

Sugar-Sweetened Beverage Intake Is Positively Associated with Baseline Triglyceride Concentrations, and Changes in Intake Are Inversely Associated with Changes in HDL Cholesterol over 12 Months in a Multi-Ethnic Sample of Children^{1–3}

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Abstract

Background: Intake of sugar-sweetened beverages (SSBs) is linked to greater cardiometabolic risk in adults. Although longitudinal evidence is sparse among children, SSB intake reduction is targeted to reduce cardiometabolic risk factors in this group.

Objective: We investigated characteristics associated with consumption of SSBs in a multi-ethnic sample of children/adolescents and measured cross-sectional and longitudinal associations between SSB intake and plasma HDL cholesterol and triglycerides (TGs) over 12 mo.

Methods: In a diverse cohort of children aged 8–15 y, cross-sectional associations ($n = 613$) between baseline SSB intake and blood lipid concentrations and longitudinal associations ($n = 380$) between mean SSB intake, changes in SSB intake, and lipid changes over 12 mo were assessed with multivariable linear regression.

Results: Greater SSB intake was associated with lower socioeconomic status, higher total energy intake, lower fruit/vegetable intake, and more sedentary time. In cross-sectional analysis, greater SSB intake was associated with higher plasma TG concentrations among consumers (62.4, 65.3, and 71.6 mg/dL in children who consumed >0 but <2 , ≥ 2 but <7 , and ≥ 7 servings/wk, respectively; P -trend: 0.03); plasma HDL cholesterol showed no cross-sectional association. In the longitudinal analysis, mean SSB intake over 12 mo was not associated with lipid changes; however, the 12-mo increase in plasma HDL-cholesterol concentration was greater among children who decreased their intake by ≥ 1 serving/wk (4.6 ± 0.8 mg/dL) compared with children whose intake stayed the same (2.0 ± 0.8 mg/dL) or increased (1.5 ± 0.8 mg/dL; $P = 0.02$).

Conclusions: In a multi-ethnic sample of children, intake of SSBs was positively associated with TG concentrations among consumers, and changes in SSB intake were inversely associated with HDL cholesterol concentration changes over 12 mo. Further research in large diverse samples of children is needed to study the public health implications of reducing SSB intake among children of different racial/ethnic groups. The Daily D Health Study was registered at clinicaltrials.gov as NCT01537809. *J Nutr* 2015;145:2389–95.

Keywords: dyslipidemias, sweetening agents, ethnic groups, health status disparities, child

Introduction

The impact of sugar-sweetened beverage (SSB) intake on obesity and development of other cardiometabolic risk factors in children, including dyslipidemia and insulin resistance, has

received considerable attention (1–3). In 2009–2010, SSBs were the main source of added sugars in children's diets, accounting for as much as 8% of total energy intake among US children/adolescents aged 2–19 y (4). Aside from promoting energy imbalance and poor diet quality (5, 6), SSB intake is linked to

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³ Supplemental Table 1 is available from the "Online Supporting Material" link in the online posting of the article and from the same link in the online table of contents at <http://jn.nutrition.org>.

development of dyslipidemia through ectopic fat accumulation, de novo lipogenesis, visceral adiposity, and hypertriglyceridemia (7–9). In combination with low HDL cholesterol and obesity, high TG concentrations in children characterize a dyslipidemia associated with cardiometabolic risk (10).

Although a decrease in overall SSB intake in the United States was detected recently (4, 11), prevalence of SSB consumption has tended to be higher among some children, particularly children with lower socioeconomic status (SES) (12) and racial/ethnic minorities, including non-Hispanic black individuals (13). Consumption of SSBs among children is particularly concerning because dietary habits in childhood track into adulthood (14), potentially contributing years of exposure. To date, few longitudinal studies conducted on SSBs or added sugar intake in children/adolescents have examined the role of SSB consumption on changes in cardiometabolic risk factors such as blood lipids over time (1, 15).

Given that socioeconomic and racial/ethnic differences were reported in consumption of SSBs and cardiometabolic risk factors and that adverse effects of SSBs may be strongest in children (16), it is important to investigate the relation between SSB intake and dyslipidemia measures in large, socioeconomically and racially/ethnically diverse samples of children. Our overall aims were to investigate characteristics associated with SSB consumption in a multi-ethnic sample of children/adolescents and to measure associations between SSB intake and dyslipidemia, both cross-sectionally and longitudinally over 12 mo. For the cross-sectional analyses, associations between SSB intake at baseline and plasma HDL-cholesterol and TG concentrations were measured. In conducting the longitudinal analyses, the following 2 research questions were addressed: 1) the relation between mean SSB intake over 12 mo and changes in HDL cholesterol and TGs and 2) the relation between changes in SSB intake and changes in HDL cholesterol and TGs over 12 mo.

Methods

Study population. Secondary analyses were conducted with the use of data from children enrolled in a randomized, double-blind vitamin D supplementation trial, the Daily D Health Study. Details on study methodology are presented elsewhere (17). Briefly, in the fall of 2011 and 2012, 690 children aged 8–15 y in Boston area schools were randomly assigned to 1 of 3 doses of vitamin D₃ daily for 6 mo, with an additional follow-up at 12 mo; the primary outcome was serum 25-hydroxyvitamin D, and secondary outcomes were blood lipids and glucose. The study protocol and documents were approved by Tufts University's Institutional Review Board, and parental informed consent and the child's assent were obtained. The sample was predominantly non-white/Caucasian (41% white/Caucasian, 15% black/African American, 22% Hispanic/Latino, 8% Asian, and 14% multi-racial/other), 68% were from low SES households (assessed through the proxy measure eligibility for free or reduced-price school meals), and 47% were overweight/obese [≥ 85 th BMI (in kg/m²) percentile].

Measurements and variables. Dietary intake was measured with the 2004 Block FFQ for Children (NutritionQuest), a semiquantitative instrument that inquires about the frequency and portion size of consumption of 72 food and beverage line items and 6 clarification questions on food types, over the past week (i.e., past 7 d), as a proxy for usual intake (18, 19). Children self-reported their intake with the use of the FFQ, which inquired about the number of days in the past week (none, 1, 2, 3–4, 5–6, or 7) they consumed each beverage type; the number of bottles, cans, glasses, or juice boxes; and the size of soda [12 ounce (370 g) can, 20 ounce (615 g) bottle, or >20 ounces] consumed at each occasion. SSBs included regular sodas, non-100% fruit juices/drinks, and other beverages such as sweetened teas. The FFQ was

completed by children at baseline and at 6 and 12 mo, and data collected were analyzed and translated into daily intakes of foods, beverages, nutrients, and energy by NutritionQuest. With the use of previously defined cutoffs for implausible energy intakes among children/adolescents (20), FFQ data were excluded from analysis if total energy intake was <500 or >5000 kcal/d (baseline, $n = 67$; 6 mo, $n = 66$; 12 mo, $n = 59$). Further exclusion criteria included having diabetes ($n = 4$) or missing baseline or 12-mo data on SSBs (baseline, $n = 5$; 12 mo, $n = 11$) or blood lipids (baseline, $n = 1$; 12 mo, $n = 10$). The final sample size for the cross-sectional and longitudinal analyses were 613 and 380, respectively.

SSB intake data were originally provided as daily kilocalories from SSBs, and to convert to servings per day a serving was defined as 150 kcal for an ~12-oz (370 g) can or bottle (21). We multiplied daily SSB servings by 7 to convert to weekly servings. For cross-sectional analyses, we created a 4-level categorical variable for baseline SSB intake data: non-consumer (i.e., zero reported SSB intake at baseline, $n = 92$), >0 but <2 servings/wk, ≥ 2 but <7 servings/wk, and ≥ 7 servings/wk; the SSB consumption groups represent approximately once-weekly, every-other-day, and daily consumption of SSBs and closely follow the frequency categories provided on the FFQ. In the longitudinal analyses, categorical SSB variables were created for each research question. For the first longitudinal research question, the mean of the reported weekly servings of SSBs at baseline, 6 mo, and 12 mo was calculated to estimate mean SSB intake over 12 mo, and then each child was classified into the defined categories as described above. The non-consumer category represented children who reported zero consumption of SSBs at all time points ($n = 13$). To calculate change in SSB intake between baseline and 12 mo, we subtracted the estimated weekly servings of SSBs at baseline from estimated weekly servings of SSBs at 12 mo. Change in SSB intake was then categorized as ≥ 1 serving/wk decrease, approximately no change, and ≥ 1 serving/wk increase in SSBs. Lipid changes were calculated by subtracting the baseline lipid concentration from the 12-mo concentration. Because distributions of lipid changes between baseline and 12 mo showed outliers, before performing statistical testing, 5 data points were winsorized (22) by identifying those that were >2 SDs from the remainder of the distribution and substituting them with the next closest data point.

Blood was collected after an overnight fast and used to measure plasma HDL cholesterol and TGs. The determination of TG and HDL-cholesterol concentrations was simultaneously performed on the Hitachi 917 analyzer with the use of reagents and calibrators from Roche Diagnostics in a laboratory certified by the CDC/National Heart, Lung, and Blood Institute Lipid Standardization Program. Height and weight were directly measured by study personnel with the use of standard procedures (17). BMI was calculated and converted into a percentile and z score according to the CDC age- and sex-specific growth charts (23).

Parents reported SES and their child's race/ethnicity via questionnaire, as reported previously (17). Physical activity was assessed with the Block Kids Physical Activity Screener (NutritionQuest). The question capturing screen time from television, video games, and Internet was used as a proxy measure of sedentary time and dichotomized at <4 or ≥ 4 h/d. Children assessed their pubertal status by completing a brief pubertal questionnaire designed and validated for this age group (24), which inquired whether menarche was reached (for girls) or voices had changed (for boys) (25); an affirmative response to these questions was classified as late/after puberty, in comparison with before/early/mid-puberty.

Statistical analysis. Statistical analyses were conducted with SAS 9.3 software (SAS Institute Inc.), with 2-tailed tests and $P < 0.05$ representing statistical significance. To compare characteristics of children associated with category of SSB consumption in the cross-sectional and longitudinal study samples, baseline continuous data were compared across the 4 SSB intake categories with the use of ANCOVA or the Kruskal-Wallis test for variables with normal or skewed distributions, respectively, and proportions with the use of Pearson's chi-square test. Values in the text and Table 1 are means \pm SDs for normally distributed continuous variables, medians \pm IQRs for continuous variables with skewed distributions, or percentages. Dietary intake data were energy-adjusted with the residual method before computing

means \pm SDs by SSB category; for the longitudinal study, mean intakes over the 12 mo of total energy and energy-adjusted fruits/vegetables and discretionary solid fats are provided in Table 1.

Multivariable linear regressions with the use of ANCOVA modeled associations between SSB intake category and baseline HDL-cholesterol or TG concentrations, adjusting for age, sex, race/ethnicity, pubertal status, BMI z score, sedentary time, total energy intake, and intakes of fruits/vegetables (in servings/d) and discretionary solid fats (in g/d) as a proxy measure of diet quality. Baseline TG concentrations were log-transformed before regression analysis; thus, back-transformed adjusted geometric means and 95% CIs are presented. For HDL cholesterol, baseline adjusted means and 95% CIs are presented. Tests for linear trend of blood lipid concentrations across categories of SSB intake were conducted by including the median value per category as a continuous variable in regression models.

Longitudinal analyses compared SSB category with changes in HDL-cholesterol and TG concentrations between baseline and 12 mo. ANCOVA was used to compute unadjusted mean \pm SEM lipid changes by SSB category and least square mean \pm SEM lipid changes, and Tukey's HSD test was used to adjust for multiple comparisons. For the first longitudinal research question, mean \pm SEM lipid changes that adjusted for sex, race/ethnicity, baseline age, baseline lipid concentration, baseline pubertal status, baseline BMI z score, baseline sedentary time, and mean intakes of total energy, fruits/vegetables, and discretionary solid fats were compared by category of mean SSB intake. For the second longitudinal research question, mean \pm SEM lipid changes that adjusted for sex, race/ethnicity, baseline age, baseline lipid concentration, baseline pubertal status, baseline BMI z score, baseline sedentary time, baseline SSB intake category, and changes in intakes of total energy, fruits/vegetables, and discretionary solid fats between baseline and 12 mo were compared by category of SSB intake change. Other preselected variables that had biological plausibility as potential confounders, including vitamin D supplementation dose and free/reduced-price school meals eligibility, were assessed as possible covariates but were not retained in the final regression models because they were not significantly correlated with SSB intake nor independently associated with HDL-cholesterol or TG concentrations in regression analyses. Effect modification by race/ethnicity was tested with the use of cross-product terms in linear regression models; however, P -interactions were not significant. Thus, results are presented for the full sample of children.

Results

At baseline, \sim 85% of children reported consuming SSBs during the past week. Among SSB consumers ($n = 521$), median \pm IQR intake was 63 ± 90 kcal/d, constituting $\sim 4.7\% \pm 6.1\%$ of total daily energy intake and 2.9 ± 4.2 servings/wk (data not shown). In total, 109 children (18% of the baseline sample) consumed ≥ 7 servings/wk, or approximately ≥ 1 serving of SSBs daily (Table 1). When comparing sociodemographic and behavioral characteristics among baseline non-consumers and children who reported consuming < 2 , ≥ 2 but < 7 , and ≥ 7 SSB servings weekly, greater SSB consumption was associated with older age, late/after puberty status, and lower SES ($P \leq 0.007$ for each). Overall racial/ethnic distributions did not differ across SSB intake categories ($P = 0.15$). However, other characteristics such as puberty status, SES, BMI z score, sedentary time, and both HDL cholesterol and TG concentrations differed by race/ethnicity at baseline (Supplemental Table 1). Higher SSB consumption was associated with progressively greater intakes of total energy and lower intakes of fruits/vegetables per day at baseline, whereas discretionary solid fat intake was lower in the highest intake group than in the other groups. In the cross-sectional study, a significant linear trend was observed between SSB intake categories and baseline plasma TG concentrations after multivariable adjustment among consumers (P -trend: 0.03), but with

non-consumers included the trend was not significant (P -trend: 0.06; Table 1). No cross-sectional association was observed between SSB intake categories and HDL cholesterol.

For the longitudinal study, associations between SSB intake and low SES, total energy, and intake of fruits/vegetables persisted (Table 1). Moreover, greater mean SSB intake was associated with greater likelihood of sedentary time ≥ 4 h/d ($P = 0.004$); notably, no non-consumers were recorded as having ≥ 4 h/d of sedentary time. Over the 12-mo follow-up period, 97% of children reported consuming SSBs, and mean SSB intake among consumers comprised a median of $4.1\% \pm 5.9\%$ of total energy daily and 2.7 ± 3.3 servings/wk (data not shown). Among 380 children, 12% consumed ≥ 1 SSB servings/d over the 12 mo. Between baseline and 12 mo, SSB intake decreased by ~ 0.4 servings/wk (IQR: 3.5), and total energy also decreased (-195 ± 766 kcal/d). Over this same time period, HDL cholesterol increased a median of 2.7 ± 9.7 mg/dL and TGs increased 3.0 ± 32.5 mg/dL (data not shown). No association was observed between mean SSB intake and changes in HDL cholesterol or TGs (Table 2). However, over the 12-mo period, the increase in HDL-cholesterol concentrations was greater among children who decreased SSB intake by at least 1 serving/wk, controlling for SSB intake category at baseline, compared with children whose intake did not change or increased by at least 1 serving/wk (Table 3). No association was observed between change in SSB intake and TG changes.

Discussion

In a racially and ethnically diverse population of children, 85% consumed SSBs at baseline, and 18% consumed the equivalent of at least seven 12-oz (150 kcal) servings of SSBs weekly, approximating ≥ 1 SSB serving daily. Nearly all (97%) of the children who were followed over 12 mo were SSB consumers, and 12% consumed ≥ 1 SSB serving daily. Both cross-sectional and longitudinal analyses revealed associations between SSB intake and blood lipids; however, the associations differed. In cross-sectional analyses, greater SSB intake was associated with higher TG concentrations among consumers. Longitudinally over 12 mo, increases of ≥ 1 SSB servings weekly, or maintaining the same intake, were associated with lower HDL cholesterol increases, in comparison with children who decreased their SSB intake by ≥ 1 serving weekly.

Characteristics associated with SSB intake in our sample were largely expected. Greater SSB intake in children of lower SES was noted across many study samples (12) and may be related to SSBs being more heavily marketed in racial/ethnic-minority neighborhoods (26, 27) and less expensive than nutrient-dense food/beverage options. In both our cross-sectional and longitudinal analyses, higher SSB intake was associated with higher intake of total energy and lower intake of fruits/vegetables, which may suggest a diluting effect on diet quality among SSB consumers (5, 6, 28). Further, substantial evidence exists for direct associations between sedentary time, particularly screen time, and poor diet quality, including SSB intake (29–32).

In children and adolescents, although considerable evidence suggests positive associations between SSBs and weight gain or obesity (3, 33–37), data are sparse on associations with other cardiometabolic risk factors such as blood lipids. Analyses of the multi-ethnic NHANES population have demonstrated positive associations between greater SSB intakes and TGs and inverse associations with HDL cholesterol (38, 39). In a smaller multi-ethnic pediatric sample, an adverse, positive association between added sugars and TGs was observed, but no association was

TABLE 1 Characteristics by SSB intake category in the cross-sectional and longitudinal studies of children aged 8–15 y¹

Characteristic	Cross-sectional study, baseline SSB intake category			Longitudinal study, baseline to 12 mo, mean SSB intake category ²			P ³
	Non-consumer	>0 to <2 svg/wk	≥2 to <7 svg/wk	Non-consumer	>0 to <2 svg/wk	≥2 to <7 svg/wk	
<i>n</i>	92	168	244	109	135	186	46
SSB, svg/wk							
Median	0	1.0	3.5	11.6	1.2	3.4	10.6
Range	0	0.68–1.92	2.02–6.81	7.04–34.98	0.23–1.99	2.01–6.98	7.31–24.78
Age, y	11.5 ± 1.3	11.5 ± 1.4	11.9 ± 1.4	11.9 ± 1.5	11.1 ± 1.3	11.2 ± 1.5	11.5 ± 1.4
Female, %	63.0	45.2	53.3	50.5	48.2	51.6	50.0
Race/ethnicity, %							
White/Caucasian	50.0	36.9	45.1	33.0	46.7	43.6	39.1
Black/African American	12.0	13.1	16.0	17.4	9.6	15.1	17.4
Hispanic/Latino	14.1	26.8	18.0	26.6	20.7	15.1	26.1
Asian	10.9	10.1	7.0	6.4	11.9	9.7	2.2
Multi-racial/Other	13.0	13.1	13.9	16.5	11.1	16.7	15.2
BMI z score	0.87 ± 1.7	0.81 ± 1.8	0.90 ± 1.5	0.84 ± 1.6	0.84 ± 1.7	0.84 ± 1.6	0.70 ± 1.9
Late/after puberty, %	26.1	29.8	39.3	46.8	27.4	36.6	39.1
Sedentary ≥4 h/d, %	14.1	10.7	16.8	22.9	12.6	15.1	32.6
Eligible for free or reduced-price school meals, %	51.1	64.9	68.4	81.7	58.5	65.6	87.0
Total energy, kcal/d	1025 ± 583	1098 ± 663	1339 ± 663	1962 ± 1553	1042 ± 404	1315 ± 590	1799 ± 1078
Fruits/vegetables, svg/d	3.0 ± 1.5	2.7 ± 1.4	2.3 ± 1.3	1.9 ± 1.7	2.4 ± 1.2	2.2 ± 1.1	1.7 ± 0.9
Discretionary solid fats, g/d	27.4 ± 7.1	27.9 ± 6.3	28.0 ± 7.1	25.3 ± 9.2	26.4 ± 5.1	26.0 ± 5.4	25.6 ± 6.1
Plasma HDL-C, ⁴ mg/dL	51.5 (49.0, 54.1)	51.7 (49.9, 53.6)	51.8 (50.3, 53.4)	50.2 (47.6, 52.7)	51.1 (48.9, 53.3)	52.0 (50.2, 53.8)	51.6 (47.7, 55.6)
Plasma TGs, ⁴ mg/dL	68.1 (62.5, 74.1)	62.4 (58.6, 66.4)	65.3 (61.9, 68.9)	71.6 (65.7, 78.0)	68.0 (63.4, 73.0)	63.8 (60.1, 67.6)	63.9 (56.3, 72.6)

¹ Values are as follows: categorical variables, percentages; age, means ± SDs; BMI z score and total energy, medians ± IQRs because of skewed distributions; fruits/vegetables and discretionary solid fats, energy-adjusted means ± SDs because data were energy-adjusted with the use of the residual method before computing means and SDs; HDL-C, adjusted least square geometric means (95% CI) because of skewed distributions. HDL-C, HDL cholesterol; SSB, sugar-sweetened beverage; svg, serving.

² For the 380 children who had valid dietary data at baseline and 12 mo in the longitudinal study, the mean of SSB servings per week at baseline, 6 mo, and 12 mo was calculated to estimate mean SSB intake over 12 mo, and the same categories were created. 30 children were missing dietary data at 6 mo. Non-consumers represent children who reported zero consumption of SSBs at all time points. Baseline data for age, BMI z score, pubertal status, sedentary time, and HDL-C and TG concentrations are presented. Dietary data are mean intakes over 12 mo.

³ P values are P-trends for plasma HDL-C and TGs only.

⁴ Baseline HDL-C and TG concentrations were adjusted as follows: for the cross-sectional study, age, sex, race/ethnicity, pubertal status, BMI z score, sedentary time, total energy intake, and intakes of fruits/vegetables and discretionary solid fats; for the longitudinal study, baseline age, sex, race/ethnicity, baseline pubertal status, baseline BMI z score, baseline sedentary time, and mean intakes of total energy, fruits/vegetables, and discretionary solid fats.

TABLE 2 Longitudinal associations between mean SSB intake and changes in plasma lipid concentrations over 12 mo in children aged 8–15 y¹

Concentration	Unadjusted lipid changes (by SSB intake category), ² mg/dL				P	Adjusted lipid changes (by SSB intake category), ³ mg/dL				P
	Non-consumer	>0 to <2 svg/wk	≥2 to <7 svg/wk	≥7 svg/wk		Non-consumer	>0 to <2 svg/wk	≥2 to <7 svg/wk	≥7 svg/wk	
<i>n</i>	13	135	186	46		13	135	186	46	
Plasma HDL-C, mg/dL	1.4 ± 2.2	3.2 ± 0.7	2.5 ± 0.6	3.3 ± 1.2	0.76	0.8 ± 2.2	3.7 ± 0.7	2.7 ± 0.6	2.5 ± 1.3	0.47
Plasma TGs, mg/dL	11.8 ± 8.1	4.0 ± 2.5	3.5 ± 2.1	4.8 ± 4.3	0.80	18.6 ± 8.1	4.5 ± 2.7	2.1 ± 2.2	3.8 ± 4.8	0.26

¹ HDL-C, HDL cholesterol; SSB, sugar-sweetened beverage; svg, serving.² Values are unadjusted means ± SEMs.³ Least square means ± SEMs were adjusted for baseline age, sex, race/ethnicity, baseline lipid concentration, baseline pubertal status, baseline BMI z score, baseline sedentary time, and mean intakes of total energy, fruits/vegetables, and discretionary solid fats.

detected with HDL cholesterol (40). Our cross-sectional analyses demonstrated an association with increased TG concentrations across SSB intake categories among consumers, up to 71.6 mg/dL in the top category, after adjusting for BMI z score, total energy, and other possible confounders; however, no association was observed with HDL-cholesterol concentrations.

Our first longitudinal research question considered whether mean SSB intake over 12 mo was associated with changes in blood lipids between baseline and 12 mo. The use of mean SSB intake data from multiple FFQs likely improved the precision of the SSB intake estimate (41–43), which reduced random measurement error and was expected to increase power to detect associations in the smaller longitudinal sample ($n = 380$ vs. 613 for cross-sectional analyses). However, mean SSB intake did not show an association with lipid changes over 12 mo. In this study, children's self-reporting of dietary intake, particularly over time, likely introduced measurement error, most plausibly contributing to attenuation of findings. Specifically, misclassification of SSB intake may have occurred, because underreporting of foods perceived to be unhealthy such as SSBs is common, particularly among children who are overweight or obese (44). Notably, in both the cross-sectional and longitudinal studies, we found that children identified as non-consumers appeared to be characteristically different (28) from children in the SSB consumption categories, with relatively high TG concentrations at baseline. Another possibility is that children may have recently changed their SSB consumption behavior due to underlying health concerns. For example, children who were less healthy or overweight/obese may have been told to reduce SSB consumption, which our data may have captured. Nonetheless, underreporting of SSB intake by children in this study likely played a role in attenuating these longitudinal study findings.

To take advantage of the temporal aspect of the longitudinal data, we also examined the association between change in SSB

and change in lipids. We report a significant association of a more favorable HDL cholesterol change in children who decreased their SSB intake compared with children who stayed the same or increased intake over 12 mo. Although the change in SSB consumption captured in this study was the difference between reported intake at baseline and 12 mo, with non-consumers at both times included within the no change category, by controlling for baseline SSB intake category, SSB changes were placed into context within the spectrum of SSB intake. Other studies in this age group have reported longitudinal associations between added sugars or SSBs and HDL cholesterol, including decreased HDL cholesterol over 3 y in adolescents with greater SSB consumption (1) and among white/Caucasian and African American girls aged 9–10 y at baseline, a 2.2-mg/dL mean increase in HDL cholesterol over 10 y among children with low added-sugar intakes compared with a 0.4-mg/dL decrease among children with high added-sugar intakes (15). Because between 9 and 12 y of age, HDL cholesterol was reported to decline slightly and to rebound in late teens (15), the increased HDL cholesterol observed in this study, and the greater HDL cholesterol increase in children who decreased their SSB intake, are hypothesis-generating findings worth pursuing in further studies. Given that children in this study took a daily vitamin D supplement for 6 mo, potential beneficial effects on HDL-cholesterol and/or TG concentrations (45–47) may have persisted at 12 mo; however, we found that dose distributions and serum 25-hydroxyvitamin D changes did not differ across SSB intake categories (data not shown); thus, vitamin D supplementation effects cannot explain the longitudinal study's findings.

The Daily D Health Study sample comprised a large sample of children that was predominantly non-white/Caucasian and of lower SES, providing a valuable sample with which to conduct this research. Having repeated measures of dietary, sociodemographic, anthropometric, and fasting blood data allowed us to

TABLE 3 Longitudinal associations between changes in SSB intake and changes in plasma lipid concentrations over 12 mo in children aged 8–15 y¹

Concentration	Unadjusted lipid changes (by SSB change category), ² mg/dL				P	Adjusted lipid changes (by SSB change category), ³ mg/dL				P
	≥1 svg/wk decrease	No change	≥1 svg/wk increase			≥1 svg/wk decrease	No change	≥1 svg/wk increase		
<i>n</i>	154	122	104		154	122	104			
Plasma HDL-C, mg/dL	4.1 ± 0.6 ^a	2.2 ± 0.7 ^{a,b}	1.5 ± 0.8 ^b	0.02	4.6 ± 0.8 ^a	2.0 ± 0.8 ^b	1.5 ± 0.8 ^b	0.02		
Plasma TGs, mg/dL	3.2 ± 2.3	1.4 ± 2.6	8.6 ± 2.8	0.16	2.2 ± 3.0	1.0 ± 2.9	7.9 ± 3.0	0.19		

¹ HDL-C, HDL cholesterol; SSB, sugar-sweetened beverage; svg, serving.² Values are unadjusted means ± SEMs. Labeled means in a row without a common letter differ, $P < 0.05$ (ANCOVA with Tukey's HSD test).³ Least square means ± SEMs were adjusted for baseline age, sex, race/ethnicity, baseline lipid concentration, baseline pubertal status, baseline BMI z score, baseline sedentary time, baseline SSB intake category, and changes in intakes of total energy, fruits/vegetables, and discretionary solid fats over 12 mo. Labeled means in a row without a common letter differ, $P < 0.05$ (ANCOVA with Tukey's HSD test).

investigate longitudinal associations over 12 mo between SSB intake and dyslipidemia measures. However, the study has limitations. As noted, children's self-reporting of dietary intake likely introduced measurement error. Moreover, although validation studies for the Block FFQ for Children have reported relatively high relative validity (intraclass correlation: 0.69) for measuring percentage of energy from carbohydrate (19) and similar accuracy in capturing intake of fruit drinks and sodas as 3-d food diaries (48), children aged ≥ 12 y reported more accurately than younger children (19), and a lack of traditional, cultural food and beverage items on the FFQ resulted in underestimates of dietary intake among minority racial/ethnic groups (49, 50). In addition, the FFQ does not include nontraditional SSBs, such as sports/energy drinks (12), which may have contributed to misclassification of SSB intake. Most likely, these sources of dietary measurement error resulted in underestimating levels of exposure, attenuating study findings. Similarly, imprecise physical activity data precluded the use of a more quantitative measure as a covariate in regression analyses; however, self-reported sedentary time has also shown strong correlations with SSB intake (29–32) and cardiometabolic risk (51, 52).

In conclusion, this study observed a positive association among consumers between higher SSB intake and higher TG concentrations in cross-sectional analyses and an inverse longitudinal association between SSB intake changes and HDL cholesterol changes, with decreased SSB intake associated with a greater increase in HDL cholesterol over 12 mo. Thus, both greater SSB intake at baseline and increased SSB intake over 12 mo showed associations with blood lipids. These findings reinforce the importance of minimizing consumption of SSBs among children/adolescents, particularly among groups with greater tendency to consume them. However, given that few longitudinal studies investigating SSBs and blood lipids have been conducted in racially/ethnically diverse samples of children/adolescents and that our cross-sectional and longitudinal results showed differing associations with TGs and HDL cholesterol, respectively, additional longitudinal research in large, multi-ethnic samples is needed to better understand the health implications of SSB intake in diverse samples of children.

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