Dietary sodium intake is associated with total fluid and sugar-sweetened beverage consumption in US children and adolescents aged 2–18 y: NHANES 2005–2008

Carley A Grimes, Jacqueline D Wright, Kiang Liu, Caryl A Nowson, and Catherine M Loria

ABSTRACT

Background: Increasing dietary sodium drives the thirst response. Because sugar-sweetened beverages (SSBs) are frequently consumed by children, sodium intake may drive greater consumption of SSBs and contribute to obesity risk.

Objective: We examined the association between dietary sodium, total fluid, and SSB consumption in a nationally representative sample of US children and adolescents aged 2–18 y.

Design: We analyzed cross-sectional data from NHANES 2005–2008. Dietary sodium, fluid, and SSB intakes were assessed with a 24-h dietary recall. Multiple regression analysis was used to assess associations between sodium, fluid, and SSBs adjusted for age, sex, race-ethnic group, body mass index (BMI), socioeconomic status (SES), and energy intake.

Results: Of 6400 participants, 51.3% (n = 3230) were males, and the average (±SEM) age was 10.1 ± 0.1 y. The average sodium intake was 3056 ± 48 mg/d (equivalent to 7.8 ± 0.1 g salt/d). Dietary sodium intake was positively associated with fluid consumption (r = 0.42, P < 0.001). After adjustment for age, sex, race-ethnic group, SES, and BMI, each additional 390 mg Na/d (1 g salt/d) was associated with a 74-g/d greater intake of fluid (P < 0.001). In consumers of SSBs (n = 4443; 64%), each additional 390 mg Na/d (1 g salt/d) was associated with a 32-g/d higher intake of SSBs (P < 0.001) adjusted for age, sex, race-ethnic group, SES, and energy intake.

Conclusions: Dietary sodium is positively associated with fluid consumption and predicted SSB consumption in consumers of SSBs. The high dietary sodium intake of US children and adolescents may contribute to a greater consumption of SSBs, identifying a possible link between dietary sodium intake and excess energy intake.


INTRODUCTION

In the United States, childhood obesity is a major public health problem. In 2009–2010 in children and adolescents aged 2–19 y, it was estimated that 15% of them were overweight, and 17% of them were obese (1). Sugar-sweetened beverage (SSB) consumption in children has been identified as a contributor in the development of childhood obesity (2–5). Evidence in children has suggested that a high dietary sodium intake may be associated with obesity risk, mediated by increased SSB consumption (6). After the ingestion of dietary sodium, there is a subsequent rise in plasma sodium, and to maintain fluid homeostasis, thirst is stimulated, which promotes fluid consumption (7–9). The association between dietary sodium and thirst is well established. In an experimental trial in hypertensive adults, the daily urinary output (a marker of fluid consumption) decreased on a low-sodium diet (10). In this study, a 2300-mg/d (100-mmol/d) decrease in dietary sodium reduced the 24-h urinary volume by 367 mL. Furthermore, data from the large INTERSALT study showed a positive association between dietary sodium intake and urinary volume in normotensive adults (10). In a recent analysis that included German children aged 4–18 y, it was shown that a higher sodium intake did not alter children's hydration status likely because of a compensatory increase in beverage consumption (11). Together, these findings indicate that dietary sodium predicts fluid consumption.

Because SSBs are readily available and form part of a usual diet for many children and adolescents, it has been proposed that a high sodium intake may drive greater consumption of SSBs (8). Data from the 1997 National Diet and Nutrition Survey in UK children and a nationally representative sample of Australian children indicated a positive association between dietary sodium intake and overall fluid consumption as well as SSB consumption (6, 12).

Because of the ubiquity of sodium in the US food supply (13) and existing evidence that has identified SSB consumption as a correlate of childhood obesity (2–5), an investigation of the association between dietary sodium and SSB consumption in US children is warranted. The aim of the current study was to examine the cross-sectional association between dietary sodium,
total fluid, and SSB consumption in a nationally representative sample of US children and adolescents aged 2–18 y.

SUBJECTS AND METHODS

Study design

The NHANES is a continual nationally representative survey designed to assess the health and nutritional status of the non-institutionalized US civilian population. The cross-sectional survey uses a complex, multistage probability sampling procedure with oversampling of selected subpopulations to provide reliable estimates. During the period 2005–2006, the following subgroups were oversampled to provide more-reliable estimates: low-income persons, adolescents 12–15 and 16–19 y old, persons aged ≥60 y, African Americans, and Mexican Americans. In 2007–2008, oversampled groups were changed to include low-income persons, African Americans, all Hispanics (not just Mexican Americans), and persons aged ≥60 y. Full details of the sampling methodology and data-collection procedures are available elsewhere (14). For this analysis, we used data from NHANES 2005–2008. Written parental or guardian consent was obtained for all children aged ≤18 y, and in addition, written assent was obtained for children aged 7–17 y; subjects aged 18 y provided written consent. The National Center for Health Statistics (NCHS) ethics review board approved the study (15).

Study participants

Participants included in this analysis were children and adolescents aged 2–18 y. We excluded participants if they did not provide dietary data or did not meet the reliable and minimum criteria set for dietary intake as determined by the NCHS (n = 472) (16, 17). An additional 4 participants who reported consuming no fluid over the 24-h dietary recall period were excluded because this was deemed unreliable. In addition, participants with either missing data or a response of “I don’t know” for education status of the head of household (n = 161 males; 67%), our marker for socioeconomic status (SES) (n = 260) or BMI (in kg/m²) (n = 80) were excluded. This exclusion resulted in a final sample of 6400 participants.

Measures

In brief, NHANES participants complete an initial household interview, which collects demographic and general health information followed by a Mobile Examination Center (MEC) visit, which includes a dietary intake interview and anthropometric measurements. In this analysis, we have used data collected during the household interview and MEC examination. In each survey cycle, data are collected throughout the year (ie, January to December). For each participant, the NHANES codes the time period of data collection in one of two 6-mo blocks from 1 November to 20 April or 1 May to 31 October. We have used this variable as a marker for seasonal adjustment.

Demographic characteristics

During the household interview, participants self-reported information on sex, age, race-ethnic group, and other sociodemographic details. Proxy-assisted interviews were completed in participants aged 2–15 y. Participants self-reported race-ethnic group, and NHANES categories for race-ethnic group were used (Mexican American, other Hispanic, non-Hispanic black, and other race, including multi-racial). Because of the small sample size for other race, in this analysis, we have combined the other race group with other Hispanic. The highest level of education attained by the head of household (n = 3034 males; 53%) was used as a marker for SES. On the basis of this variable, each participant was grouped into one of 3 SES categories as follows: 1) low, which included individuals with some or no level of high school education (less than ninth grade and ninth through 11th grades); 2) middle, which included individuals with high school graduate/General Educational Development equivalent; or 3) high, which included individuals with some college or associates degree, or a college graduate or higher.

Dietary intake

Participant dietary intake was assessed by using a person computer-assisted, 24-h dietary recall interview. The dietary recall was administered by trained interviewers by using the USDA automated multiple-pass method (18). In brief, participants were asked to list all food and beverages consumed in the 24-h period from midnight to midnight on the day before the interview. Dietary intake was recalled by a proxy in 2–5-y-olds, was proxy assisted in 6–11-y-olds, and was self-reported in 12–18-y-olds (19, 20).

The NHANES uses the USDA’s Food and Nutrient Database for Dietary Studies (FNDDS) to calculate nutrient intake from food and beverage data (21, 22). The FNDDS uses food-composition data from the USDA National Nutrient Database for Standard Reference (23). In this analysis, we report intake data for dietary sodium (mg/d) and energy (kcal/d) as calculated by the NCHS. In NHANES, dietary sodium (mg/d) is adjusted for salt use in food preparation for foods likely to be prepared at home on the basis of responses to the following question after the 24-h dietary recall: “How often is ordinary salt or seasoned salt added in cooking or preparing foods in your household? Is it never, rarely, occasionally, or very often?” If the participant answered “rarely” or “never,” the amount of optional salt used in recipes was removed; if the participant answered “occasionally,” one- half of the optional salt used in recipes was removed (16, 17). Information related to salt used in food preparation was recalled by a proxy in 2–5-y-olds, was proxy assisted in 6–11-y-olds, and was self-reported in 12–18-y-olds (19, 20). Reported dietary sodium intake did not include salt added at the table. In addition to sodium, the salt equivalent was reported by using the conversion 390 mg Na = 1 g salt (ie, sodium chloride). Because dietary sodium is generally highly correlated to energy intake (13), sodium density (mg/1000 kcal) is also reported.

The total fluid intake included all sources of fluid consumed either as a beverage or added to meals or recipes. The definition of SSBs included sugar-sweetened soda, vitamin waters, fruit ades, fruit drinks, flavored mineral waters, and sports and energy drinks (12, 24, 25), that contained ≥20 kcal/100 mL. In a sensitivity analysis, we used an alternative definition of SSBs that included sugar-sweetened tea. The FNDDS food-group classification system was used to identify food groups that fell within the definition of fluid and SSBs. These food codes were used to aggregate data to calculate the total fluid (g/d) and SSBs (g/d). Consistent with the methodology used to collect dietary data in NHANES and the FNDDS food-composition database, which
lists nutrient data per 100 g, the total fluid and SSB intake is reported as grams.

**Anthropometric measures**

Height and weight were measured by using standardized protocols during the MEC visit (26, 27). BMI was calculated as body weight divided by the square of body height. BMI was converted to age- and sex-adjusted z scores by using the least-mean squares method and the 2000 CDC growth-reference charts (28, 29).

**Physical activity**

Physical activity was assessed by using a questionnaire. Data from 4 questions were used to create one variable that described the number of times participants engaged in vigorous intensity activity per week. In both survey years (2005–2006 and 2007–2008, proxy respondents for children aged 2–11 y were asked, “How many times per week does study participant play or exercise enough to make him/her sweat and breathe hard?” (30, 31). For this analysis, it was assumed that this type of activity represented vigorous intensity. In 12–18-y-olds, the question that was related to vigorous intensity activity varied between survey cycle years. In 2005–2006, 12–18-y-olds were asked, “Over the past 30 days what vigorous activities did you do?” followed by, “Over the past 30 days, how often did you do the activity?” (32). The number of times the activity was engaged in the past 30 d was divided by 4 to represent the number of times the activity was completed per week. In 2007–2008, 12–18-y-olds were asked, “In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreation activities?” (31). For the purposes of this analysis, the number of days per week was assumed to represent the number of times per week. Participants with missing data or who responded “I don’t know” or refused to answer (n = 723) were excluded from analyses adjusted for physical activity.

**Statistical analysis**

All statistical analyses were completed with STATA/SE 12.0 software (StataCorp LP). All analyses accounted for the complex survey design used in the NHANES (ie, clustering and stratification). To produce nationally representative estimates and account for nonresponses, survey weights were applied. In this analysis, the day 1 dietary weight, which made additional adjustment for a nonresponse to the dietary component and the day of the survey cycle years. In 2005–2006, 12–18-y-olds were asked, “Over the past 30 days what vigorous activities did you do?” followed by, “Over the past 30 days, how often did you do the activity?” (32). The number of times the activity was engaged in the past 30 d was divided by 4 to represent the number of times the activity was completed per week. In 2007–2008, 12–18-y-olds were asked, “In a typical week, on how many days do you do vigorous-intensity sports, fitness or recreation activities?” (31). For the purposes of this analysis, the number of days per week was assumed to represent the number of times per week. Participants with missing data or who responded “I don’t know” or refused to answer (n = 723) were excluded from analyses adjusted for physical activity.

**RESULTS**

**Basic demographic characteristics and nutrient intake**

Basic demographic characteristics along with intakes of dietary sodium, fluid, and SSBs of US children and adolescents are shown in Table 1. Of the 6400 participants, 51.3% of subjects were males, and more than one-half of subjects were non-Hispanic White and had a high SES. The average dietary sodium intake of all participants aged 2–18 y was 3056 ± 48 mg/d (salt equivalent: 7.8 ± 0.1 g/d). The average sodium intake was higher with increasing age from 2246 ± 30 mg/d (salt: 5.7 ± 0.1 g/d) to 2997 ± 53 mg/d (salt: 7.6 ± 0.1 g/d) and 3545 ± 79 mg/d (salt 9.0 ± 0.2 g/d) in 2–5-y-olds, 6–11-y-olds, and 12–18-y-olds, respectively (P < 0.001). Dietary sodium intake was significantly greater in males than females across all 3 age groups (all P < 0.05; Table 1). However, this difference was no longer significant when energy intake was adjusted for (ie, mg Na/1000 kcals) (2–5 y; P = 0.29; 6–11 y: P = 0.76; 12–18 y: P = 0.15).

The total fluid consumption was higher as age increased from 1090 ± 20, 1272 ± 25, and 1961 ± 57 g/d in 2–5-, 6–11-, and 12–18-y-olds (P < 0.001), respectively, and was significantly greater in males in each age group (all P < 0.05; Table 1). Sixty-

**Public health implications**

Although the average dietary sodium intake of all participants aged 2–18 y was 3056 ± 48 mg/d, this intake is significantly higher than the dietary sodium intake recommended by the American Heart Association (1500 mg/d). The highest sodium intake was found in 12–18-y-olds, males, and non-Hispanic White participants (Table 1). Approximately one-third (33%) of participants reported consuming some SSBs (>0 g/d) over the 24-h dietary recall period. Nonconsumers of SSBs reported consuming no SSBs (0 g/d). In sensitivity analyses to address a more-typical SSB intake, we alternatively defined SSB consumers as having reported consuming some SSB (>0 g/d) in at least one of the two 24-h dietary recall periods albeit in a smaller sample (n = 5580).

Pearson’s correlation coefficients were calculated to assess the association between dietary sodium intake and 1) total fluid consumption or 2) SSB consumption. Multiple regression analysis was used to adjust for the following potential confounding variables: age, sex, race-ethnic group, SES, BMI, season, and physical activity; only those variables that exhibited significant bivariate associations with the dependent variable were included in the final model. Additional adjustment for the number of times per week engaged in vigorous intensity physical activity was only completed in the subsample of participants with available physical activity data (n = 5677).

Because 36% of participants (n = 1957) did not consume any SSBs (ie, 0 g/d) on the day of the survey, this resulted in a highly negative skewed variable for SSBs (g/d). Hence, the analysis of dietary sodium intake and SSB consumption was completed within the subsample of participants who reported consuming SSBs (n = 4443). The SSB model was adjusted for age, sex, race-ethnic group, SES, and, in addition, energy derived from sources other than SSBs. Because neither season nor time spent in vigorous physical activity exhibited a significant bivariate association with SSBs, these variables were not included in the multivariate model. Because the outcome variable (ie, SSBs) is a source of energy, controlling for total energy (kcal/d) would have over-adjusted in the model. Therefore, the partition method was used to adjust for energy, which included only the energy (kcal/d) that was derived from sources other than SSBs (ie, the total energy intake minus the energy from SSBs). Results from linear regression analyses are presented as regression coefficients (βs) and 95% CIs, corresponding P values, and the coefficient of determination (R²).
four percent of overall participants (n = 4443) reported consuming SSBs. The likelihood of consuming SSBs was significantly higher as age increased, with SSB consumption reported in 53%, 66%, and 69% of 2–5-, 6–11-, and 12–18-y-olds (P < 0.001). In adolescents, males were more likely to report consuming SSBs (P < 0.05; Table 1). In only consumers of SSBs (n = 4443), the average daily intake of SSB was 344 ± 14, 512 ± 21, and 843 ± 33 g/d in 2–5-, 6–11-, and 12–18-y-olds, respectively. The amount of SSBs consumed was significantly greater in males than females in the 6–11-y-old (P < 0.01) and 12–18-y-old (P < 0.001) groups (Table 1).

### Association between dietary sodium intake and total fluid consumption

In the total population, there was a moderate positive correlation between dietary sodium intake and total fluid consumption (r = 0.42, P < 0.001); each additional 390 mg Na/d (1 g salt/d) was associated with a 101-g/d greater intake of fluid consumption (P < 0.001; Table 2), and dietary sodium intake accounted for 17% of the variance in fluid consumption. After the adjustment for age, sex, SES, race-ethnic group, BMI, and season, the association between dietary sodium intake and fluid consumption remained significant; each additional 390 mg Na/d (1 g salt/d) was associated with a 74-g/d greater intake of fluid consumption (P < 0.001; Table 2). In the smaller sample of participants with available physical activity data (n = 5677), additional adjustment for the number of times engaged in vigorous physical activity per week, attenuated the association marginally (P < 0.001; Table 2). When stratified by age group and sex, the positive association between dietary sodium intake and fluid consumption remained significant in all age and sex subcategories in both unadjusted and adjusted models (Table 2). In participants with physical activity data, additional adjustment for the number of times engaged in vigorous physical activity per week did not remarkably alter the association across any age or sex group (Table 2).

### Association between dietary sodium intake and SSB consumption

In consumers of SSBs (n = 4443), there was a moderate positive correlation between dietary sodium intake and SSB consumption (r = 0.35, P < 0.001). In an unadjusted regression model, dietary sodium intake alone accounted for 12% of the variance in SSB consumption, in which each additional 390 mg Na/d (1 g salt/d) was associated with a 45-g/d greater intake of SSBs (P < 0.001; Table 3). Adjustment for age, sex, race-ethnic group, SES, and energy derived from sources other than SSBs reduced the effect to 32 g/d (P < 0.001). Association between dietary sodium intake and SSB consumption in SSB consumers stratified by sex and age group are shown in Table 3. In the fully adjusted model, the positive association between sodium and SSB consumption remained significant in all age and sex groups, except in 12–18-y-old females (all P < 0.05; Table 3). In a sensitivity analysis, the inclusion of sweetened tea in the definition of SSBs did not alter the association between sodium and SSB intake (data not shown). We performed the analysis by using 2 d of 24-h dietary recalls on a smaller sample (n = 4569) and defined SSB consumers as having reported the intake of SSBs (>0 g/d) on at least one of two 24-h dietary recalls.
### TABLE 2

<table>
<thead>
<tr>
<th>Age group</th>
<th>M</th>
<th>F</th>
<th>2–5 y</th>
<th>6–11 y</th>
<th>12–18 y</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n</strong></td>
<td></td>
<td></td>
<td>1050</td>
<td>773</td>
<td>1374</td>
</tr>
<tr>
<td><strong>β (95% CI)</strong></td>
<td>0.85 (0.62, 1.10)</td>
<td>0.05 &lt; 0.001</td>
<td>0.017 &lt; 0.001</td>
<td>0.05 &lt; 0.001</td>
<td>0.017 &lt; 0.001</td>
</tr>
<tr>
<td><strong>R²</strong></td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
<td>0.02</td>
</tr>
</tbody>
</table>

*In all models, the dependent variable was fluid consumption (g/d), and the independent variable was sodium intake (390 mg/d). Model 1a was unadjusted. Model 1b was adjusted for age, sex, race-ethnic group, socioeconomic status, BMI score, and season. Age and sex were not adjusted for in the stratified models. Model 1c was adjusted as for model 1b and for the number of times engaged in vigorous activity per week; the analysis was completed in a subsample of participants with physical activity data available (n = 5677). For F values, the second value in each cell represents the p value of the overall significance of F test of the regression model.*

### DISCUSSION

The positive association between dietary sodium intake and SSB consumption in US children is relatively consistent with results from the UK (6) and Australian (12) studies as well as one smaller study in German children aged 3–18 y, in which each additional 390 mg Na/d (1 g salt/d) was associated with a 74-g/d (2.6-oz/d) greater intake of fluid after adjustment for confounders, which remained consistent across age groups and by sex. In consumers of SSBs, each additional 390 mg Na/d (1 g salt/d) was associated with a 49-g/d (1.7-oz/d) greater intake of fluid consumption, respectively. The magnitude of the association was greatest in UK children, and this result may have been because of the adjustment of fewer covariates. It is well understood that a small rise in plasma osmolality (2–3%) will create an osmotic gradient shift that leads to intracellular dehydration and that the subsequent stimulus of the hypothalamic thirst center will initiate drinking behavior to restore body-fluid homeostasis (9, 33). Osmotic-induced thirst in response to dietary sodium intake has been shown in animal (34–36) and human (37, 38) studies. In addition, an intervention trial in adults showed that a low-sodium diet led to a significant reduction in the 24-h urinary volume, which is a marker of fluid consumption (10). Taken together, these findings support the notion that a high dietary sodium intake may increase fluid consumption.

The positive association between dietary sodium intake and SSB consumption in US children was 3191 ± 58 mg/d (8.1 ± 0.1 g salt/d). The 2010 Dietary Guidelines for Americans recommended that children consume ≤2300 mg Na/d and, in the case of African American children, ≤1500 mg Na/d (25). Therefore, dependent on the race-ethnic group, on average, a reduction in dietary sodium from 891 mg d (2.3 g salt/d) to 1691 mg/d (salt 4.3 g/d) is required to comply with dietary recommendations. When the results from the regression analysis were extrapolated, this level of sodium reduction would be associated with a reduction of 74–138 g SSBs/d in consumers of SSBs, which would be equivalent to a reduction of 30–50 kcal/d (23).
### Table 3

Multiple linear regression analysis of SSB consumption (g/d) and dietary sodium intake (390 mg/d) in consumers of SSBs by age group and sex: NHANES 2005–2008 (n = 4443)

<table>
<thead>
<tr>
<th>Age group</th>
<th>Total (n = 4443)</th>
<th>2–5 y</th>
<th>6–11 y</th>
<th>12–18 y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (n = 508)</td>
<td>F (n = 213)</td>
<td>M (n = 718)</td>
<td>F (n = 972)</td>
</tr>
<tr>
<td>2a</td>
<td>45 (27, 63), &lt;0.01</td>
<td>27 (12, 41), &lt;0.01</td>
<td>34 (19, 59), &lt;0.05</td>
<td>32 (13, 50), &lt;0.001</td>
</tr>
<tr>
<td>2b</td>
<td>40 (18, 62), &lt;0.01</td>
<td>30 (15, 43), &lt;0.001</td>
<td>27 (5, 51), &lt;0.05</td>
<td>25 (11, 38), &lt;0.01</td>
</tr>
</tbody>
</table>

In all models, the dependent variable was SSB consumption (g/d), and the independent variable was sodium intake (390 mg/d). Model 2a was unadjusted. Model 2b was adjusted for age, sex, race-ethnic group, socioeconomic status, and energy derived from sources other than SSBs (kcal/d). Age and sex were not adjusted for in the stratified models. For the large variation in the sodium content of different brand quality of food-composition databases, which may not capture reliable dietary intake data as determined by the NCHS. In the potential bias was minimized by excluding participants with unusually prone to underreporting bias (44); however, the potential bias was minimized by excluding participants with unreliable dietary intake data as determined by the NCHS. In the case of dietary sodium intake, assessments are limited by the quality of food-composition databases, which may not capture the large variation in the sodium content of different brand...
products (45, 46). In addition, the 24-h dietary recall does not measure the amount of salt added at the table, which is estimated to be small at ~6% of intake (41). Salt added during cooking is also estimated to be small at ~5% (41), and was adjusted for in NHANES data (16, 17). The collection of physical activity data were not standardized across all participants, which may have resulted in discrepancies in the reported physical activity between children and teens and across survey cycle years. Finally, because of the cross-sectional nature of the study, the causality between salt and either fluid or SSB intake could not be established. To confirm these findings, experimental study designs that control dietary sodium intake in children are required to determine the effect of an altered sodium intake on overall fluid and SSB consumption in children.

In conclusion, dietary sodium intake was associated with total fluid consumption and SSB intake in consumers of SSBs in US children and adolescents. Therefore, reductions in dietary sodium intake may be associated with modest reductions in SSB consumption and, consequently, with reductions in calorie intake. Because of our findings and the complexities in overcoming the childhood obesity epidemic, a comprehensive obesity prevention approach that includes wide-ranging strategies, such as sodium reduction, should be explored. If the sodium content of the US food supply continues at current amounts or increases, stronger messages to encourage children and their parents to replace children’s SSB intakes with water to help prevent excess weight gains may enhance obesity-prevention efforts.

The authors’ responsibilities were as follows—CAG, JDW, CAN, and CML: designed the research; CAG: analyzed data, wrote the manuscript, and had primary responsibility for the final content of the manuscript.; KL: provided statistical advice; JDW, KL, CML, and CAN: helped with data interpretation and revision of the manuscript and provided significant advice and consultation; and all authors: read and approved the final manuscript. None of the authors had a conflict of interest.

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