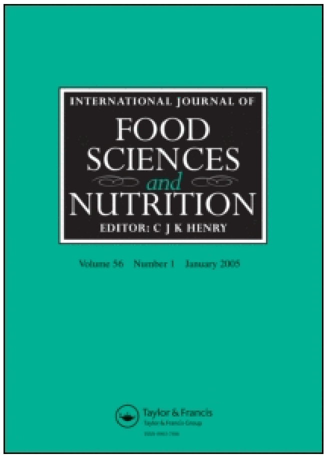
INTERNATIONAL JOURNAL OF
FOOD
SCIENCES
and
NUTRITION
EDITOR: C J K HENRY
Volume 56 Number 1 January 2005
Taylor & Francis

International Journal of Food Sciences and Nutrition,
September 2007; 58(6): 445–460

Sugar intake, soft drink consumption and body weight among British children: Further analysis of National Diet and Nutrition Survey data with adjustment for under-reporting and physical activity

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Abstract

We investigated associations between body mass index (BMI) and intake of non-milk extrinsic sugars (NMES) and caloric soft drinks using weighed 7-day food records, nutrient intakes, BMI measurements and 7-day physical activity (PA) diaries from the UK National Dietary and Nutritional Survey of Young People ($n = 1{,}294$ aged 7–18 years). NMES and caloric soft drinks (excluding 100% fruit juice) were quantified by their contribution to energy intake. BMI z-scores were calculated from UK reference curves and International Obesity Task Force (IOTF) cut-off values were used to define overweight.

The BMI z-score was weakly inversely correlated with percentage energy from NMES after adjustment for under-reporting and dieting ($r = -0.06$, $P = 0.03$). The percentage of energy from soft drinks was not associated with the BMI z-score or PA. After excluding under-reporters and dieters, the heaviest children (top quintile: Q5 of BMI z-scores) consumed more total energy (+1,220 kJ/day) than those in the lowest quintile (Q1), but only 60 kJ (5%) was from soft drinks.

In logistic regression (adjusted for age and gender, under-reporting, and dieting), overweight was positively associated with energy intake (MJ) (odds ratio [OR] = 1.58, confidence interval [CI] = 1.42–1.77) and sedentary activity (h) (OR = 1.11, CI = 1.01–1.23), and inversely associated with moderate/vigorous activity (h) (OR = 0.71, CI = 0.58–0.86). In the macronutrient model, high fat and protein intake (top tertile vs lowest tertile, g/day) were positively associated with overweight (OR > 2.5, $P < 0.001$) while starch had less impact (OR = 1.60, CI = 1.0–2.55, $P < 0.05$). Top tertile intakes of caloric soft drinks were weakly associated with overweight (OR = 1.39, CI = 0.96–2.0, P=0.08), while other sources of NMES showed no association (OR = 0.81, CI = 0.52–1.27, $P = 0.4$). Risk associated with caloric soft drinks appeared non-linear with an increase in odds only for very high consumers (top quintile, mean 870 kJ/day; OR = 1.67, CI = 1.04–2.66, $P = 0.03$). These data are not consistent with any specific role for NMES or caloric soft drinks in obesity among British children and adolescents, but point instead to a general role of overeating and physical inactivity. Evidence of successful interventions is urgently needed but these must use reliable measurements of exposure (diet and PA) and outcome (BMI z-score, body fat, waist circumference) and have a sufficient timescale.

Keywords: *Children, diet, overweight, sugar, soft drinks, activity*

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ISSN 0963-7486 print/ISSN 1465-3478 online
DOI: 10.1080/09637480701288363

Introduction

Childhood obesity is considered to have adverse implications for health because the body mass index (BMI) may track into adolescence and beyond, with attendant risks of higher mortality and morbidity (Freedman et al. 2001; Reilly et al. 2003; Reilly 2006). Obesity also has detrimental consequences for psychological well-being, especially if it persists into adulthood (Parsons et al. 1999; Viner and Cole 2005).

Definitive conclusions about the relative contributions of energy intake and expenditure to increasing body weight are far from clear (Jeffery and Utter 2003) but it is likely that both physical inactivity and modern eating patterns act synergistically (Prentice and Jebb 2004). In the bio-medical literature more attention has been given to the intake side of the energy balance equation, especially the role of energy-dense foods and drinks in encouraging 'passive over-consumption'. In regard to drinks it has been suggested that energy in liquid form may fail to induce adequate satiety (DiMeglio and Mattes 2000; St-Onge et al. 2004), although evidence to support the hypothesis that liquids and solids have different effects on caloric compensation is conflicting (Almiron-Roig et al. 2003; Bachman et al. 2006).

Circumstantial evidence implicating caloric soft drinks has been found in their temporal association with the rise in obesity (Bray et al. 2004). In the USA, soft drink consumption increased by approximately 135% between 1977 and 2001 (Nielsen and Popkin 2004) and now averages around 8% of energy among children and adolescents. In the United Kingdom soft drink consumption has risen by 30% in the past 10 years, but about one-half of the increase comprises diet (sugar-free) versions (DEFRA 2005). Consumption of all soft drinks (carbonates, dilutables and fruit drinks) among 4–18 year olds accounts for around 5% of energy intake (Gregory and Lowe 2000). However, in the United Kingdom a major role for sugary food or drinks is hard to reconcile with the long-term downward trend in total energy intakes and static consumption of non-milk extrinsic sugars (NMES) as a proportion of energy (DEFRA 2005).

Three recent reviews have assessed the scientific literature on consumption of calorically sweetened soft drinks in relation to obesity (Bachman et al. 2006; Malik et al. 2006; Pereira 2006). Malik et al. (2006) concluded that the evidence was strong but research was needed 'to provide more convergence in the data' and to elucidate mechanisms. Bachman et al. (2006) concluded that evidence was strongest for the excess calories hypothesis, but was not conclusive because many studies either failed to control for physical activity or used exposure measures with limited reliability and validity. Pereira (2006) has described the evidence implicating sugar-sweetened drinks in the aetiology of obesity as 'equivocal', and criticized the unsatisfactory methodology of many experimental and prospective studies.

We found 14 cross-sectional studies among children and adolescents, one of which (Janssen et al. 2005) was not included in Malik et al.'s review. Of these, five reported significant positive associations, three showed non-significant positive associations and the remaining six showed either no association or mixed positive and negative associations (Table I). In the largest of these, overweight among more than 130,000 school-aged children from 34 European countries was associated with television viewing and lower physical activity levels, but not with intake of fruit or vegetables, or soft drinks (Janssen et al. 2005). Of the seven cohort studies in children and adolescents, four found significant positive associations between caloric soft drinks and body weight, including two large American studies ($n > 10{,}000$). Intake of

Table I. Studies of associations between soft drinks and BMI/overweight among children and adolescents

Study	Association with caloric soft drinks (SSD) and sugar: Positive association (significant)	Positive but not significant	No association	Negative association
Cross-sectional				
Andersen et al. (2005)			SSD	
Ariza et al. (2004)	SSD			
Bandini et al. (1999)			Soda (energy)	
Berkey et al. (2004)	SSD			
Forshee and Storey (2003)		Soda (non-diet)		
Forshee et al. (2004)		Soda (non-diet)		
Giammattei et al. (2003)		SSD		
Gibson (1998)			SSD	
Gillis and Bar-Or (2003)	SSD			
Janssen et al. (2005)			SSD	
Nicklas et al. (2003)	SSD			
Overby et al. (2004)		Added sugar (boys only)		Added sugar (girls only)
Rodriguez-Artalejo et al. (2003)			SSD	
Troiano et al. (2000)	SSD (P values not given)			
Prospective cohort				
Berkey et al. (2004)	SSD (boys only)			
Blum et al. (2005)			SSD	
Kvaavik et al. (2005)			SSD	
Ludwig et al. (2001)	SSD			
Newby et al. (2004)			SSD	
Phillips et al. (2004)	SSD			
Welsh et al. (2005)	SSD			
Interventions				
James et al. 2004)	Soda (all)			
Ebbeling et al. 2006)	SSD			

Note: SSD, sugar-sweetened soft drinks; soda, carbonated soft drinks.

sugar-added beverages over 2 years was associated with increased (self-reported) BMI among 9–14 year olds, although this was statistically significant only among boys (Berkey et al. 2004). The estimated effects were small: a boy consuming three servings/day over 10 years was predicted to gain 0.9 BMI units more than if he consumed none. In the other large study, by Welsh et al. (2005) among pre-school children, consumption of one or more sugar-containing drinks (versus none) was associated with increased risk of being overweight 1 year later. However, this was only statistically significant among children heavier at baseline (BMI $>$85th percentile) and the risk did not appear to rise further with more than one serving (Welsh et al. 2005). Of the smaller studies, a tracking study by Phillips et al. (2004) found that girls with above-average proportion of energy from soda had a higher BMI z-score than those with low intakes but did not have a higher percentage body fat. Lastly, the prospective study by Ludwig et al. (2001) has been particularly influential in driving public policy (WHO/FAO 2003; Department of Health 2004). Among 548 children in the Planet Health project they reported an association between weight gain and both baseline consumption and change in consumption of sugar-containing drinks, estimating that a single serving was associated with a gain in BMI of 0.2 kg/m^2 over 19 months and a 60% increase in odds of obesity (Ludwig et al. 2001). In contrast to these four positive studies, the remaining three showed no association between overweight and consumption of sugar-sweetened soft drinks.

Randomized control trials represent the strongest form of evidence, but there have only been two studies of this design conducted among children and adolescents. James et al.'s (2004) intervention trial to reduce consumption of (all types of) fizzy drinks in six primary schools in England found a 7.7% difference in the prevalence of obesity between intervention and control group after 1 year, but no significant change in mean BMI. Unfortunately, methodological limitations, including missing and inadequate dietary data, leave unanswered questions in this study (French et al. 2004). Moreover, the prevalence of overweight increased in the control group, despite no change in beverage intake. In the second intervention trial, a pilot study ($n = 103$) involving home delivery of non-caloric beverages to 13–18 year olds, BMI was only reduced among those heaviest at baseline (Ebbeling et al. 2006).

We considered that evidence for an impact of caloric soft drinks on overweight is flawed by methodological issues, including biased dietary reporting and failure to consider other contributors to energy balance. The purpose of this project was to examine the association between overweight and intake of sugars and caloric soft drinks among children in Britain using data from the National Diet and Nutrition Survey of Young People (NDNS) aged 4–18 years (Gregory and Lowe 2000). In particular we hypothesized that intake of sugars and sugar-containing soft drinks might be associated with higher BMI score after adjustment for physical activity and the potentially confounding effects of under-reporting and dieting.

Methods

Survey design

The NDNS was conducted over a 12-month period in 1997. Full details of the methodology are available in published reports (Gregory and Lowe 2000). The sample was selected using a multi-stage random probability design, using postcodes stratified by Census variables. Food and drinks were weighed by subjects using digital scales and recorded in detail over seven consecutive days. Second helpings, leftovers and home-made recipes were also recorded. Trained interviewers demonstrated procedures and revisited each family as needed to give support, probe for adequate descriptions, and check for missing items and changes to eating pattern. Where items could not be weighed, portion sizes were assigned from description, size, price, and packaging details, or duplicate items were purchased by the interviewer.

Computer files of the NDNS (Gregory and Lowe 2000) were obtained from the UK Data Archive (www.data-archive.ac.uk). Our study included those children ($n = 1294$) who had completed the three relevant aspects of the survey; namely, weight and height measurement (by trained fieldworkers), personal 7-day weighed food record and concurrent 7-day physical activity diary (for those aged 7 years and above). This represented 77% of the sample aged 7–18 years who were interviewed ($n = 1{,}673$). The age distribution of the final sample (36% aged 7–10 years, 35% aged 11–14 years and 29% aged 15–18 years) was comparable with that of the interview sample (35%, 34% and 31%, respectively).

Energy and nutrient intakes were calculated in the original survey using an NDNS nutrient databank of over 7,000 foods. NMES is the UK definition of free sugars that is used in dietary reference values, and essentially comprises all added sugars, plus sugars in fruit juice and 50% of sugars in dried and canned fruit. Our definition of soft drinks included all types (carbonated, still, dilutable, ready to drink, diet and non-diet), *except* pure fruit juice. We evaluated the contribution of soft drinks in terms of energy, so the effect studied is that of caloric soft drinks, in proportion to their energy content. Overall, soft drinks contributed 5% of total energy and 25% of the NMES intake.

Definition of overweight

Adult BMI cut-off values are not appropriate for children, so we calculated BMI z-scores based on UK reference curves using software that calculates z-scores by gender and age in months (Child Growth Foundation, London, UK). Children were designated 'overweight' or 'normal weight' using IOTF cut-off values corresponding to the adult criteria of BMI $>$25 kg/m^2, extrapolated back to childhood (Bellizzi and Dietz 1999; Cole et al. 2000; Dietz and Robinson 1998). The cut-off values for overweight were BMI z-scores of 1.3 (boys) and 1.19 (girls). Approximately 19% of boys ($n = 128$) and 22% of girls ($n = 149$) were 'overweight' by these criteria, with approximately one in five of these in the obese category (equivalent to adult BMI $>$30 kg/m^2). To examine trends across the entire range from underweight to obese, girls and boys were also classified by fifths of BMI z-score. Thus Q5 comprised the top 20% of the distribution, approximately equivalent to the 'overweight and obese' group.

Under-reporting and dieting

To identify potential under-reporters we used a combination of three criteria, using the ratio of energy intake to (predicted) BMR (EI:BMR), augmented with data on dieting and physical activity level to give more precision (Black et al. 1997; Lof and Forsum 2004). Young people identified on any one of these were classified as probable under-reporters or dieters (LER3) The remainder was classified as 'reliable' (OK).

- Criterion 1: a value of less than 1.2 for EI:BMR (Goldberg et al. 1991). One hundred and sixty-nine boys (26%) and 245 girls (38%) were classified as under-reporters by this method.
- Criterion 2: a ratio of energy intake to estimated energy expenditure of less than 0.67, approximately one standard deviation below the mean. Energy expenditure was calculated as (BMR x PAL), where PAL is the calculated activity score divided by 24 h. We chose a low cut-off value for exclusion because the calculated activity score is thought to overestimate true expenditure. This identified 32 (24 boys and eight girls) more physically active under-reporters, missed by Criterion 1.
- Criterion 3: Young people on a diet to lose weight. These may have been avoiding sweet foods, hence distorting the relationship being investigated. Twenty boys and 51 girls (5% of the total sample) reported being on a diet, of whom seven boys and 16 girls were not identified by the previous two criteria.

Statistical methods

All analyses were conducted using SPSS software (SPSS Inc. Chicago, IL, USA), versions 12.0, 13.0, 14.0 (SPSS, UK). For continuous variables, differences between groups were assessed using analysis of variance, with tests for linearity and inter-group contrasts. Bonferroni correction was used for multiple comparisons. For categorical variables and prevalence data we used chi-square tests. Finally we used stepwise logistic regression to identify which variables were significant predictors of overweight after adjustment for age, sex, dieting and under-reporting. Model 1 was based on total energy intake and activity variables, and Model 2 explored the impact of the macronutrients, classified into tertiles. Soft drinks were expressed as kilojoules per day and other sources of sugars (i.e. NMES (excluding soft drinks) and intrinsic and milk sugars), were both included in the model. Finally, Model 3 explored the impact of soft drinks as quintiles, in comparison with non-sugar energy, to examine non-linear trends.

Results

Impact of low energy reporting and dieting

In total, 36% of the sample ($n=469$) was judged to be either under-reporting or under-eating by one of the three chosen criteria (LER3), with a range from 25% in Q1 to 57% in Q5. The remainder ($n=821$) were classified as 'reliable' (OK). Under-reporters/dieters (LER3) reported mean energy intakes 22% lower than the reliable sample (mean 6.45 MJ vs 8.32 MJ, $P<0.001$) (Figure 1). They appeared to have diets lower in NMES (14.9% vs 17.8%, $P<0.001$) (Figure 2). The diet composition of LER3 was also slightly lower in fat (34.3% vs 34.9%, $P=0.03$) but higher in protein (13.9% vs 12.8%) and starch (30% vs 28%, $P<0.001$). The percentage energy from soft drinks was similar among both groups (4.5% vs 4.6%) (Figure 3). This suggests that under-reporters/dieters may report (or eat) fewer sugar-containing foods than reliable reporters, but this did not apply to caloric soft drinks in this survey.

Associations between BMI and intake of sugars and caloric soft drinks

In the total sample there was a weak inverse correlation between the BMI z-score and the percentage of energy from NMES (Pearson partial correlation adjusted for age and sex, $r=-0.10$, $P<0.001$), which was attenuated (but not reversed) after adjusting for under-reporting and dieting ($r=-0.06$, $P=0.03$). In both the LER3 and OK groups there was the same upward trend in energy intake with BMI (Figure 1). In absolute terms, reliable reporters in Q5 consumed about 1,220 kJ more energy than those in Q1 (Figure 1 and Table II) but only 60 kJ (5%) of this was soft drinks (Q5 vs Q1, $P=0.14$) (Figure 4 and Table II). In a linear regression of the BMI z-score (in reliable reporters, adjusted for age and sex), soft drinks energy (kJ) accounted for less than 0.5% of the variance in BMI ($P=0.18$) whereas other energy accounted for 11% ($P<0.0001$) (data not shown). The percentage of energy from soft drinks did not vary across quintiles of BMI (Figure 3 and Table II). Neither was there any evidence for an association among overweight children when all the data were examined in a scatterplot (Figure 5).

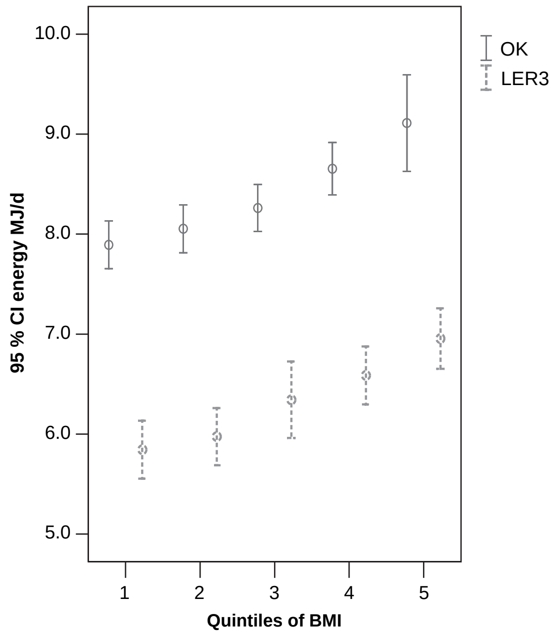

Figure 1. Intake of energy according to quintile of BMI (z-score) in under-reporters/dieters (LER3) and reliable reporters (OK) (trend with BMI significant, $P < 0.001$).

Associations between physical activity and BMI

Older children (11–14 and 15–18 years) spent more time in sedentary activities (including watching television) and less time in moderate or vigorous activities than younger children (7–10 years), but this was offset by less time asleep (data not

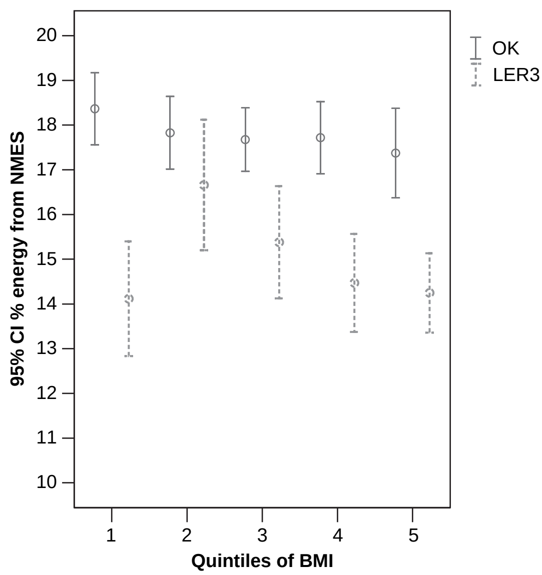

Figure 2. Intake of NMES as a percentage of energy intake according to quintile of BMI (z-score) in under reporters/dieters (LER3) and reliable reporters (OK) (trend with BMI not significant, $P > 0.1$).

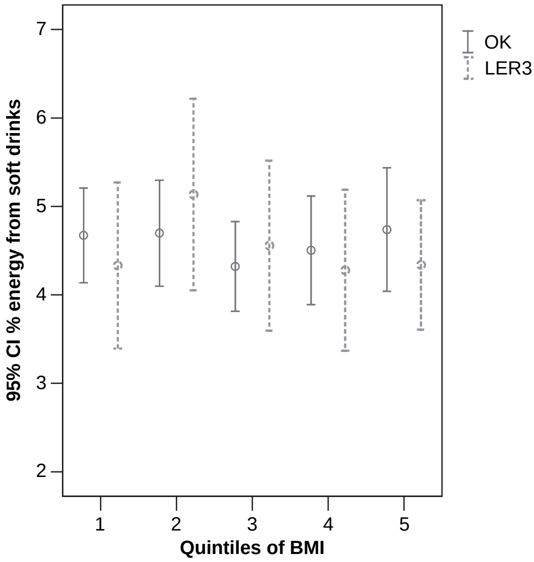

Figure 3. Intake of soft drinks as a percentage of energy intake according to quintile of BMI (z-score) in under reporters/dieters (LER3) and reliable reporters (OK) (trend with BMI not significant, $P > 0.1$).

shown). In the total sample, overweight children (Q5 age-adjusted BMI z-score) spent about 20 min longer per day in sedentary (very light intensity) activities than lean youngsters (Q1) ($P < 0.001$; Table III). This difference in sedentary behaviour between lean and overweight was more marked among boys (Gibson et al. 2004). Despite these differences in specific activities, there was no significant difference in the overall calculated activity score across BMI quintiles, either for the total sample or by age group. This suggests that the calculated activity score may not be sufficiently sensitive to activity patterns. Associations with physical activity and their impact on associations between diet and overweight were explored further in logistic regression models (Table IV).

Associations between physical activity and sugars intake

There was no association between activity levels or patterns and the percentage of energy from soft drinks. However, young people with above-average intakes of NMES (as% energy) had a higher calculated activity score than those with lower intakes ($P = 0.0013$), spending about 15 min less in very light (sedentary) activities ($P = 0.028$) and 6 min more in sports and exercise ($P = 0.04$) (data not shown). Exclusion of under-reporters and dieters weakened the associations but did not alter their direction.

Multivariate analysis: logistic regression models of overweight

The impact of dieting and under-reporting, as well as age and gender, was controlled for in all models. Table IV presents the independent impact of each factor, adjusting for all other variables at the same level. According to Model 1, each megajoule of energy consumed increased the odds of being overweight by 58% (odds ratio [OR] = 1.58, confidence interval [CI] = 1.42–1.77, $P < 0.0001$), while the odds of overweight increased by 11% for each hour of sedentary activity (OR = 1.11, CI =

Table II. Intakes of energy, macronutrients and soft drinks according to the BMI z-score (excluding dieters and under-reporters)

	Quintiles of BMI (z-score)						Analysis of variance
	Q1	Q2	Q3	Q4	Q5	Total	Linear P value
n	192	176	186	157	110	821	
Energy (kJ)							
Mean	7,892	8,053	8,261	8,654	9,111	8,319	0.000
Standard error	121	121	119	133	243	63.9	
% energy from protein							
Mean	12.7	12.8	12.9	12.8	13.0	12.8	0.216
Standard error	0.1	0.2	0.1	0.1	0.2	0.1	
% energy from fat							
Mean	34.7	35.2	34.9	34.6	35.2	34.9	0.930
Standard error	0.3	0.3	0.3	0.4	0.4	0.1	
% energy from starch							
Mean	27.5	27.8	27.6	28.1	27.8	27.8	0.343
Standard error	0.3	0.3	0.3	0.3	0.4	0.1	
% energy from intrinsic and milk sugars							
Mean	6.3	6.2	6.8	6.4	6.5	6.4	0.141
Standard error	0.2	0.2	0.2	0.2	0.2	0.1	
% energy from NMES							
Mean	18.4	17.8	17.7	17.7	17.4	17.8	0.118
Standard error	0.4	0.4	0.4	0.4	0.5	0.2	
% energy from soft drinks							
Mean	4.7	4.7	4.3	4.5	4.7	4.6	0.813
Standard error	0.3	0.3	0.3	0.3	0.4	0.1	
Energy from Soft drinks (kJ)							
Mean	380	377	365	388	439	385	0.241
Standard error	25	25	24	27	36	12	

1.01–1.23, $P=0.03$) and decreased by 29% for every hour of moderate/vigorous activity (OR = 0.71, CI = 0.58–0.86, $P < 0.0005$).

Model 2 replaced total energy with its components (macronutrients), classified into tertiles. Both high fat intake (top third or >80 g/day) and high protein intake (>65 g/day) were associated with more than twice the odds of being overweight compared with a low fat or low protein intake (lowest third) ($P < 0.001$). Starch intake was more weakly predictive (for highest vs lowest tertile, OR = 1.6, CI = 1.0–2.6, $P = 0.03$). High intakes of caloric soft drinks (top tertile >396 kJ/day, mean 710 kJ/d\y) were associated with a small increase in odds of overweight, compared with low intakes (<163 kJ/day, mean 72 kJ/day) (OR = 1.39, CI = 0.95–1.98, $P = 0.08$). There was no association between overweight and other sources of NMES (kJ/day) (OR = 0.81, CI = 0.52–1.27, $P = 0.4$) or with intrinsic and milk sugars.

Model 3 explored the possibility of a threshold effect of soft drink consumption using quintiles of energy from soft drinks, compared with energy from other sources. Only the highest quintile of soft drink consumption (Q5: >550 kJ/day, mean 870 kJ/day—equivalent to 870 ml or 2.6 cans per day) was associated with significantly increased odds of overweight (OR = 1.67, CI = 1.04–2.66, $P = 0.033$).

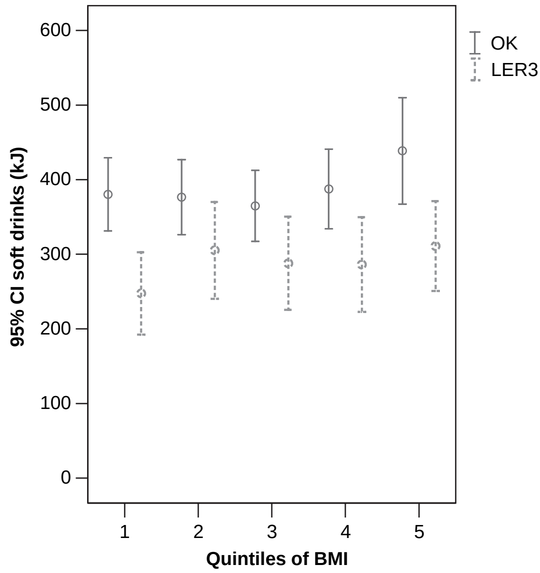

Figure 4. Intake of soft drinks (kJ/day) according to quintile of BMI (z-score) in under reporters/dieters (LER3) and reliable reporters (OK) (trend with BMI not significant, $P > 0.1$).

The net impact of caloric soft drinks can be interpreted as follows. Consuming 870 kJ from soft drinks (mean intake in top tertile) was associated with a 67% increased odds of being overweight compared with consuming none. However, lesser amounts (e.g. 430 kJ in Q4—equivalent to 1.3 cans per day) were not associated with excess risk.

Discussion

Cross-sectional studies cannot by their nature prove causality, but can add to the evidence-base, especially when the exposure measurements are of high quality and multivariate analysis is used to adjust for possible confounders. A major strength of

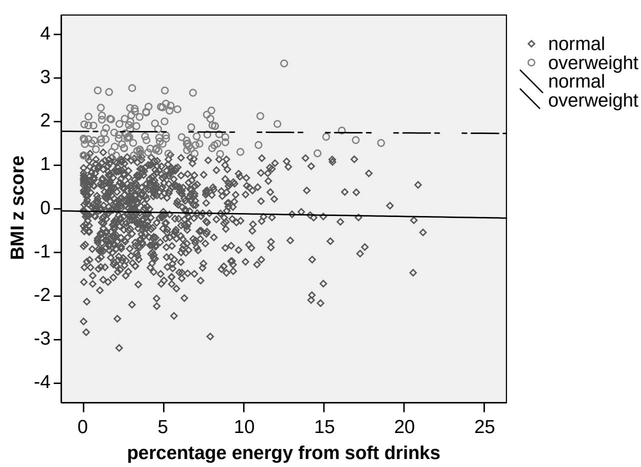

Figure 5. Scatterplot of the BMI z-score against the percentage of energy from soft drinks in overweight versus normal weight children (excluding dieters and under-reporters).

Table III. Time in activities of different intensity (per 24 h), according to the BMI z –core (total sample)

Time spent in activities of different intensity (min/day)	Quintiles of BMI Q1	Q2	Q3	Q4	Q5	Analysis of variance Linear P value	Contrast Q5 vs Q1–Q4 P value
Very light							
Mean	315	310	327	312	336	0.056	0.006
Standard error	7	8	8	8	7		
Light							
Mean	451	452	436	462	448	0.92	0.50
Standard error	8	8	8	9	8		
Moderate							
Mean	56	56	62	58	55	0.90	0.61
Standard error	3	3	3	4	4		
Vigorous/very vigorous							
Mean	18	24	18	18	18	0.14	0.56
Standard error	1	2	1	1	1		
Asleep/in bed							
Mean	599	598	596	590	583	0.002	0.002
Standard error	4	4	4	4	4		
Calculated activity score							
Mean	42.4	42.9	42.5	42.7	42.3	0.53	0.23
Standard error	0.2	0.2	0.2	0.2	0.2		

the NDNS is that it includes a 7-day physical activity diary contemporaneous with the weighed diet record, allowing inclusion of both sets of variables in models. Our results are consistent with other data suggesting that energy intake (from whatever source) and both lack of exercise and excess inactivity are associated with overweight in children and adolescents (Berkey et al. 2000; Livingstone et al. 2003; Reilly 2006).

Evidence from longitudinal studies confirms than overweight is a lifestyle issue, not merely a matter of the type of food and drink consumed. The Oslo Youth study, for example, found that long-term physical activity, father's BMI, and adolescent BMI were predictors of BMI in adulthood, but failed to find an association with long-term soft drink consumption (Kvaavik et al. 2005). In a careful longitudinal study of American girls followed from the age of 9 to 19 years, change in BMI and adiposity was strongly associated with habitual activity but not with energy intake (Kimm et al. 2005). Our results are in close agreement with a cross-sectional study using National Health and Nutrition Examination Survey (NHANES) data for 12–16 year olds, which found that participation in team sports or exercise programs had the largest impact in multivariate regression models of predicted BMI, while decreased television viewing had a smaller impact and reducing soft drinks the smallest impact (Forshee et al. 2004). Associations between BMI and sedentary activities such as television watching and computer games (Gibson et al. 2004) have been reported in numerous other studies (Francis et al. 2003; Giammattei et al. 2003; Ariza et al. 2004; Janssen et al. 2004; Andersen et al. 2005). The inverse relationship observed with sleep (paradoxical when viewed in energetic terms) has also been reported recently (Reilly et al. 2005; Chaput et al. 2006). Whether this reflects a direct effect of sleep on

Table IV. Adjusted models of dietary intake and physical activity on overweight (adjusted for age, sex, under-reporting and dieting)

			95% confidence interval	
	P value	Odds ratio (adjusted)	Lower	Upper
Model 1, total energy and activity				
Energy intake (MJ/day)	<0.0001	1.58	1.42	1.77
Moderate or vigorous activity (/h)	0.0005	0.71	0.58	0.86
Television watching, etc. (/h)	0.032	1.11	1.01	1.23
Model 2, Macronutrients and activity				
Activity/inactivity				
Moderate or vigorous activity (/h)	0.002	0.73	0.60	0.89
Television watching, etc. (/h)	0.038	1.11	1.01	1.23
Macronutrients (tertiles)				
Fat	0.001			
Low, ≤63 g/day		1.00		
Average, 64–79 g/day	0.018	1.67	1.09	2.55
High, 80+ g/day	<0.001	2.83	1.65	4.86
Protein	0.002			
Low, ≤51 g/day		1.00		
Average, 52–64 g/day	0.13	1.40	0.91	2.16
High, 65+ g/day	0.001	2.46	1.46	4.16
Starch	0.033			
Low, ≤118 g/day		1.00		
Average, 119–147 g/day	0.88	0.97	0.64	1.46
High, 148+ g/day	0.049	1.60	1.00	2.55
Intrinsic and milk sugars	0.80			
Low, <20 g/day		1.00		
Average, 20–30 g/day	0.73	1.08	0.71	1.63
High, >30 g/day	0.51	1.17	0.74	1.85
Soft drinks (caloric)	0.19			
Low, <163 kJ/day		1.00		
Average, 163–396 kJ/day	0.71	1.07	0.75	1.53
High, >396 kJ/day	0.08	1.39	0.96	2.01
NMES (excluding soft drinks)	0.33			
Low, <724 kJ/day		1.00		
Average, 724–1,088 kJ/day	0.62	1.10	0.76	1.58
High, >1,088 kJ/day	0.36	0.81	0.52	1.27
Model 3, soft drinks (caloric) (kJ/day) and other energy				
Moderate or vigorous activity (/h)	0.001	0.72	0.59	0.87
Television watching, etc. (/h)	0.041	1.11	1.00	1.22
Q1 soft drinks (<0.09 MJ)	0.149			
Q2 soft drinks (0.09–0.2 MJ) vs Q1	0.857	0.96	0.6	1.52
Q3 soft drinks (0.2–0.35 MJ/day) vs Q1	0.52	1.16	0.74	1.82
Q4 soft drinks (0.35–0.55 MJ/day) vs Q1	0.842	1.05	0.66	1.66
Q5 soft drinks (>0.55 MJ/day) vs Q1	0.033	1.67	1.04	2.66
NMES (excluding soft drinks) (MJ)	0.226	0.78	0.52	1.17
Other energy (non-NMES) (MJ)	<0.001	1.8	1.57	2.06

Note: Overweight defined using IOTF cut-off values; BMI z-scores >1.3 (boys) or BMI z-scores >1.19 (girls). P values quoted as the overall value and for contrasts with lowest tertile (OR = 1). R^2 = 0.20, sensitivity = 65%, specificity = 67%.

metabolism or its displacement by television watching with its associated opportunities for calorie consumption (Francis et al. 2003) remains to be established.

Many other studies assessing associations between BMI and dietary sugars content have found an inverse association, or no association (Lewis et al. 1992; Gibson 1993, 1996; Bolton-Smith and Woodward 1994; Anderson 1995; Mendez et al. 2004; Overby et al. 2004). However, most of these studies did not consider the impact of confounding by dieting and misreporting (Mendez et al. 2004). Using a cut-off based on the EI:BMR ratio, augmented with data on dieting and physical activity level to give more precision, we found that the inverse association between the BMI z-score and NMES was attenuated after excluding low energy reporters but was not reversed. Higher cut-off values for EI:BMR (Torun et al. 1996) gave similar results but excluded more than one-half of the sample, compromising power. It is impossible to eliminate entirely the impact of misreporting and under-eating but, as we found no evidence of under-reporting of soft drinks, or association of soft drinks with BMI in plausible reporters, we do not consider this a threat to the findings.

The extensive data on body weight in relation to intake of soft drinks were discussed in the Introduction. On balance, the evidence that caloric soft drinks contribute in part to obesity is suggestive, but not conclusive. As pointed out by Bachmann et al. (2006), assessing the contribution of one food group to obesity is difficult because energy balance is a function of total energy intake and expenditure. Any food or drink has the potential to contribute to obesity in so far as it provides energy. Some studies reporting associations with obesity appear to have been narrowly focused on soft drinks, leaving open questions as to whether other potential contributors or confounders were adequately assessed.

In this major British survey we found no evidence that overweight children (as defined by BMI z-score) derived a greater proportion of their energy from caloric soft drinks compared with lean children. In absolute terms, they consumed more soft drinks (+60 kJ/day) but much more energy from other sources (+1,160 kJ/day). The excess risk of overweight associated with soft drink consumption was only significant at high levels of intake (top quintile, mean 870 kJ/day). Overall, the adjusted models suggest a potential role for savoury, rather than sweet foods. This hypothesis requires confirmation, but would be consistent with the high energy density of fatty foods and meat products and a reciprocal association between relative proportions of fat and sugar in the diet of free-living populations (Bolton-Smith and Woodward 1994; Gibney et al. 1995; Gibson 2000).

The reasons why some people become overweight yet others do not are many and varied. Nutritionists should resist pressures to over-simplify a complex issue whose aetiology involves genetics, diet and lifestyle, and whose solution is likely to be multifactorial. Research is now required to test the various prevention strategies that have been advanced (e.g. eliminating soft drinks, restricting television viewing, reducing fast foods, limiting portion sizes), but these studies must use reliable dietary and physical activity measurements and have an adequate length of follow-up.

Acknowledgements

This secondary analysis of NDNS survey data (MAFF/DH) was funded by the Sugar Bureau (UK) and UNESDA (European Soft Drinks Association). The authors are independent consultants in nutrition and statistics. The National Diet and Nutrition

Survey of Young People aged 4–18 years was commissioned and funded jointly by the UK Ministry of Agriculture, Fisheries and Food and the Department of Health. The opinions expressed in this paper are those of the authors.

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This paper was first published online on iFirst on 6 June 2007.