconomic status, behavioural variables in England, Wales and Northern Ireland.

| Variable | N (%), unweighted | Daily sugar-added drinks consumption freq, n (%) | | | | Daily sugar-added foods consumption freq, n (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Weighted mean † (95% CI) | 0 | 1-3 | ≥ 4 | Weighted mean † (95% CI) | ≤1 | 2-3 | ≥4 | Weighted mean DMFT † (95% CI) |
| Age, y | | | | | | | | | | |
| 12 | 2532 (51.2) | 1.7 (1.5, 2.0) | 909 (35.9) | 1174 (46.3) | 449 (17.7) | 2.7 (2.5, 2.8) | 866 (34.2) | 844 (33.3) | 822 (32.5) | 0.8*** (0.7, 1.0) |
| 15 | 2418 (48.9) | 1.5 (1.3, 1.6) | 925 (38.3) | 1085 (44.9) | 408 (16.9) | 2.5 (2.3, 2.6) | 817 (33.8) | 800 (33.1) | 801 (33.1) | 1.4 (1.2, 1.7) |
| Gender | | | | | | | | | | |
| Male | 2377 (48.0) | 1.7 (1.5, 1.9) | 830 (34.9) | 1097 (46.2) | 450 (18.9) | 2.6 (2.4, 2.7) | 785 (33.0) | 794 (33.4) | 798 (33.6) | 1.1 (0.9, 1.2) |
| Female | 2573 (52.0) | 1.5 (1.3, 1.7) | 1004 (39.0) | 1162 (45.2) | 407 (15.8) | 2.5 (2.4, 2.6) | 898 (34.9) | 850 (33.0) | 825 (32.1) | 1.2 (1.1, 1.4) |
| Region | | | *** | | | | *** | | | |
| West Midlands | 266 (5.4) | 1.4*** (1.0, 1.9) | 109 (41.0) | 126 (47.4) | 31 (11.7) | 2.2*** (2.0, 2.4) | 106 (39.9) | 89 (33.5) | 71 (26.7) | 0.9*** (0.7, 1.1) |
| East Midlands | 199 (4.0) | 2.4 (2.2, 2.5) | 63 (31.7) | 86 (43.2) | 50 (25.1) | 3.0 (2.9, 3.0) | 57 (28.6) | 62 (31.2) | 80 (40.2) | 1.2 (0.8, 1.7) |
| East England | 257 (5.2) | 1.2 (1.0, 1.4) | 121 (47.1) | 105 (40.9) | 31 (12.1) | 2.4 (2.1, 2.6) | 99 (38.5) | 90 (35.0) | 68 (26.5) | 0.8 (0.5, 1.1) |
| London | 369 (7.5) | 1.6 (1.2, 2.0) | 142 (38.5) | 155 (42.0) | 72 (19.5) | 2.6 (2.3, 2.8) | 138 (37.4) | 111 (30.1) | 120 (32.5) | 1.0 (0.6, 1.4) |
| North East | 353 (7.1) | 1.7 (1.4, 1.9) | 114 (32.3) | 169 (47.9) | 70 (19.8) | 2.6 (2.4, 2.9) | 117 (33.1) | 114 (32.3) | 122 (34.6) | 1.5 (1.2, 1.8) |
| North West | 466 (9.4) | 2.0 (1.5, 2.5) | 143 (30.7) | 214 (45.9) | 109 (23.4) | 3.2 (3.1, 3.4) | 128 (27.5) | 138 (29.6) | 200 (42.9) | 1.7 (1.3, 2.0) |
| South East | 260 (5.3) | 1.3 (1.1, 1.5) | 101 (38.9) | 123 (47.3) | 36 (13.9) | 2.2 (2.0, 2.3) | 107 (41.2) | 80 (30.8) | 73 (28.1) | 0.8 (0.6, 1.0) |
| South West | 289 (5.8) | 1. 5 (1.2, 1.8) | 97 (33.6) | 163 (56.4) | 29 (10.0) | 2.3 (2.0, 2.6) | 118 (40.8) | 98 (33.9) | 73 (25.3) | 0.9 (0.5, 1.4) |
| Yorkshire and the Humber | 288 (5.8) | 1.5 (1.2, 1.6) | 123 (42.7) | 127 (44.1) | 38 (13.2) | 2.5 (2.5, 2.6) | 108 (37.5) | 91 (31.6) | 89 (30.9) | 1.0 (0.5, 1.5) |
| Wales | 1168 (23.6) | 1.7 (1.4, 1.9) | 398 (34.1) | 548 (46.9) | 222 (19.0) | 2.5 (2.4, 2.7) | 431 (36.9) | 394 (33.7) | 343 (29.4) | 1.8 (1.4, 2.1) |
| Northern Ireland | 1035 (20.9) | 1.5 (1.3, 1.7) | 423 (40.9) | 443 (42.8) | 169 (16.3) | 2.9 (2.8, 3.1) | 274 (26.5) | 377 (36.4) | 384 (37.1) | 2.5 (2.2, 2.9) |
| SES | | | *** | | | | * | | | |
| low | 1692 (34.2) | 2.1*** (1.9, 2.3) | 508 (30.0) | 749 (44.3) | 435 (25.7) | 2.7* (2.5, 2.9) | 534 (31.6) | 517 (30.6) | 641 (37.9) | 1.5*** (1.2, 1.7) |
| Medium | 1986 (40.1) | 1.5 (1.3, 1.7) | 778 (39.2) | 919 (46.3) | 289 (14.6) | 2.5 (2.4, 2.6) | 697 (35.1) | 670 (33.7) | 619 (31.2) | 1.2 (1.0, 1.4) |
| High | 1064 (21.5) | 1.2 (1.1, 1.4) | 474 (44.6) | 495 (46.5) | 95 (8.9) | 2.4 (2.3, 2.6) | 383 (36.0) | 388 (36.5) | 293 (27.5) | 0.7 (0.5, 0.9) |
| Tooth-brushing/day | | | *** | | | | | | | |
| ≤1 | 1104 (22.3) | 2.0*** (1.8, 2.3) | 323 (29.3) | 530 (48.0) | 251 (22.7) | 2.8 (2.6, 3.0) | 335 (30.3) | 358 (32.4) | 411 (37.2) | 1.4*** (1.2, 1.7) |
| ≥2 | 3760 (76.0) | 1.5 (1.3, 1.6) | 1471 (39.1) | 1701 (45.2) | 588 (15.6) | 2.5 (2.4, 2.7) | 1292 (34.4) | 1276 (33.9) | 1192 (31.7) | 1.1 (0.9, 1.2) |
| Dental Attendance | | | *** | | | | * | | | |
| Regular check up | 4011 (82.3) | 1.5*** (1.3, 1.6) | 1567 (39.1) | 1855 (46.3) | 589 (14.7) | 2.5* (2.4, 2.6) | 1390 (34.7) | 1359 (33.9) | 1262 (31.5) | 1.0*** (0.9, 1.1) |
| Only when in trouble / never | 860 (17.7) | 2.2 (1.9, 2.5) | 232 (27.0) | 378 (44.0) | 250 (29.1) | 2.9 (2.6, 3.1) | 244 (28.4) | 273 (31.7) | 343 (39.9) | 1.8 (1.5, 2.0) |
| Daily water consumption freq | | | *** | | | | * | | | |
| <1 | 766 (15.5) | 2.3*** (2.0, 2.5) | 194 (25.3) | 359 (46.9) | 213 (27.8) | 3.0 * (2.7, 3.3) | 231 (30.2) | 236 (30.8) | 299 (39.0) | 1.5*** (1.3, 1.8) |
| 1-3 | 2623 (53.0) | 1.6 (1.4, 1.8) | 907 (34.6) | 1299 (49.5) | 417 (15.9) | 2.5 (2.3, 2.6) | 888 (33.9) | 911 (34.7) | 824 (31.4) | 1.2 (1.0, 1.3) |
| 4 | 1561 (31.5) | 1.3 (1.1, 1.5) | 733 (47.0) | 601 (38.5) | 227 (14.5) | 2.5 (2.3, 2.7) | 564 (36.1) | 497 (31.8) | 500 (32.0) | 1.0 (0.8 1.1) |
| Daily sugar-added drinks consumption freq | | | | | | | *** | | | |
| 0 | 1834 (37.1) | | | | | 1.8*** (1.7, 1.9) | 909 (49.6) | 586 (32.0) | 339 (18.5) | 0.9 *** (0.7, 1.0) |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1-3 | 2259 (45.6) | | | | | 2.7 (2.5, 2.8) | 659 (29.2) | 850 (37.6) | 750 (33.2) | 1.2 (1.0, 1.3) |
| >=4 | 857 (17.3) | | | | | 4.2 (3.9, 4.5) | 115 (13.4) | 208 (24.3) | 534 (62.3) | 1.7 (1.5, 2.0) |
| Daily sugar-added foods consumption freq | | | *** | | | | | | | |
| <=1 | 1683 (34.0) | 0.9*** (0.8, 1.0) | 909 (54.0) | 659 (39.2) | 115 (6.8) | | | | | 1.0 *** (0.8, 1.1) |
| 2-3 | 1644 (33.2) | 1.5 (1.3, 1.7) | 586 (35.6) | 850 (51.7) | 208 (12.7) | | | | | 1.1 (0.9, 1.3) |
| >=4 | 1623 (32.8) | 2.6 (2.3, 2.9) | 339 (20.9) | 750 (46.2) | 534 (32.9) | | | | | 1.4 (1.2, 1.6) |
| All | **4950** | **1.6 (1.4, 1.8)** | **1834 (37.1)** | **2259 (45.6)** | **857 (17.3)** | **2.6 (2.4, 2.7)** | **1683 (34.0)** | **1644 (33.2)** | **1623 (32.8)** | **1.1 (1.0, 1.3)** |

Note: CI = confidence interval; DMFT = dentinal decayed, missing, and filled permanent teeth. P-values were obtained using ANOVA for continuous covariates, Pearson's chi-square test for categorical variables. All weighted by survey design.

*p<0.05

** p <0.01

*** p<0.001

┼ Mean consumption frequency of sugar-added foods, mean consumption frequency of sugar-added drinks, and mean DMFT is weighted by survey sample

**Table 2.** Associations between consumption frequency of products with added sugars and caries experience, Children's Dental Health Survey (n=4,950), 2013.

| | **Drinks with added sugar consumption frequency**[a] | | | **Foods with added sugar consumption frequency**[b] | | |
|---|---|---|---|---|---|---|
| **Models, adjusted for** | Zero-inflated NB model | | NB regression model | Zero-inflated NB model | | NB regression model |
| | Negative Binomial part, IRR[c] (95% CI) | Zero-inflated part, OR[c] (95% CI) | IRR (95% CI) | Negative Binomial part, IRR (95% CI) | Zero-inflated part, OR (95% CI) | IRR (95% CI) |
| Demographic characteristics[d] | | | | | | |
| <=3 | 1.1 (.9, 1.4) | 0.5** (0.4, 0.8) | 1.4** (1.1, 1.8) | 0.9 (0.7, 1.1) | 0.5** (0.3, 0.8) | 1.1 (0.9, 1.4) |
| >=4 | 1.3 (1.0, 1.7) | 0.3*** (0.1, 0.7) | 1.9*** (1.6, 2.2) | 1.0 (0.8, 1.3) | 0.4*** (0.2, 0.7 ) | 1.5*** (1.3, 1.7) |
| Demographic characteristics and dental behaviour[e] | | | | | | |
| <=3 | 1.1 (0.9, 1.4) | 0.6** (0.4, 0.8) | 1.4** (1.1, 1.8) | 0.9 (0.7, 1.1) | 0.5* (0.3, 0.9) | 1.1 (0.9, 1.4) |
| >=4 | 1.2 (1.0, 1.6) | 0.4** (0.2, 0.8) | 1.7*** (1.5, 2.0) | 1.1 (0.9, 1.3) | 0.4*** (0.2, 0.7) | 1.5*** (1.3, 1.7) |
| Demographic characteristics, dental behaviours, and water consumption frequency | | | | | | |
| <=3 | 1.1 (0.9, 1.4) | 0.6** (0.4, 0.9) | 1.4** (1.1, 1.7) | 0.9 (0.7, 1.1) | 0.6** (0.4, 0.9) | 1.1 (0.9, 1.4) |
| >=4 | 1.2 (0.9, 1.5) | 0.4** (0.2, 0.8) | 1.6*** (1.4, 1.9) | 1.1 (0.9 1.3) | 0.4*** (0.2, 0.7) | 1.5*** (1.3, 1.7) |
| Fully adjusted[f] | | | | | | |
| <=3 | 1.2 (.9, 1.4) | 0.7 (0.5, 1.1) | 1.3* (1.1, 1.6) | 0.8 (0.7, 1.0) | 0.6 (0.4, 1.0) | 1.0 (0.8 1.3) |
| >=4 | 1.3 (1.0, 1.6) | 0.6 (0.3, 1.3) | 1.4*** (1.2, 1.7) | 1.0 (0.8, 1.2) | 0.5** (0.3, 0.8) | 1.3*** (1.1, 1.5) |

*p<0.05

**p<0.01

***p<0.001

[a] Drinks with added sugar consumption frequency was represented by 3 levels (0, 1-3, and 4). Reference category is 0.

[b] Foods with added sugar consumption frequency was represented by 3 levels (<=1, 2-3, and 4). Reference category is <=1.

[c] Incidence rate ratio, IRR. Odds ratio, OR.

[d] Demographics include age, gender, SES.

[e] Dental behaviours include tooth-brushing frequency and dental attendance.

[f] Adjustment for all the covariates listed above, and include both variables of drinks and foods with added sugar in the model.

**Figure legend**

Figure 1. Benefit of drinking water and comparison between West Midlands where 70% population have access to fluoridated water versus regions with no water fluoridation scheme. Fluoridation effect on protection teeth DMFT score is of strong contrast between fluoridated and non-fluoridated regions for caries-prone population. Probability of being 'caries-free' in each region: WM =42%, comparing with regions with no fluoridation scheme: London = 33%, SW= 42%, SE= 43%, Wales =36%, NI = 35%. Sample size is over 30 in each case for this subgroup analysis.