Gradual reduction of sugar in soft drinks without substitution as a strategy to reduce overweight, obesity, and type 2 diabetes: a modelling study

Yuan Ma, Feng J He, Yunjian Yin, Kawther M Hashem, Graham A MacGregor

Summary

Background Sugar-sweetened beverages are a major source of free sugar intake in both children and adults, and are an important contributor to obesity and obesity-related diseases, including type 2 diabetes. We proposed an incremental and stepwise reduction in free sugars added to sugar-sweetened beverages by 40% over 5 years without the use of artificial sweeteners and assessed the effect of the proposed strategy on energy intake and weight status.

Methods In this modelling study, we used nationally representative data from the National Diet and Nutrition Survey rolling programme (NDNS RP) from 2008–12 and British Soft Drinks Association annual reports to calculate sugar-sweetened beverage consumption (both with and without fruit juices) and its contribution to free sugar and energy intake in the UK population. We then estimated the predicted reduction in energy intake resulting from the proposed strategy at an individual level. We further predicted the reduction in steady-state bodyweight for each adult using a weight loss model. By scaling up the distribution of the predicted bodyweight in the NDNS RP to the UK adult population, we estimated reductions in the number of overweight and obese adults, and the number of adults with type 2 diabetes.

Findings A 40% reduction in free sugars added to sugar-sweetened beverages over 5 years would lead to an average reduction in energy intake of 38·4 kcal per day (95% CI 36·3–40·7) by the end of the fifth year. This would lead to an average reduction in steady-state bodyweight of 1·20 kg (1·12–1·28) in adults, resulting in a reduction in the prevalence in adults of overweight by 1·0 percentage point (from 35·5% to 34·5%) and obesity by 2·1 percentage points (from 27·8% to 25·7%). This reduction would lead to a reduction of roughly 0·5 million adults from being overweight and 1 million adults from being obese, which in turn would prevent about 274 000–309 000 incident cases of obesity-related type 2 diabetes over the two decades after the predicted reduction in bodyweight is achieved. If fruit juices were excluded from the category of sugar-sweetened beverages (because of potential challenges for reformulation), the corresponding reductions in energy intake and steady-state bodyweight would be 31·0 kcal per day (95% CI 28·6–33·7) and 0·96 kg (0·88–1·04), respectively. These reductions would result in a 0·7 percentage point (0·3 million) reduction in overweight and a 1·7 percentage point (0·8 million) reduction in obesity, which would in turn prevent about 221 000–250 000 cases of type 2 diabetes over two decades after the predicted reduction in bodyweight is achieved. The predicted effect was greater in adolescents, young adults, and individuals from low-income families (who consume more sugar-sweetened beverages).

Interpretation An incremental reduction in free sugars added to sugar-sweetened beverages without the use of artificial sweeteners is predicted to reduce the prevalence of overweight, obesity, and type 2 diabetes. The proposed strategy should be implemented immediately, and could be used in combination with other approaches, such as taxation policies, to produce a more powerful effect.

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Introduction

Over the past two decades, obesity has increased substantially worldwide[1] and is estimated to be associated with more than 3 million deaths per year.[1] In the UK, roughly two in three adults and more than one in four children were overweight or obese in 2013.[2] Meanwhile, consumption of sugar-sweetened beverages has also risen worldwide,[3,4] and it is the largest source of added sugar (roughly 30% of all added sugar) for children and the second largest in adults in the UK.[5] Sugar-sweetened beverages provide so-called empty calories, with less feeling of fullness or satiety compared with solid food.[6] Clear evidence now exists that consumption of sugar-sweetened beverages is an important contributor to obesity in both children and adults[7,8] and is also linked to an increased risk of type 2 diabetes.[9] Roughly 184 000 deaths a year worldwide are estimated to be attributable to the consumption of sugar-sweetened beverages.[10]

The UK developed and implemented a successful national salt reduction programme by getting the food industry to gradually reduce the amount of salt added to processed food over the past decade. The programme was pioneered by the Food Standards Agency, with input from Consensus Action on Salt and Health, and is now being

Research in context

Evidence before this study

We searched PubMed, Embase, and Google Scholar for scientific literature published up to Oct 1, 2015, with no language restrictions, using the following terms: ("carbonated beverages" OR "SSB" OR "sugar sweetened beverages" OR "soft drinks" OR "sweet drinks" OR "soda" OR "sugary drinks" OR "fruit drinks" OR "sport drinks" OR "cold drinks" OR "non-alcoholic drinks") AND (reduc* OR limit* OR decrea*) AND ("energy" OR "weight" OR "calorie" OR obes*) AND ("strategy" OR "intervention" OR "policy" OR "way" OR "approach"). Among these terms, "carbonated beverages" was used as a MeSH term in PubMed. We screened the retrieved results for research articles, reviews, commentaries, and reports of public health strategies related to sugar-sweetened beverages. Based on existing evidence, several countries have worked to develop and implement strategies that focus on reducing the consumption of sugar-sweetened beverages through increasing marketing price, limiting its availability, and raising public awareness. These strategies included tax policies, public education through media and school, restricting the portion size and availability of sugar-sweetened beverages, and clear labelling. A meta-analysis of all quantitative studies showed that a 10% increase in the price of sugar-sweetened beverages would lead to reduction of about 13% in sugar-sweetened beverage demand, based on the experience of several countries including France, several US states, and Mexico. Other studies have modelled the risks and benefits of substituting sugars added to sugar-sweetened beverages with non-caloric sweeteners. However, we did not identify any studies in which a strategy to gradually reduce sugars added to sugar-sweetened beverages was proposed and systematically assessed with respect to its effect on weight status.

Added value of this study

To our knowledge, our study is the first to propose and assess an innovative strategy for the gradual and stepwise reduction of free sugars added to sugar-sweetened beverages. Our findings suggest that this approach could potentially lead to an effective and sustainable reduction in population energy intake and bodyweight, which would in turn reduce the prevalence of obesity and obesity-related diseases nationwide and lead to cost savings. The previous success of a similar strategy to reduce salt intake suggests that this approach should be both feasible and effective.

Implications of all the available evidence

A systematic and gradual reduction in free sugars added to sugar-sweetened beverages by 40% over 5 years is a feasible and potentially important public health strategy, which could be implemented immediately. The proposed strategy could be used in combination with other approaches for the reduction of sugar-sweetened beverage consumption, such as tax policies, to produce a more powerful effect.

implemented by many other countries.[11] The key to the success of the programme was setting incremental salt reduction targets for more than 80 food categories with a clear timeframe for the food industry to achieve this. Average and maximum targets to be achieved in 4 years were set, and the targets were reset 2 years after the setting of the initial targets; the intention was to continue to reset these targets until maximum adult salt intake met the target of 6 g per day. As a result of this programme, salt intake fell from 9·5 g per day to 8·1 g per day between 2003 and 2011, accompanied by a substantial fall in population blood pressure and a substantial reduction in mortality from stroke and ischaemic heart disease.[12]

The UK Scientific Advisory Committee on Nutrition (SACN) has recently recommended reducing free sugar intake to no more than 5% of daily energy intake.[13] Meanwhile, Action on Sugar, a non-governmental organisation similar to Consensus Action on Salt and Health, has produced an action plan to reduce free sugars added to food by 40% by 2020.[14] Sugar-sweetened beverages are a major source of free sugars and should be targeted immediately. The removal of free sugars from sugar-sweetened beverages does not affect the volume and should be easier to achieve than the removal of free sugars from solid foods. Application of this approach to solid food would affect its mass and therefore mass substitutes such as insoluble fibre would be needed to maintain the same weight. In this study, we propose a strategy in which free sugars added to sugar-sweetened beverages are reduced gradually by 40% over 5 years without the use of artificial sweeteners, and assess the effect of this strategy on population energy intake and overweight and obesity.

Methods

Strategy overview and definitions

In this modelling study, we proposed a gradual reduction of 9·7% per year in the amount of free sugars added to sugar-sweetened beverages, aiming for a 40% reduction over 5 years (figure 1). To ensure that the strategy works effectively, several key components are emphasised, including setting targets to provide a level playing field for industry and an independent agency with strong leadership to take action and monitor the process. Our strategy also includes a recommendation for a parallel reduction in artificial sweeteners added to soft drinks, and our proposal specifies not using artificial sweeteners to replace the free sugars removed.

We used the term "free sugars" proposed by WHO[15] and SACN[16] in 2015, which includes all monosaccharides and disaccharides added to soft drinks, plus sugars naturally present in honey, syrups, and unsweetened fruit juices. The value of free sugars is very similar to the value of "non-milk extrinsic sugars", a term commonly used in the UK National Diet and Nutrition Survey (our data source). Sugar-sweetened beverages were defined as sugar-sweetened carbonated drinks, still and juice drinks, dilutable drinks, and fruit juices; sugar-sweetened energy drinks were categorised as carbonates or still drinks. Overweight was defined as a BMI of 25 or greater and obesity was defined as a BMI of 30 or greater in adults.[17]

Our proposed strategy included a reduction of free sugars in 100% fruit juices because they are important contributors to free sugar intake and should be targeted to meet the SACN's target of reducing free sugar to no more than 5% of daily energy intake.[13] However, we acknowledge the potentially limited scope for the reformulation of fruit juices because of technical difficulties. We therefore did a separate analysis in which we excluded fruit juices from the category of sugar-sweetened beverages.

Data sources and modelling

To assess the proposed strategy, we analysed the historical trend and current status of sugar-sweetened beverage consumption and weight status in the UK population. We then calculated the predicted reduction in energy intake if the proposed strategy is implemented, modelled its effect on bodyweight, and thereby estimated the reduction in the prevalence of overweight, obesity, and diabetes.

To study the historical trend in the consumption of sugar-sweetened beverages in the UK, we used the UK soft drink sales data from 2005 to 2013 from the British Soft Drinks Association (BSDA) annual reports,[18] which were obtained by Zenith International, a food and drink consultancy, from more than 100 soft drink producers. We assumed that the proportion of soft drinks that were sugar-sweetened beverages remained stable between 2005 and 2010 and was the same for 2011–13 (39%). We estimated the trend in consumption of sugar-sweetened beverages both with and without 100% fruit juices. Data for the historical trend in bodyweight status for adults were obtained from the Health Survey for England, which are survey series done annually in a random sample of the English population to monitor trends in population health status, and we assumed that this was a representative sample of the UK general population.[2]

To estimate current sugar-sweetened beverage consumption, we also used data for annual soft drink sales between 2008 and 2012 reported in the UK Soft Drinks Annual Report[18] in combination with the data from National Diet and Nutrition Survey rolling programme (NDNS RP) from 2008 to 2012. We obtained the NDNS data from the UK Data Service.[5] The NDNS RP was originally designed to quantitatively assess the dietary and nutritional status of the general population aged 1·5 years or older living in private households in the UK. Additionally, consumption of sugar-sweetened beverages was assessed by a 4 day diary; participants were asked to keep a record of everything they ate and drank during these 4 days. Individuals were also asked to provide demographic and health-related information and have height and weight measured by nurses. In total, 4156 individuals (48% children, 47% men) participated in the survey. The methods of the survey are detailed elsewhere.[19]

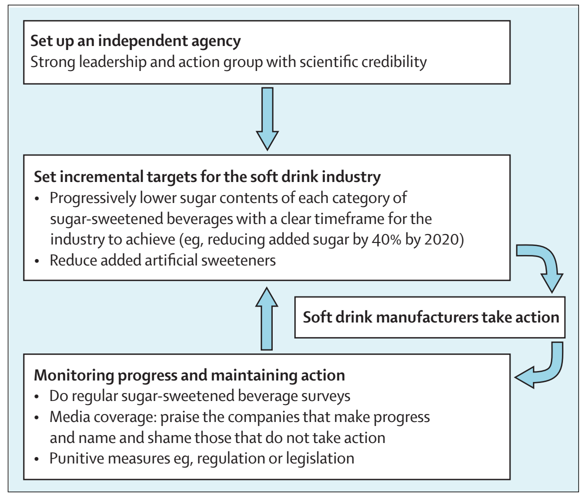

Figure 1: **Framework of the proposed strategy**

The average daily sugar-sweetened beverage consumption in the UK was estimated from sales data using the following formula:

$$\text{Average daily sugar-sweetened beverage consumption per person (mL/day)} = \frac{\text{Total sugar-sweetened beverage sales in the UK (mL/day)} \times \left(1 - \text{Percentage of sugar-sweetened beverage waste}\right)}{\text{Population size of the UK}}$$

In this formula, sugar-sweetened beverage waste (roughly 7% for general soft drink waste and 11% for fruit juices waste) was taken from the survey of Household Food and Drink Waste in the UK 2012,[20] wherein data for total soft drink waste was obtained from nationally representative UK households, including waste collected by local authorities, sewer waste, and home waste composted or fed to animals. Soft drink waste was quantified through waste compositional analysis, a 7 day diary of sewer-related waste, and a 7 day waste diary of multiple disposal routes. The average mid-year population size in the UK during the same period (ie, between 2008 and 2012) was 62·8 million.[21]

To study the population distribution of sugar-sweetened beverage consumption, we calculated sugar-sweetened beverage consumption for each individual participating in NDNS, taking into account dietary under-reporting. This calculation was based on two observations. First, there was a 30% discrepancy between the average sugar-sweetened beverage consumption estimated from BSDA sales data (272 mL per person per day) and that estimated from

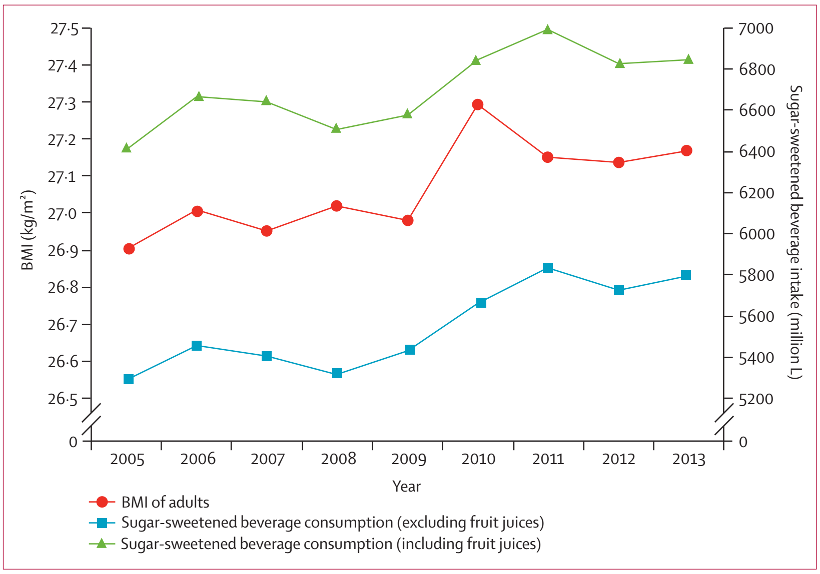

Figure 2: **Soft drink consumption and BMI of adults in the UK, 2005–13**
Data for BMI from Health Survey for England. Estimated sugar-sweetened beverage consumption data from British Soft Drinks Association annual reports

See Online for appendix

NDNS diary data (191 mL per person per day) after sugar-sweetened beverage waste was subtracted from sales data. This discrepancy increased to 41% when fruit juices were excluded from sugar-sweetened beverages in both data sources (227 mL per day from BSDA sales data and 133 mL per day from NDNS diary data). Second, the average self-reported total energy intake was 27% lower than total energy expenditure[19] derived from the gold standard method—ie, the double labelled water method[22]—in the NDNS RP, suggesting substantial under-reporting in dietary surveys.[23] A selectively higher under-reporting for sugar intake and unhealthy food intake was also reported.[24,25] We therefore assumed the discrepancy between the two figures was attributable to under-reporting—ie, 30% under-reporting in sugar-sweetened beverage consumption including fruit juices and 41% under-reporting when fruit juices were excluded. We addressed this issue by proportionally increasing self-reported sugar-sweetened beverage consumption (ie, divided by 70% when fruit juices were included and 59% when fruit juices were excluded), assuming that under-reporting occurred proportionally for all individuals. Equally, free sugars and energy intake from consumption of sugar-sweetened beverages were also proportionally multiplied. We described overall and subgroup sugar-sweetened beverage consumption by age and household income. The descriptive statistics were weighted for the population structure and non-response in NDNS where appropriate.

We calculated the predicted reduction in energy intake for each individual participating in the NDNS RP between 2008 and 2012, assuming that sugar-sweetened beverage consumption will remain stable in the period in which the proposed strategy is being implemented. To better understand the effect of the proposed strategy, we attempted to relate predicted energy reduction to change in steady-state bodyweight. However, this analysis was difficult because of the variation in resting metabolic rate and energy cost of physical activity in individuals, and their change with bodyweight. To overcome these complexities, we calculated the expected change in steady-state bodyweight for each adult at an individual level using the mathematical model proposed by Kevin Hall and colleagues,[26] which took into account the dynamic physiological adaptation to changes in bodyweight. The predicted change in bodyweight from this model closely matches the observed change (r=0·983) in their study.[26] We applied the model to each adult in NDNS RP between 2008 and 2012, on the basis of his or her predicted reduction in energy intake, age, sex, height, weight, and physical activity. A detailed description of the modelling procedure is provided in the appendix. On the basis of the predicted steady-state bodyweight and BMI of each adult in the NDNS RP, each adult was classified into the relevant weight status group (ie, obese, overweight, or normal and underweight), from which the predicted reduction in the number of overweight and obese adults was obtained and thereby the reduction in the prevalence of overweight and obesity was derived. These values were then scaled up to the whole UK adult population to obtain the number of overweight and obese cases that would be prevented nationwide.

To predict the number of obesity-related type 2 diabetes cases that would be prevented, we used the calculation from Wang and colleagues,[27] whereby a 1% reduction in BMI of the entire UK population would prevent 179 000–202 000 incident diabetes cases in two decades. This estimation was simulated by creating virtual UK individuals based on the projected BMI distribution, and the risk of developing type 2 diabetes was simulated as a function of age, sex, and, BMI.[27]

Statistical analysis

Means and 95% CI were reported where appropriate. We calculated 95% CIs using the bootstrapping method (resampling 1000 times) because it provides robust estimates even when data are skewed.[28] All the analyses, including the consumption level of sugar-sweetened beverages, the predicted reduction in energy intake, and the predicted reduction in bodyweight were done for the general population as a whole rather than for consumers of sugar-sweetened beverages only. For individuals who didn't consume sugar-sweetened beverages, the consumption level was zero, and the predicted reductions in energy intake and bodyweight were also zero. Data analyses were done with SAS version 9.4 and models for change in bodyweight were built with R version 3.2.2.

Sensitivity analysis

To test the robustness of the results with respect to the assumption that under-reporting occurred proportionally for all individuals, we simulated several

	Total number of individuals	Male	Sugar-sweetened beverages (including fruit juices)				Sugar-sweetened beverages (excluding fruit juices)			
			Consumers	Average consumption (g per day)	Free sugar intake from sugar-sweetened beverages (g per day)	Energy intake from sugar-sweetened beverages (kcal per day)	Consumers	Average consumption (g per day)	Free sugar intakes from sugar-sweetened beverages (g per day)	Energy intakes from sugar-sweetened beverages (kcal per day)
Age (years)										
1–5	634	334 (52·7%)	473 (74·6%)	213 (193–235)	18 (29·5%)	72 (4·1%)	319 (50·3%)	141 (119–161)	11 (15·1%)	42 (2·0%)
6–11	664	349 (52·6%)	576 (86·7%)	339 (312–366)	30 (31·9%)	118 (5·1%)	460 (69·3%)	241 (217–269)	21 (18·8%)	78 (2·8%)
12–18	775	383 (49·4%)	681 (87·9%)	502 (470–533)	47 (43·9%)	182 (7·1%)	608 (78·5%)	468 (430–503)	44 (34·4%)	166 (5·4%)
19–25	183	74 (40·4%)	153 (83·6%)	491 (413–584)	49 (44·5%)	185 (6·6%)	135 (73·8%)	490 (406–590)	49 (37·1%)	185 (5·5%)
26–35	319	138 (43·3%)	246 (77·1%)	343 (301–387)	30 (33·0%)	116 (4·2%)	190 (59·6%)	297 (251–342)	26 (23·9%)	97 (2·9%)
36–64	1153	498 (43·2%)	710 (61·6%)	195 (177–216)	17 (22·1%)	67 (2·6%)	487 (42·2%)	152 (133–172)	13 (14·1%)	50 (1·6%)
≥65	428	191 (44·6%)	231 (54·0%)	146 (125–169)	13 (17·6%)	52 (2·1%)	144 (33·6%)	93 (73–116)	8 (9·1%)	32 (1·1%)
Household income per year										
<£5000	140	54 (38·6%)	107 (76·4%)	344 (234–467)	32 (33·3%)	122 (4·9%)	90 (64·3%)	330 (213–469)	30 (26·1%)	115 (3·9%)
£5000–19 999	1223	534 (43·7%)	852 (69·7%)	245 (218–276)	23 (28·0%)	88 (3·6%)	670 (54·8%)	209 (180–242)	19 (19·4%)	74 (2·5%)
£20 000–49 999	1231	620 (50·4%)	933 (75·8%)	286 (261–312)	25 (29·4%)	96 (3·7%)	727 (59·1%)	248 (222–277)	21 (20·6%)	80 (2·6%)
≥£50 000	998	500 (50·1%)	770 (77·2%)	284 (256–317)	24 (28·6%)	96 (3·6%)	552 (55·3%)	213 (183–251)	18 (17·8%)	67 (2·1%)
Overall	4156	1967 (47·3%)	3070 (73·9%)	272 (258–287)	25 (29·8%)	96 (3·8%)	2343 (56·4%)	227 (211–243)	21 (20·8%)	78 (2·6%)

Data are n (%) or n (95% CI), unless otherwise specified. Descriptive statistics were for the general population as a whole rather than for sugar-sweetened beverage consumers alone.

Table 1: **Sugar-sweetened beverage consumption and its contribution to sugar and energy intake in the UK population**

	1st year (↓9·7%)	2nd year (↓18·5%)	3rd year (↓26·4%)	4th year (↓33·5%)	5th year (↓40·0%)
Age (years)					
1–5	–7·0 (–7·7 to –6·3)	–13·3 (–14·7 to –12·0)	–19·1 (–21·0 to –17·2)	–24·2 (–26·7 to –21·9)	–28·9 (–31·9 to –26·1)
6–11	–11·4 (–12·3 to –10·6)	–21·8 (–23·4 to –20·1)	–31·1 (–33·4 to –28·8)	–39·5 (–42·5 to –36·5)	–47·1 (–50·7 to –43·6)
12–18	–17·6 (–18·7 to –16·5)	–33·6 (–35·7 to –31·4)	–48·0 (–50·9 to –44·8)	–61·0 (–64·7 to –57·0)	–72·7 (–77·2 to –67·9)
19–25	–18·0 (–22·0 to –14·4)	–34·2 (–41·8 to –27·3)	–48·8 (–59·7 to –39·0)	–62·0 (–75·8 to –49·6)	–74·0 (–90·4 to –59·1)
26–35	–11·3 (–12·7 to –9·9)	–21·5 (–24·2 to –18·8)	–30·7 (–34·5 to –26·9)	–39·0 (–43·9 to –34·2)	–46·5 (–52·3 to –40·8)
36–64	–6·5 (–7·2 to –5·9)	–12·4 (–13·7 to –11·2)	–17·7 (–19·5 to –16·1)	–22·5 (–24·8 to –20·4)	–26·9 (–29·6 to –24·3)
≥65	–5·1 (–5·9 to –4·4)	–9·7 (–11·2 to –8·3)	–13·8 (–16·0 to –11·9)	–17·6 (–20·4 to –15·1)	–20·9 (–24·3 to –18·0)
Household income per year					
<£5000	–11·9 (–16·9 to –7·9)	–22·6 (–32·1 to –15·0)	–32·2 (–45·8 to –21·5)	–41·0 (–58·3 to –27·3)	–48·8 (–69·5 to –32·5)
£5000–19 999	–8·6 (–9·6 to –7·6)	–16·3 (–18·3 to –14·4)	–23·2 (–26·1 to –20·6)	–29·5 (–33·2 to –26·1)	–35·2 (–39·6 to –31·2)
£20 000–49 999	–9·4 (–10·2 to –8·6)	–17·8 (–19·4 to –16·3)	–25·4 (–27·7 to –23·3)	–32·3 (–35·2 to –29·6)	–38·5 (–42·0 to –35·3)
>£50 000	–9·4 (–10·5 to –8·4)	–17·8 (–20·0 to –16·0)	–25·5 (–28·6 to –22·8)	–32·3 (–36·3 to –29·0)	–38·6 (–43·3 to –34·6)
Overall	–9·3 (–9·9 to –8·8)	–17·8 (–18·8 to –16·8)	–25·4 (–26·9 to –24·0)	–32·2 (–34·2 to –30·5)	–38·4 (–40·7 to –36·3)

Data are n (95% CI) kcal per day.

Table 2: **Predicted reduction in energy intake from a 40% reduction in sugar contents of soft drinks over 5 years (including fruit juices)**

scenarios wherein the under-reporting of sugar-sweetened beverage consumption was higher in overweight or obese individuals and lower in normal weight or underweight individuals (with the total sugar-sweetened beverage consumption unchanged), which has been the case in most dietary surveys. We calculated the predicted reductions in bodyweight in these scenarios and compared them with the results of our main analysis.

Additionally, to test the robustness of the Kevin Hall model used in the main analysis, we calculated the predicted change in bodyweight arising from reduction in energy intake using two alternative methods. First, we used the commonplace, although widely disregarded, "3500 kcal=1 lb" rule—ie, a cumulative deficit of 3500 kcal would result in a reduction in bodyweight of 1 lb (ie, 0·45 kg), irrespective of the variation between individuals.[29] Second, we used the model proposed by

Christiansen and Garby,[30] which has been used elsewhere to assess weight change from energy reduction in UK settings.[31] The variables used in these two alternative models were consistent with the main analysis (appendix).

Role of the funding source

There was no funding source for this study.

Results

The estimated annual consumption of sugar-sweetened beverages in the UK has increased by at least 400 million litres during the past decade and has remained steadily high during 2010–13 (figure 2). In parallel with the increase in consumption of sugar-sweetened beverages, there has been a gradual rise in the average BMI of adults from 26·9 kg/m² in 2005 to 27·2 kg/m² in 2013, and an increase in the prevalence of overweight and obesity from 60·5% to 62·1% in adults.

The average consumption of sugar-sweetened beverages in the UK in 2008–12 was 272 g per person per day. 1654 (83·5%) of 1982 children and 1416 (65·1%) of 2174 adults consumed sugar-sweetened beverages on a daily basis. The proportions of sugar-sweetened beverage consumers were particularly high in 576 (87%) of 664 children aged 6–11 years, 681 (88%) of 775 adolescents aged 12–18 years, and 153 (84%) of 183 young adults aged 19–25 years. Daily sugar-sweetened beverage consumption contributed to 47 g (43·9%) and 49 g (44·5%) of total free sugar intake, and 182 kcal (7·1%) of the daily energy intake in adolescents and 185 kcal (6·6%) of the daily intake in young adults, both exceeding the UK SACN's recommendation of a daily free sugar intake of no more than 5% of daily energy intake. Moreover, sugar-sweetened beverage consumption was highest in low-income households (<£5000 per year), with an average of 344 g per person per day, contributing to 32 g (33·3%) of daily free sugar intake and 122 kcal (4·9%) of daily energy intake. Average consumption of sugar-sweetened beverages excluding fruit juices was 227 g per person per day in the overall population, with about 70% of young people aged 6–25 years being consumers. The distribution of the consumption level in different age groups and household income groups was similar to the distribution when fruit juices were included (table 1).

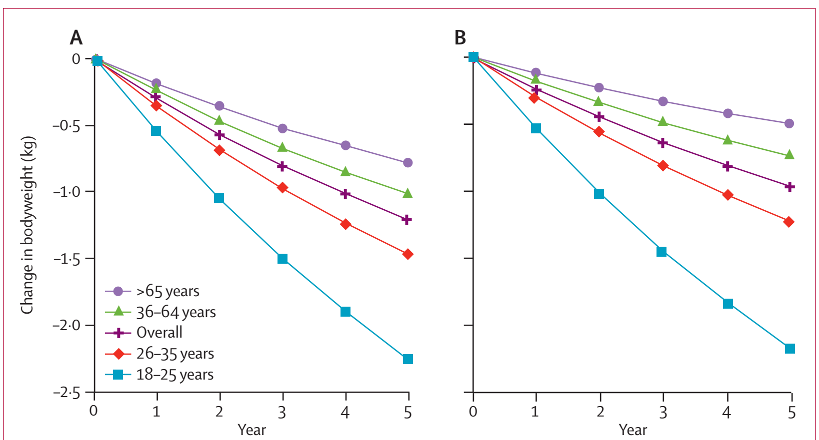

Figure 3: **Predicted change in steady-state bodyweight in UK adults by age group if the proposed strategy is implemented over 5 years, with fruit juices included (A) or excluded (B)**

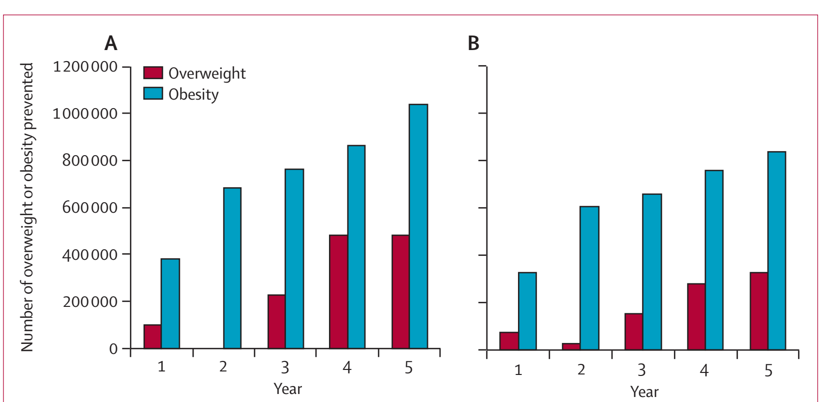

Figure 4: **Predicted reduction in the number of overweight and obese adults in the UK if the proposed strategy is implemented over 5 years, with fruit juices included (A) or excluded (B)**

The proposed strategy is predicted to reduce the average energy intake by 38·4 kcal per day (95% CI 36·3–40·7) by the end of the fifth year since the start of the sugar reduction programme. For adolescents aged 12–18 years and young adults aged 19–25 years, energy intake would be reduced by 72·7 kcal and 74·0 kcal per day in the fifth year, respectively. There would also be a greater reduction of 48·8 kcal per day by the end of the fifth year in individuals from low-income households (table 2).

The predicted reduction in energy intake would lead to a gradual reduction in bodyweight in the long term. The average reduction in steady-state bodyweight is predicted to be 1·20 kg (95% CI 1·12–1·28; figure 3), resulting in a reduction in the prevalence in adults of overweight by 1·0 percentage point (from 35·5 % to 34·5%) and obese by 2·1 percentage points (from 27·8% to 25·7%). This reduction would amount to roughly 0·5 million cases of overweight and 1·0 million cases of obesity being reduced in the UK (figures 3, 4).

The BMI of UK adults is predicted to be reduced from 27·48 kg/m² in 2010 to 27·06 kg/m² when the predicted reduction in bodyweight is achieved, representing a 1·5% reduction. This reduction would in turn prevent about 274 000–309 000 incident cases of type 2 diabetes over the subsequent two decades (ie, roughly 15 000 per year).

In the separate analysis in which we excluded fruit juices, the average predicted reduction in energy intake would be 31·0 kcal per day (95% CI 28·6–33·7; table 3), which would lead to a 0·96 kg (0·88–1·04) reduction in steady-state bodyweight (figure 3). This reduction would result in a 0·7 percentage point (0·3 million) reduction in overweight and a 1·7 percentage point (0·8 million) reduction in obesity in the UK adult population (figure 4).

	1st year (↓9·7%)	2nd year (↓18·5%)	3rd year (↓26·4%)	4th year (↓33·5%)	5th year (↓40·0%)
Age (years)					
1–5	–4·1 (–4·8 to –3·4)	–7·8 (–9·1 to –6·5)	–11·1 (–13·0 to –9·2)	–14·1 (–16·5 to –11·7)	–16·8 (–19·7 to –14·0)
6–11	–7·6 (–8·4 to –6·8)	–14·4 (–16·0 to –13·0)	–20·6 (–22·9 to –18·5)	–26·2 (–29·1 to –23·6)	–31·2 (–34·6 to –28·1)
12–18	–16·2 (–17·4 to –14·8)	–30·7 (–33·1 to –28·3)	–43·9 (–47·3 to –40·4)	–55·8 (–60·1 to –51·3)	–66·6 (–71·7 to –61·2)
19–25	–18·0 (–22·6 to –14·1)	–34·3 (–43·1 to –26·8)	–48·9 (–61·5 to –38·3)	–62·2 (–78·2 to –48·7)	–74·2 (–93·2 to –58·1)
26–35	–9·4 (–10·8 to –8·0)	–17·9 (–20·6 to –15·2)	–25·5 (–29·4 to –21·8)	–32·5 (–37·4 to –27·7)	–38·7 (–44·5 to –33·0)
36–64	–4·8 (–5·5 to –4·3)	–9·2 (–10·5 to –8·1)	–13·1 (–15·0 to –11·6)	–16·7 (–19·0 to –14·7)	–19·9 (–22·7 to –17·5)
≥65	–3·1 (–3·7 to –2·5)	–5·8 (–7·1 to –4·7)	–8·3 (–10·2 to –6·7)	–10·6 (–12·9 to –8·5)	–12·6 (–15·4 to –10·1)
Household income per year					
<£5000	–11·2 (–17·1 to –6·8)	–21·3 (–32·5 to –13·0)	–30·4 (–46·5 to –18·6)	–38·7 (–59·1 to –23·6)	–46·1 (–70·4 to –28·2)
£5000–19 999	–7·1 (–8·3 to –6·1)	–13·6 (–15·7 to –11·6)	–19·4 (–22·5 to –16·6)	–24·7 (–28·6 to –21·1)	–29·4 (–34·1 to –25·2)
£20 000–49 999	–7·8 (–8·6 to –7·0)	–14·9 (–16·4 to –13·3)	–21·2 (–23·4 to –19·1)	–27·0 (–29·8 to –24·2)	–32·1 (–35·5 to –28·9)
>£50 000	–6·5 (–7·8 to –5·5)	–12·4 (–14·8 to –10·5)	–17·8 (–21·2 to –15·0)	–22·6 (–26·9 to –19·0)	–26·9 (–32·1 to –22·7)
Overall	–7·5 (–8·2 to –6·9)	–14·3 (–15·5 to –13·2)	–20·5 (–22·2 to –18·9)	–26·0 (–28·2 to –24·0)	–31·0 (–33·7 to –28·6)

Data are n (95% CI) kcal per day.

Table 3: **Predicted reduction in energy intake (kcal per day, 95% CI) from a 40% reduction in sugar added to soft drinks over 5 years (excluding fruit juices)**

The predicted reduction in average BMI (from 27·48 to 27·14 kg/m²) in the analysis excluding fruit juices is estimated to prevent around 221 000–250 000 diabetes cases over two decades after the predicted reduction in bodyweight is achieved. In our sensitivity analyses, with the increase in the proportion of under-reporting of sugar-sweetened beverage consumption by overweight and obese individuals and the decrease in the proportion of under-reporting by normal weight and underweight individuals, the reduction in the average bodyweight of all adults was larger than in the main analysis (appendix).

If the "3500 kcal=1 lb" is used, the average cumulative reduction in energy intake would be around 14 016 kcal (95% CI 13 250–14 856) over 5 years since the start of the sugar reduction programme, considering that the average reduction in energy intake was 38·4 kcal per day (95% CI 36·3–40·7) at the end of the fifth year. This energy reduction would lead to an average reduction in bodyweight of about 1·80 kg (95% CI 1·70–1·91). Alternatively, if the model proposed by Christiansen and Garby[30] was used to predict the change in steady-state bodyweight, the average reduction would be 1·55 kg (1·44–1·65) if the proposed strategy was implemented for 5 years since the start of the sugar reduction programme, representing a 1·3 percentage point reduction in the prevalence of overweight and 2·4 percentage point reduction in the prevalence of obesity. The predicted reduction in bodyweight from both models was greater than that from our main analysis, suggesting that our main results might be conservative estimates of the effect of the proposed strategy.

Discussion

Although tackling obesity has been listed as a priority by WHO,[32] very few public health strategies that reduce obesity at a national or worldwide level exist. Several factors are implicated in obesity. However, increased energy intake from energy-dense foods and drinks, largely because of changes in food environment, is the key contributor to the worldwide rise in obesity.[33] Without changing the food environment, effective behavioural interventions targeted at individuals have been shown not to be sustainable in the long term.[33]

The proposed strategy in our study is an important and practical approach to lead the way in changing the food environment to curb or reverse the obesity epidemic. Our findings show that a stepwise, gradual, unobtrusive reduction in free sugars added to sugar-sweetened beverages would potentially lead to an effective and sustainable reduction in energy intake, resulting in a substantial reduction in bodyweight and obesity in the long term. This reduction will in turn reduce the obesity-related disease burden, including diabetes, and also lead to cost savings for health-care systems.

On the basis of the UK's salt reduction programme, which led to a reduction in the salt content of many food products by 40% over 5 years,[11] we proposed a similar gradual and stepwise reduction in sugar contents in sugar-sweetened beverages. The proposed strategy has several advantages, as shown by the success of the UK national salt reduction programme.[11] First, human sugar taste preference adapts to a small and gradual reduction in sugar and it is unlikely that the proposed strategy will affect consumers' choices provided that the reduction is done gradually over 5 years. Sugar taste preference has been shown to be adjustable in a couple of weeks by cutting out all added sugars and artificial sweeteners.[34] Second, a reduction in energy intake from sugar-sweetened beverages is unlikely to increase energy intake from other pathways;[35] this is also supported by the fact that reducing salt in processed food did not increase the use of table salt.[36] Third, a reduction of sugar added to sugar-sweetened beverages will have little effect on the cost and price of the product and therefore is unlikely to affect sales and profits for the soft drink industry, meaning it could be seen as an attractive prospect politically. However, some industry players, such as the sugar industry itself, might be resistant.[37] Most major UK supermarkets have already agreed to gradually reduce the amount of sugar in their own brands added to soft drinks. British Retail Consortium, which represents the British supermarkets, has called for mandatory targets to be set.[38–40] This would ensure—as happened with salt reduction—that branded companies are forced to follow their example. Finally, compared with behaviour change at an individual level, the proposed strategy would change the environmental determinants of obesity and will benefit all consumers of sugar-sweetened soft drinks, particularly those who consume more—ie, children, adolescents, young adults, and individuals from low-income households (who are more likely to become obese and develop type 2 diabetes).

To ensure that the proposed strategy works in a sustainable and practical way, several key components are necessary. First and most importantly, clear targets, both average and maximum targets for each category of soft drinks, should be set to provide a level playing field for soft drink manufacturers. A survey done by Action on Sugar shows that the amount of free sugars added to carbonated sugar-sweetened beverages varies hugely, from 3 g to 53 g per 330 mL (regular serving size).[41] For example, free sugar contents in sugar-sweetened cola drinks, the most popular flavour soft drink in the UK, ranged from 19 g to 37 g per 330 mL, suggesting that the scope for reduction of the free sugar content is substantial. Second, an independent agency with strong leadership should be set up to ensure that manufacturers comply with the targets, with punitive measures for companies that do not take action. Third, the successful implementation of the proposed strategy will depend on close collaboration and active engagement between the soft drink industry, government, non-governmental organisations, and health professionals.

With the lower free sugar targets set by WHO[15] and SACN[13] in 2015, the role of sugar-sweetened beverage consumption in contributing to obesity has received much attention. Heated debates have occurred about possible strategies to reduce free sugar intake from sugar-sweetened beverages, with the substitution of sugar with non-caloric sweeteners and the levying of a tax on sugar-sweetened beverages among the most practical suggestions discussed.

Substitution of sugary sweeteners with non-caloric sweeteners might be perceived as more practical than our proposed strategy. However, the existing evidence for the effectiveness of such substitution to tackle obesity is insufficient. First, the effect on bodyweight of replacing sugar-sweetened beverages with drinks containing artificial sweeteners is controversial.[42] Second, although several artificial sweeteners have been assessed as safe if consumed below the acceptable daily intake,[43] evidence from some experimental studies[44] and epidemiological studies[45,46] suggests the opposite. More problematically, non-caloric sweeteners might change the reward processing of sweet taste[47] and might cause a taste preference for very sweet foods, which is usually high in calories and would therefore lead to a poor quality, energy-dense diet.[46] Our proposed strategy will lead to a gradual reduction in the density of sweetness of soft drinks through reduction of free sugar content and non-caloric sweeteners, which is important for creating a supportive environment to help people to become less habituated to sweet tastes and choose foods with less sugar.

Another promising public health strategy is levying tax or introducing sugar duty on sugar-sweetened beverages, which has been implemented in several countries including Finland, France, Hungary, several states of the USA, and Mexico.[48] An increase in sugar-sweetened beverage price by 10% has been estimated to lead to a reduction of about 13% in demand for sugar-sweetened beverages.[49] For this reason, soft drink manufacturers might be more resistant to the tax policy compared with our proposed strategy. However, our proposed strategy is compatible with the tax strategy and the effect on calorie intake could be even greater if both policies are implemented together.

Our study has several strengths. First, it is the first study to have proposed and assessed a stepwise and sustainable reduction in free sugars added to sugar-sweetened beverages, which could potentially lead to a substantial reduction in the prevalence of overweight, obesity, and type 2 diabetes. The approach has a great chance of success, since a similar strategy has been proven effective with salt. Second, we used representative national survey data at population and individual levels, enabling us to produce nationally representative results that can inform national public health policies. Third, to estimate sugar-sweetened beverage consumption more accurately, sales data and diary data were combined to address the highly prevalent issue of diet misreporting, which has rarely been considered in similar studies.[31,50] Finally, we did several separate analyses to test the robustness of our assumptions and modelling, the results of which suggested that our main findings are conservative.

Our study also has several potential limitations. First, our main analysis was based on the assumption that under-reporting occurs proportionally in all individuals, whereas under-reporting is higher in adults and in overweight and obese individuals, and under-reporting tends to be selectively higher for intake of sugars and other unhealthy foods.[23–25] Although we have tried to correct for the issue of under-reporting, our results are still likely to have underestimated the potential effect of the proposed policy. Second, we used data from several sources and built models based on previous studies, making the quality of our study dependent on the quality of the data and model used. However, the data we used were from nationally representative samples of the UK population and the models were also validated[26] and used in other similar studies.[50] Finally, we only predicted weight change for adults because the model for bodyweight is for energy-balanced individuals and is not suitable for children, who usually have a positive energy intake.

In conclusion, the results of our study show that the proposed strategy could lead to a profound reduction in energy intake from sugar-sweetened beverages and could therefore lower the prevalence of overweight, obesity, and type 2 diabetes in the long term. These findings provide strong support for the implementation of the proposed strategy. Individuals should also reduce their consumption of sugar-sweetened beverages in the long term, but this can be difficult because of the advertising power of industry. Our proposed strategy provides an innovative and practical way to gradually reduce energy intake from sugar-sweetened beverages and its combination with other strategies, including a tax on sugar-sweetened beverages, would produce a more powerful effect.

Contributors

GAM, FJH, and YM designed the study. YM and YY developed the analysis plan and did the statistical analyses. YM wrote the report. FJH, GAM, and KMH critically reviewed the report. All authors checked and approved the final report.

Declaration of interests

We declare no competing interests.

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References

1 Ng M, Fleming T, Robinson M, et al. Global, regional, and national prevalence of overweight and obesity in children and adults during 1980–2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet* 2014; **384:** 766–81.

2 Health and Social Care Information Centre. Health Survey for England–2013, trend tables 2014. http://www.hscic.gov.uk/catalogue/PUB16077 (accessed Aug 14, 2015).

3 Lasater G, Piernas C, Popkin BM. Beverage patterns and trends among school-aged children in the US, 1989–2008. *Nutr J* 2011; **10:** 103.

4 Basu S, McKee M, Galea G, Stuckler D. Relationship of soft drink consumption to global overweight, obesity, and diabetes: a cross-national analysis of 75 countries. *Am J Public Health* 2013; **103:** 2071–77.

5 NatCen Social Research, MRC Human Nutrition Research and University College London. Medical School, National Diet and Nutrition Survey years 1–4, 2008/09–2011/12. http://dx.doi.org/10.5255/UKDA-SN-6533-6 (accessed April 5, 2015).

6 Pan A, Hu FB. Effects of carbohydrates on satiety: differences between liquid and solid food. *Curr Opin Clin Nutr Metab Care* 2011; **14:** 385–90.

7 Pan A, Malik VS, Hao T, Willett WC, Mozaffarian D, Hu FB. Changes in water and beverage intake and long-term weight changes: results from three prospective cohort studies. *Int J Obes (Lond)* 2013; **37:** 1378–85.

8 Chen L, Appel LJ, Loria C, et al. Reduction in consumption of sugar-sweetened beverages is associated with weight loss: the PREMIER trial. *Am J Clin Nutr* 2009; **89:** 1299–306.

9 Greenwood DC, Threapleton DE, Evans CE, et al. Association between sugar-sweetened and artificially sweetened soft drinks and type 2 diabetes: systematic review and dose-response meta-analysis of prospective studies. *Br J Nutr* 2014; **112:** 725–34.

10 Singh GM, Micha R, Khatibzadeh S, et al. Estimated global, regional, and national disease burdens related to sugar-sweetened beverage consumption in 2010. *Circulation* 2015; **132:** 639–66.

11 He FJ, Brinsden HC, MacGregor GA. Salt reduction in the United Kingdom: a successful experiment in public health. *J Hum Hypertens* 2014; **28:** 345–52.

12 He FJ, Pombo-Rodrigues S, Macgregor GA. Salt reduction in England from 2003 to 2011: its relationship to blood pressure, stroke and ischaemic heart disease mortality. *BMJ Open* 2014; **4:** e004549.

13 Scientific Advisory Committee on Nutrition. Carbohydrates and health 2015. London: Stationery Office, 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/445503/SACN_Carbohydrates_and_Health.pdf (accessed July 20, 2015).

14 Action on Sugar. Childhood obesity action plan. London: Action on Sugar, 2015. http://www.actiononsalt.org.uk/actiononsugar/Press%20Release%20/133979.pdf (accessed Sept 5, 2015).

15 WHO. Guideline: sugars intake for adults and children. Geneva: World Health Organization, 2015. http://apps.who.int/iris/bitstream/10665/149782/1/9789241549028_eng.pdf (accessed Aug 5, 2015).

16 Public Health England. Why 5%? An explanation of the Scientific Advisory Committee on Nutrition's recommendations about sugars and health, in the context of current intakes of free sugars, other dietary recommendations and the changes in dietary habits needed to reduce consumption of free sugars to 5% of dietary energy. London: Public Health England, 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/446010/Why_5__-_The_Science_Behind_SACN.pdf (accessed Sept 1, 2015).

17 NICE NCC-PC. Obesity: the prevention, identification, assessment and management of overweight and obesity in adults and children. London: National Institute for Health and Clinical Excellence, 2006.

18 British Soft Drinks Association. Annual soft drinks reports. http://www.britishsoftdrinks.com/-publications- (accessed May 1, 2015).

19 Public Health England, Food Standards Agency. National Diet and Nutrition Survey: results from years 1 to 4 (combined) of the rolling programme for 2008 and 2009 to 2011 and 2012. London: Public Health England, 2014. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/310995/NDNS_Y1_to_4_UK_report.pdf (accessed March 25, 2015).

20 WRAP. Methods used for household food and drink waste in the UK 2012. Oxon: Waste & Resources Action Programme, 2013. http://www.wrap.org.uk/sites/files/wrap/Methods%20Annex%20Report%20v2.pdf (accessed June 20, 2015).

21 Office for National Statistics. Overview of the UK population. Office for National Statistics, 2015. http://www.ons.gov.uk/ons/rel/pop-estimate/population-estimates-for-uk--england-and-wales--scotland-and-northern-ireland/mid-2014/sty---overview-of-the-uk-population.html (accessed July 28, 2015).

22 Schoeller DA. Recent advances from application of doubly labeled water to measurement of human energy expenditure. *J Nutr* 1999; **129:** 1765–68.

23 Archer E, Hand GA, Blair SN. Validity of US nutritional surveillance: National Health and Nutrition Examination Survey caloric energy intake data, 1971–2010. *PLoS One* 2013; **8:** e76632.

24 Scagliusi FB, Polacow VO, Artioli GG, Benatti FB, Lancha AH Jr. Selective underreporting of energy intake in women: magnitude, determinants, and effect of training. *J Am Diet Assoc* 2003; **103:** 1306–13.

25 Heitmann BL, Lissner L. Dietary underreporting by obese individuals—is it specific or non-specific? *BMJ* 1995; **311:** 986–89.

26 Hall KD, Jordan PN. Modeling weight-loss maintenance to help prevent body weight regain. *Am J Clin Nutr* 2008; **88:** 1495–503.

27 Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. *Lancet* 2011; **378:** 815–25.

28 Bland JM, Altman DG. Statistics notes: bootstrap resampling methods. *BMJ* 2015; **350:** h2622.

29 Hall KD. What is the required energy deficit per unit weight loss? *Int J Obes (Lond)* 2008; **32:** 573–76.

30 Christiansen E, Garby L. Prediction of body weight changes caused by changes in energy balance. *Eur J Clin Invest* 2002; **32**: 826–30.

31 Briggs AD, Mytton OT, Kehlbacher A, Tiffin R, Rayner M, Scarborough P. Overall and income specific effect on prevalence of overweight and obesity of 20% sugar sweetened drink tax in UK: econometric and comparative risk assessment modelling study. *BMJ* 2013; **347:** f6189.

32 WHO. Global action plan for the prevention and control of noncommunicable diseases 2013–2020. Geneva: World Health Organization, 2013. http://apps.who.int/iris/bitstream/10665/94384/1/9789241506236_eng.pdf (accessed May 5, 2015).

33 Hill JO. Can a small-changes approach help address the obesity epidemic? A report of the Joint Task Force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council. *Am J Clin Nutr* 2009; **89:** 477–84.

34 Bartolotto C. Does consuming sugar and artificial sweeteners change taste preferences? *Perm J* 2015; **19:** 81–84.

35 Finkelstein EA, Zhen C, Bilger M, Nonnemaker J, Farooqui AM, Todd JE. Implications of a sugar-sweetened beverage (SSB) tax when substitutions to non-beverage items are considered. *J Health Econ* 2013; **32:** 219–39.

36 Sutherland J, Edwards P, Shankar B, Dangour AD. Fewer adults add salt at the table after initiation of a national salt campaign in the UK: a repeated cross-sectional analysis. *Br J Nutr* 2013; **110:** 552–58.

37 Owens B. Storm brewing over WHO sugar proposal. Industry backlash expected over suggested cut in intake. *Nature* 2014; **507:** 150.

38 Tesco sets out sugary drinks reformulation plan. http://www.sustainweb.org/news/may15_tesco_sugar/ (accessed Aug 15, 2015).

39 House of Commons. Health Committee oral evidence: childhood obesity strategy, HC 465 Tuesday 13 October. 2015. http://data.parliament.uk/writtenevidence/committeeevidence.svc/evidencedocument/health-committee/childhood-obesity-strategy/oral/23058.pdf (accessed Dec 17, 2015).

40 Laura Donnelly. MPs back sugar tax and ban on junk food ads during X-factor. http://www.telegraph.co.uk/news/health/news/12021871/MPs-back-sugar-tax-and-ban-on-junkfood-ads-during-X-factor.html (accessed Dec 17, 2015)

41 Action on Sugar. Soft drinks survey 2014—all data. http://www.actiononsalt.org.uk/actiononsugar/Press%20Release%20/133642.pdf (accessed Dec 17, 2015).

42 Roberts JR. The paradox of artificial sweeteners in managing obesity. *Curr Gastroenterol Rep* 2015; **17:** 423.

43 European Food Safety Authority. Sweeteners. http://www.efsa.europa.eu/en/topics/topic/sweeteners (accessed Sept 4, 2015).

44 Suez J, Korem T, Zeevi D, et al. Artificial sweeteners induce glucose intolerance by altering the gut microbiota. *Nature* 2014; **514:** 181–86.

45 Gardner C, Wylie-Rosett J, Gidding SS, et al. Nonnutritive sweeteners: current use and health perspectives: a scientific statement from the American Heart Association and the American Diabetes Association. *Diabetes Care* 2012; **35:** 1798–808.

46 Swithers SE. Artificial sweeteners are not the answer to childhood obesity. *Appetite* 2015; **93:** 85–90.

47 Green E, Murphy C. Altered processing of sweet taste in the brain of diet soda drinkers. *Physiol Behav* 2012; **107:** 560–67.

48 Cornelsen L, Carreido A. Health-related taxes on food and beverages. Food Research Collaboration, 2015. http://foodresearch.org.uk/wp-content/uploads/2015/06/Food-and-beverages-taxes-final-amended.pdf (accessed Aug 29, 2015).

49 Cabrera Escobar MA, Veerman JL, Tollman SM, Bertram MY, Hofman KJ. Evidence that a tax on sugar sweetened beverages reduces the obesity rate: a meta-analysis. *BMC Public Health* 2013; **13:** 1072.

50 Lin BH, Smith TA, Lee JY, Hall KD. Measuring weight outcomes for obesity intervention strategies: the case of a sugar-sweetened beverage tax. *Econ Hum Biol* 2011; **9:** 329–41.