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Relationship Between Insulin Resistance-Associated Metabolic Parameters and Anthropometric Measurements With Sugar-Sweetened Beverage Intake and Physical Activity Levels in US Adolescents:

Findings From the 1999-2004 National Health and Nutrition Examination Survey

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Abstract

Objective—To evaluate the relationship between insulin resistance-associated metabolic parameters and anthropometric measurements with sugar-sweetened beverage intake and physical activity levels.

Design—A cross-sectional analysis of the National Health and Nutrition Examination Survey data collected by the National Center for Health Statistics.

Setting—Nationally representative samples of US adolescents participating in the National Health and Nutrition Examination Survey during the years 1999-2004.

Participants—A total of 6967 adolescents aged 12 to 19 years.

Main Exposure—Sugar-sweetened beverage consumption and physical activity levels.

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Outcome Measures—Glucose and insulin concentrations, a homeostasis model assessment of insulin resistance (HOMA-IR), total, high-density lipoprotein, and low-density lipoprotein cholesterol concentrations, triglyceride concentrations, systolic and diastolic blood pressure, waist circumference, and body mass index (calculated as weight in kilograms divided by height in meters squared) percentile for age and sex.

Results—Multivariate linear regression analyses showed that increased sugar-sweetened beverage intake was independently associated with increased HOMA-IR, systolic blood pressure, waist circumference, and body mass index percentile for age and sex and decreased HDL cholesterol concentrations; alternatively, increased physical activity levels were independently associated with decreased HOMA-IR, low-density lipoprotein cholesterol concentrations, and triglyceride concentrations and increased high-density lipoprotein cholesterol concentrations. Furthermore, low sugar-sweetened beverage intake and high physical activity levels appear to modify each others' effects of decreasing HOMA-IR and triglyceride concentrations and increasing high-density lipoprotein cholesterol concentrations.

Conclusions—Sugar-sweetened beverage intake and physical activity levels are each independently associated with insulin resistance-associated metabolic parameters and anthropometric measurements in adolescents. Moreover, low sugar-sweetened beverage intake and high physical activity levels appear to modify each others' effects on several health-related outcome variables.

THE INCREASING PREVA-lence of obesity, insulin resistance, and metabolic syndrome (a group of conditions associated with insulin resistance including hypertension, dyslipidemia, central adiposity, and impaired glucose metabolism) in the pediatric population is a global health issue, especially given that these conditions in childhood may be antecedents to adult disease.1-6 As such, the long-term public health consequences of these disorders in children and adolescents with respect to premature morbidity and mortality are significant.

A considerable amount of research over the past decade has been devoted to studying the genetic aspects of these conditions7-9 and which individuals may be predisposed to disorders of weight management or insulin sensitivity. However, environmental factors are also undoubtedly contributors to these conditions' development. Specifically, 2 lifestyle behaviors associated with obesity, insulin resistance, and metabolic syndrome are (1) high levels of sugar-sweetened beverage (SSB) intake10-14 and (2) low levels of physical activity (PA).15-21 Dietary modifications and consistent exercise are thus 2 recommendations typically given by pediatricians to children and adolescents either at risk for or currently diagnosed with these disorders.

Experimental studies support the hypothesis that SSBs may increase energy intake and induce weight gain via their reduced satiety response, the promotion of a positive energy balance by liquid calories relative to isoenergetic solid calories, and their dysregulation of energy homeostasis.22-26 Although not all studies support an association between SSB consumption and obesity,27,28 SSB intake has nonetheless been associated with increased body weight, increased fat mass, dyslipidemia, and blood pressure.29,30 Experimental studies also suggest that increased PA improves insulin sensitivity.20,21,31-39 Exercise

acutely improves insulin sensitivity for up to 48 hours because of an increase in insulin-stimulated glucose transport and glycogen synthesis,40,41 and regular exercise training induces long-term changes within the skeletal muscle that may improve whole-body insulin sensitivity.35 Moreover, several clinical studies have shown that exercise improves a subject's overall health.42,43

The increasing incidence and prevalence of obesity, insulin resistance, and metabolic syndrome in the pediatric population is well recognized44-47; however, the relationship between insulin resistance-associated metabolic parameters and anthropometric measurements with SSB intake and PA levels in children and adolescents remains poorly understood. Furthermore, studies evaluating the association of SSB consumption and exercise with these conditions are limited,16,48 which is unfortunate given that a better understanding of how diet and PA are related to these conditions may provide clinical and public health information for prevention and treatment strategies.

Thus, to evaluate the relationship between insulin resistance-associated metabolic parameters and anthropometric measurements with SSB intake and PA levels in the US adolescent population, we analyzed these associations using data from the National Health and Nutrition Examination Survey (NHANES) during the years 1999-2004.

METHODS

STUDY DESIGN AND POPULATION

The NHANES is conducted by the National Center for Health Statistics of the Centers for Disease Control and Prevention and is designed to monitor the health and nutritional status of the US civilian noninstitutionalized population. Since 1999, NHANES has been planned and conducted as a continuous annual survey, and data are released in 2-year periods (eg, 1999-2000, 2001-2002). A nationally representative sample is selected annually using a stratified multistage probability cluster sample design49; oversampling Mexican American and black individuals, adolescents aged 12 to 19 years, persons 60 years and older, low-income white individuals, and pregnant women permits more precise estimates for these groups. This study is based on data obtained from NHANES 1999-2000, 2001-2002, and 2003-2004, as these were the most recently available NHANES that had released all of the data needed for the inclusion criteria, exclusion criteria, and outcome variables. The NHANES protocol was approved by the National Center for Health Statistics institutional review board, and written informed consent was obtained from all participants aged 18 years and older; for participants younger than 18 years, written informed assent was obtained in addition to parent or guardian consent. This study was approved by the institutional review board at the University of California, Davis.

DATA COLLECTION

The NHANES protocol consists of a home interview performed by a trained interviewer followed by a visit to an examination center where participants underwent physical examinations, provided blood and urine samples, and completed additional questionnaires. The details of the participant examinations and laboratory assessments are available on the

NHANES Web site.49 For our study, only data from participants aged 12 to 19 years were analyzed; individuals were excluded from analyses if they were pregnant and/or used steroids, blood glucose regulators, insulin, other antidiabetic agents, growth hormones, or sex hormones.

MEASUREMENTS

Outcome variables included glucose levels, insulin levels, homeostasis model assessment of insulin resistance (HOMA-IR) measurements, total cholesterol levels, high-density lipoprotein cholesterol (HDL-C) levels, low-density lipoprotein cholesterol (LDL-C) levels, triglyceride (TG) levels, systolic blood pressure (SBP), diastolic blood pressure, waist circumference (WC), and body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) percentile for age and sex (per the National Center for Health Statistics references).50 The HOMA-IR ([fasting glucose in millimoles per liter×fasting insulin in milliunits per milliliter]/22.5),51 LDL-C, and TG results were limited to those who had completed at least an 8-hour fast. Mean WC is presented as the least squares mean, controlling for age and sex.

DEFINITIONS

Sugar-sweetened beverage information was obtained through a 24-hour dietary recall interview. (In NHANES 2003-2004, the 24-hour recall was assessed on 2 separate days; the first day was an in-person interview comparable with the previous NHANES study periods' primary interview mode, whereas the second day was a telephone interview 3-10 days later. For consistency in the methodology of data collection among the study periods, only the first day of the NHANES 2003-2004 24-hour recall was used in our analyses.) Sugar-sweetened beverages were defined as caloric soft drinks, colas, sugar-sweetened fruit drinks, or other SSBs; pure fruit juices and diet soft drinks were not included. Sugar-sweetened beverage intake in grams for each reported beverage was divided by 250 g (a serving equivalent; approximately 8 ounces or a cup of beverage) and summed for each adolescent. In each NHANES analyzed, low SSB intake was defined as the lowest quintile (≤20th percentile) of the sum of the number of SSB serving equivalents a subject consumed per day; medium was defined as the 2nd to 4th quintiles (>20th to <80th percentile); high was defined as the highest quintile (≥80th percentile). Units of SSB intake are defined as the number of SSB serving equivalents per day. Physical activity information was obtained during the interview questionnaire. Low PA was defined as the lowest quintile (≤20th percentile) of the sum of (the mean number of times a subject did activity per day) × (the average duration of each time in minutes) × (the metabolic equivalent score)52,53; medium was defined as the 2nd to 4th quintiles (>20th to <80th percentile); high was defined as the highest quintile (≥80th percentile).

STATISTICAL ANALYSIS

Statistical analyses were performed with SUDAAN version 9.0 (Research Triangle Institute, Research Triangle Park, North Carolina) using techniques appropriate for the complex NHANES survey design. All of the analyses used the NHANES-provided sampling weights that were calculated to take into account unequal probabilities of selection resulting from the sample design, nonresponse, and planned oversampling of selected subgroups so the results

are representative of the US community-dwelling population. Dietary and activity variables were analyzed both as continuous variables and in quintiles to minimize the chance that a small number of extreme observations would have undue influence on the results. Descriptive statistics summarize the data and are expressed as the mean (standard error [SE]). Multivariate linear regression analyses were performed to determine independent associations between each outcome variable and the number of serving equivalents of SSBs consumed and/or the levels of PA after adjusting for age, sex, race, and energy intake (in kilocalories). Analyses involving female subjects were adjusted for the occurrence or nonoccurrence of menarche. All *P* values are 2-sided and statistical significance was established a priori at α=.05.

RESULTS

CHARACTERISTICS

The baseline characteristics of the study participants are shown in Table 1. A total of 6967 adolescents were studied; the mean age of the participants was 15.5 years, 51.1% of the participants were male, and 48.9% of the participants were female. The ethnic distribution of the participants was 62.1% white, 14.8% black, 10.9% Mexican American, 5.3% other (including multiracial), and 6.9% other Hispanic. For the metabolic evaluations, 442 individuals (approximately6% of the study population) were excluded from analyses because of pregnancy and/or the use of steroids, blood glucose regulators, insulin, other antidiabetic agents, growth hormones, or sex hormones.

METABOLIC PARAMETERS AND ANTHROPOMETRIC MEASUREMENTS ASSOCIATED WITH SSB INTAKE

The characteristics of the low-, medium-, and high-SSB intake groups as well as the results of the multivariate linear regression analyses evaluating the relationship between SSB intake and insulin resistance-associated metabolic parameters and anthropometric measurements are shown in Table 2. The low-SSB intake group consumed a mean of 0.01 SSB serving equivalents (approximately 0.1 oz) per day (SE, 0.003; range, 0-0.4 [approximately 0-3 oz]); the medium-SSB intake group consumed a mean of 2.5 SSB serving equivalents (approximately 20 oz) per day (SE, 0.03; range, 0.5-4.8 [approximately 4-38 oz]), and the high-SSB intake group consumed a mean of 7.4 SSB serving equivalents (approximately 60 oz) per day (SE, 0.2; range, 4.9-33.4 [approximately 40-266 oz]). Each additional SSB serving equivalent consumed per day was associated with a 5% increase in HOMA-IR, a 0.16-mm Hg increase in SBP, a 0.47-cm increase in WC, a 0.90-percentile increase in BMI for age, and a 0.48-mg/dL decrease in HDL-C concentrations.

METABOLIC PARAMETERS AND ANTHROPOMETRIC MEASUREMENTS ASSOCIATED WITH PA LEVELS

The characteristics of the low-, medium-, and high-PA level groups as well as the results of the multivariate linear regression analyses evaluating the relationship between PA levels and insulin resistance-associated metabolic parameters and anthropometric measurements are shown in Table 3. In the low-PA group, 14.4% reported having engaged in at least 1 moderate activity during the past 30 days, whereas 7.4% reported having engaged in at least

1 vigorous activity during the past 30 days. In the medium-PA group, 75.4% reported having engaged in at least 1 moderate activity during the past 30 days, whereas 79.8% reported having engaged in at least 1 vigorous activity during the past 30 days. In the high-PA group, 74.6% reported having engaged in at least 1 moderate activity during the past 30 days, whereas 96.9% reported having engaged in at least 1 vigorous activity during the past 30 days. Each incremental increase in PA level per day was associated with a 0.03% decrease in HOMA-IR, a 0.004-mg/dL decrease in LDL-C concentrations, a 0.01-mg/dL decrease in TG concentrations, and a 0.001-mg/dL increase in HDL-C concentrations.

METABOLIC PARAMETERS AND ANTHROPOMETRIC MEASUREMENTS ASSOCIATED WITH SSB INTAKE AND PA LEVELS

Because the combination of dietary modification (with decreased SSB intake) and exercise (with increased PA levels) are typically recommended to children and adolescents either at risk for or currently diagnosed with obesity, insulin resistance, or metabolic syndrome, we evaluated the factors associated with the combination of each extreme (ie, low SSB intake and high PA vs high SSB intake and low PA level); the characteristics of the 2 groups as well as the results of the multivariate linear regression analyses evaluating the relationship between low SSB intake and high PA levels with insulin resistance-associated metabolic parameters and anthropometric measurements are shown in Table 4. The combination of low SSB intake and high PA levels was significantly associated with increased HDL-C concentrations, a lower HOMA-IR, and lower TG concentrations. Furthermore, the finding that the β coefficients for these 3 outcome variables (HDL-C concentrations, HOMA-IR, and TG concentrations) are greater with the combination of low SSB intake and high PA levels than with either alone suggests an effect modification.

SEX-SPECIFIC SUBGROUP ANALYSES

Because differences between the sexes may influence the metabolic parameters and anthropometric measurements associated with SSB intake, PA levels, and their combination, sex-specific subgroup analyses were also performed; these results are shown in Table 5. (Although the NHANES 1999-2004 data did not include any information on pubertal status, it did include the age of first menses in female subjects. Thus, we were able to control for menarche in our subgroup analyses of female adolescents; subgroup analyses of male adolescents are included for comparison.)

In female adolescents, each additional SSB serving equivalent consumed per day was associated with a 7% increase in HOMA-IR, a 2.25-mg/dL increase in TG concentrations, a 0.38-mm Hg increase in SBP, a 0.75-cm increase in WC, a 0.84-percentile increase in BMI for age, and a 0.73-mg/dL decrease in HDL-C concentration. However, in male adolescents, each additional SSB serving equivalent consumed per day was associated with a 0.29-cm increase in WC, a 0.78-percentile increase in BMI for age, and a 0.35-mg/dL decrease in HDL-C concentration. Alternatively, each incremental increase in PA level in female adolescents was only associated with a 0.01-mg/dL decrease in TG concentrations, whereas each incremental increase in PA level in male adolescents was associated with a 0.04% decrease in HOMA-IR, a 0.005-mg/dL decrease in LDL-C concentrations, a 0.01-mg/dL decrease in TG concentrations, and a 0.001-cm decrease in WC. Furthermore, although the

combination of low SSB intake and high PA levels in female adolescents revealed no significant associations with any insulin resistance-associated metabolic parameters or anthropometric measurements, the combination of low SSB intake and high PA levels in male adolescents was significantly associated with increased HDL-C concentrations, a lower HOMA-IR, and lower TG concentrations.

COMMENT

In these nationally representative samples of US adolescents, we found significant differences between the degrees of SSB intake and PA levels with insulin resistance-associated metabolic parameters and anthropometric measurements.

Multivariate linear regression analyses showed that increased SSB consumption was independently associated with increased HOMA-IR, SBP, WC, and BMI percentile for age and sex and decreased HDL-C concentrations; alternatively, increased PA levels were independently associated with decreased HOMA-IR, LDL-C concentrations, and TG concentrations and increased HDL-C concentrations. Furthermore, low SSB intake and high PA levels appear to modify each others' effects on decreasing HOMA-IR and TG concentrations and increasing HDL-C concentrations. These findings thus support the promotion of each lifestyle parameter (ie, decreased SSB consumption and increased PA levels) in children or adolescents either at risk for or currently diagnosed with obesity, insulin resistance, or metabolic syndrome.

Subgroup analyses based on sex also showed that SSB intake and PA levels were independently associated with insulin resistance-associated metabolic parameters and anthropometric differences; however, the associations of each were sex-specific. In female adolescents, increased SSB consumption was associated with an increase in HOMA-IR, TG concentrations, SBP, WC, and BMI percentile and a decrease in HDL-C concentrations. However, in male adolescents, SSB consumption was only associated with an increase in WC and BMI percentile and a decrease in HDL-C concentrations. Alternatively, increased PA levels in female adolescents were only associated with a decrease in TG concentrations, whereas increased PA levels in male adolescents were associated with a decrease in HOMA-IR, LDL-C concentrations, TG concentrations, and WC. Furthermore, although the combination of low-SSB intake and high PA levels revealed no significant associations with any insulin resistance-associated metabolic parameters or anthropometric measurements in female adolescents, the combination of low SSB intake and high PA levels was significantly associated with a lower HOMA-IR, lower TG concentrations, and increased HDL-C concentrations, just as it was when the cohort was studied in its entirety.

The sex-related differences that we observed with respect to the association of SSB intake and PA levels with insulin resistance-associated metabolic parameters and anthropometric measurements are intriguing; however, given the many physiological differences that exist between male and female adolescents during the adolescent years and our limited ability in female adolescents and inability in male adolescents to assess and control for pubertal status, our results are not necessarily surprising. Furthermore, many other variables that we could

not account for during our analyses such as a subject's dietary behavior and precise body composition measurements may have influenced our results.

Sugar-sweetened beverages may negatively affect hepatic metabolism and energy homeostasis,24 and the consumption of SSBs has been implicated in many10,11,24,54 but not all27,28 studies as a contributing factor to the increased incidence and prevalence of overweight and obesity. The odds of a pediatric patient becoming obese—and therefore at risk for developing metabolic syndrome—has been reported to increase byapproximately60% for each additional SSB serving per day,12 and individuals who consume a large portion of their daily energy in the form of SSBs are reported to have increased body weight, increased fat mass, dyslipidemia, and high blood pressure.29,30 Although discrepancy exists in the literature regarding the association of SSB intake with a subject's metabolic status (which may in large part be because of the many types of studies that have been performed [ie, prospective, cross-sectional, and retrospective—all with different inclusion/exclusion criteria and means of data analysis]), our study shows an independent relationship between increased SSB intake and increased HOMA-IR, SBP, WC, and BMI percentile for age and sex and decreased HDL-C concentrations, thus supporting the beneficial relationship of limited SSB intake with insulin resistance-associated parameters.

Alternatively, PA causes more of its metabolicchanging effects by its action on skeletal muscle, and regular exercise induces long-term changes within the skeletal muscle that improve whole-body insulin sensitivity.35,40,41 Although there have been fewer epidemiological studies regarding the association of PA levels with overweight and obesity in children, data from large adult studies42,43 have convincingly shown the metabolic benefits of increased exercise. Moreover, a recent study in adolescents showed that moderate PA was positively related to improved glucose metabolism and resting energy expenditure.55 Our study further supports the metabolic and health benefits of exercise and shows an independent relationship between increased PA levels and decreased HOMA-IR, LDL-C concentrations, and TG concentrations and increased HDL-C concentrations.

Importantly, the finding that the absolute values of the β coefficients from our multivariate linear regression analyses were consistently smaller for the PA analyses than for the SSB analyses does not diminish the significance of exercise and its relationship with insulin resistance-associated parameters; rather, it is a reflection of the methodology used. Sugar-sweetened beverage intake was defined as the number of SSB serving equivalents a subject consumed per day, whereas PA levels were defined as (the mean number of times a subject did activity per day) × (the average duration of each time in minutes) × (the metabolic equivalent score). As would be expected from its determination from multiple variables, a much wider range of PA levels were calculated in the study population than SSB intake levels, influencing the effect of a single unit of incremental change on the outcome. However, based on our model, even a small increase in daily exercise by an individual (eg, increasing the mean number of times a subject engaged in PA from 2 to 3 per day and increasing the average duration of physical activity from 10 to 15 minutes) would have a profound effect on their calculated PA level (increasing it by 225%), leading to larger

changes in the outcome variables than would be expected by the small value of the β coefficient.

Given that the biological effects of SSB consumption and exercise are different, we were not surprised to find that the combination of low SSB intake and high PA levels appeared to modify each others' effects on several insulin resistance-associated parameters. However, the fact that we only observed this effect for HOMA-IR, HDL-C concentrations, and TG concentrations, but not the other outcome variables, is interesting and requires further investigation with well-designed prospective studies. Nevertheless, HOMA-IR, HDL-C concentrations, and TG concentrations are commonly used in clinical practice as markers of a subject's metabolic status, and thus our data suggest that promoting decreased SSB consumption and increased levels of exercise in adolescents is important for overall health.

Our study has several significant limitations. First, because our study is cross-sectional, all we are able to report are associations as opposed to causality. Second, because the pubertal status of our subjects was not documented in the NHANES periods that we studied, we are unable to adjust our analyses for the subjects' degree of sexual maturation. Third, studies such as ours that use questionnaire data have inherent limitations: (1) the recall method is subject to inaccuracy and bias, especially with behaviors such as dietary habits56 and levels of exercise52; and (2) an individual's dietary habits and levels of exercise can vary greatly from one day to the next, limiting the reliability of short-term recall on long-term patterns. However, given that overweight subjects often underreport their levels of energy intake56 and less active adolescents often overestimate their degree of physical fitness,52 we can have confidence in our results because these biases would be expected to diminish rather than enhance our ability to find significant associations between SSB consumption and PA levels with insulin resistance-associated measures.

In summary, we report that SSB intake and PA levels are each independently associated with insulin resistance- associated metabolic parameters and anthropometric measurements in adolescents; moreover, low SSB intake and high PA levels appear to modify each others' effect on several health-related outcome variables. Thus, although prospective studies are needed to directly test the effects of dietary modification and consistent exercise on the development of obesity, insulin resistance, and metabolic syndrome in the pediatric population, pediatricians should continue promoting these lifestyle modifications in efforts to improve overall health.

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Table 1

Characteristics of US Adolescents Aged 12 to 19 Years: NHANES 1999-2004 Cohorts

	NHANES			
Characteristic	**1999-2000**	**2001-2002**	**2003-2004**	**1999-2004**
Participants, No.	2308	2417	2242	6967
Mean age, y	15.4	15.5	15.4	15.5
Sex, %				
Male	51.5	50.6	51.1	51.1
Female	48.5	49.4	48.9	48.9
Race or ethnicity, %				
White	56.8	63.8	64.9	62.1
Black	14.9	13.9	15.7	14.8
Mexican American	13.0	9.0	11.1	10.9
Other, including multiracial	7.3	5.3	3.6	5.3
Other Hispanic	8.0	8.0	4.7	6.9

Abbreviation: NHANES: National Health and Nutrition Examination Survey.

Table 2

Characteristics of SSB Intake Groups and the Multivariate Linear Regression Coefficients[a]

		Unadjusted Mean (SE) by Intake Group[b]			β (SE)[c]	
Characteristic	**Sample Size No.**	**Low**	**Medium**	**High**	**SSB Intake**	***P* Value**
HOMA-IR[d]	2630	2.1 (0.1)	2.6 (0.1)	2.5 (0.1)	0.05 (0.02)	.01
TC, mg/dL	6028	162.1 (1.3)	161.9 (0.8)	159.8 (1.5)	-0.10 (0.23)	.66
HDL-C, mg/dL	6026	51.4 (0.6)	50.1 (0.2)	47.3 (0.5)	-0.48 (0.08)	<.001
LDL-C, mg/dL[d]	2641	91.2 (1.6)	93.6 (1.0)	91.4 (2.0)	0.13 (0.28)	.64
TG, mg/dL[d]	2652	83.9 (3.0)	91.7 (3.1)	95.5 (3.3)	1.02 (0.84)	.23
SBP, mm Hg	6401	107.8 (0.4)	108.4 (0.3)	111.1 (0.5)	0.16 (0.07)	.03
DBP, mm Hg	6401	62.3 (0.6)	61.5 (0.4)	62.4 (0.6)	0.01 (0.07)	.85
WC, cm	6470	82.0 (0.6)	80.3 (0.4)	82.0 (0.6)	0.47 (0.08)	<.001
BMI percentile	6525	63.3 (1.5)	62.4 (0.8)	63.4 (1.2)	0.90 (0.16)	<.001

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; SBP, systolic blood pressure; SSB, sugar-sweetened beverage; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

SI conversions: To convert total, LDL, and HDL cholesterol to millimoles per liter, multiply by 0.0259; to convert TG to millimoles per liter, multiply by 0.0113.

[a] Evaluating the relationship between SSB intake and insulin resistance-associated metabolic parameters and anthropometric measurements.

[b] Low defined as the lowest quintile of the sum of the number of serving equivalents of caloric soft drinks, colas, sugar-sweetened fruit drinks, or other SSBs consumed per day; medium defined as the second to fourth quintile; high defined as the highest quintile.

[c] β (SE) are for the number of serving equivalents of SSBs consumed per day, adjusting for amount of physical activity performed per day, age, sex, race, and energy intake (in kilocalories).

[d] Fasting subsample.

Table 3

Characteristics of PA Level Groups and the Multivariate Linear Regression Coefficients[a]

		Unadjusted Mean (SE) by PA Level[b]			Adjusted β (SE)[c]	
Characteristic	**Sample Size, No.**	**Low**	**Medium**	**High**	**PA Level**	***P* Value**
HOMA-IR[d]	2630	2.6 (0.1)	2.5 (0.1)	2.5 (0.1)	-0.0003 (0.0001)	<.001
TC, mg/dL	6028	164.2 (2.0)	161.6 (0.8)	158.7 (1.4)	-0.001 (0.001)	.30
HDL-C, mg/dL	6026	49.7 (0.5)	50.0 (0.3)	49.7 (0.5)	0.001 (0.0003)	.003
LDL-C, mg/dL[d]	2641	97.5 (2.8)	92.9 (0.8)	87.9 (1.6)	-0.004 (0.001)	.001
TG, mg/dL[d]	2652	95.2 (4.7)	91.9 (2.9)	85.2 (3.4)	-0.01 (0.002)	.001
SBP, mm Hg	6401	108.8 (0.4)	108.6 (0.3)	109.6 (0.5)	0.0001 (0.0003)	.67
DBP, mm Hg	6401	61.2 (0.6)	61.8 (0.4)	61.2 (0.7)	0.0001 (0.0004)	.74
WC, cm	6470	81.0 (0.6)	81.0 (0.4)	79.1 (0.6)	-0.001 (0.0005)	.06
BMI percentile	6525	61.5 (1.4)	63.6 (0.9)	61.3 (1.4)	0.0001 (0.001)	.92

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; PA, physical activity; SBP, systolic blood pressure; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

SI conversions: To convert total, LDL, and HDL cholesterol to millimoles per liter, multiply by 0.0259; to convert TG to millimoles per liter, multiply by 0.0113.

[a] Evaluating the relationship between PA levels and insulin resistance-associated metabolic parameters and anthropometric measurements.

[b] Low defined as the lowest quintile of the sum of the mean number of times a subject did activity per day × average duration of each time × metabolic equivalent score; medium defined as the second to fourth quintile; high defined as the highest quintile.

[c] β (SE) are for the sum of the mean number of times a subject did activity per day x the average duration of each time x the metabolic equivalent score of activity, adjusting for the number of serving equivalents of SSBs consumed per day, age, sex, race, and energy intake (in kilocalories).

[d] Fasting subsample.

Table 4

Characteristics of SSB and PA Level Group Combinations and the Multivariate Linear Regression Coefficients Evaluating Their Relationship With Insulin Resistance-Associated Metabolic Parameters and Anthropometric Measurements

		Unadjusted Mean (SE) by SSB Intake Group vs PA Level[a]		Adjusted β(SE) [b]	
HOMA-IR[c]	1052	1.8 (0.2)	2.9 (0.3)	-1.45 (0.32)[d,e]	-0.62 (0.31)
TC, mg/dL	2411	162.7 (3.7)	165.9 (4.5)	-4.76 (6.32)	-5.66 (4.29)
HDL-C, mg/dL	2410	51.5 (1.1)	48.2 (1.3)	4.16 (1.78)[d,f]	1.48 (1.26)
LDL-C, mg/dL[c]	1056	85.5 (4.6)	99.2 (5.6)	-14.20 (8.07)	-6.91 (5.84)
TG, mg/dL[c]	1060	79.4 (6.9)	112.7 (12.9)	-34.21 (15.19)[d,g]	-22.48 (13.41)
SBP, mm Hg	2560	108.8 (1.0)	110.8 (0.9)	-1.22 (1.37)	-0.11 (0.96)
DBP, mm Hg	2560	62.5 (1.2)	63.2 (1.3)	0.39 (1.62)	-0.05 (1.09)
WC, cm	2588	80.6 (1.1)	84.4 (1.6)	-3.95 (2.20)	-2.58 (1.63)
BMI percentile	2610	62.7 (2.8)	64.1 (3.3)	-2.45 (4.45)	-3.08 (3.71)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; PA, physical activity; SBP, systolic blood pressure; SSB, sugar-sweetened beverage; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

SI conversions: To convert total, LDL, and HDL cholesterol to millimoles per liter, multiply by 0.0259; to convert TG to millimoles per liter, multiply by 0.0113.

[a] Low SSB intake defined as the lowest quintile of the sum of the number of serving equivalents of caloric soft drinks, colas, sugar-sweetened fruit drinks, or other SSBs consumed per day; high SSB intake defined as the highest quintile; low PA defined as the lowest quintile of the sum of the mean number of times a subject did activity per day × the average duration of each time × metabolic equivalent score; high PA defined as the highest quintile.

[b] β (SE) are for SSB intake and PA level compared with high SSB intake and low PA level, adjusting for age, sex, race, and energy intake (in kilocalories).

[c] Fasting subsample.

[d] $P<.05$.

[e] β (SE) for low SSB intake alone (adjusting for PA level) = -0.48 (0.13); β (SE) for high PA level alone (adjusting for SSB intake) = -0.39 (0.14).

[f] β (SE) for low SSB intake alone (adjusting for PA level) = 1.77 (0.62); β (SE) for high PA level alone (adjusting for SSB intake) = 0.42 (0.55).

[g] β (SE) for low SSB intake alone (adjusting for PA level) = -7.01 (4.71); β (SE) for high PA level alone (adjusting for SSB intake) = -7.51 (4.54).

Table 5

Sex-Specific Multivariate Linear Regression Analyses Evaluating the Relationship Between SSB Intake, PA Levels, and Their Combination With Insulin Resistance-Associated Metabolic Parameters and Anthropometric Measurements

	β (SE)					
	SSB Intake[a]		PA Level[b]		Low SSB Intake and High PA Level[c]	
	Female	Male	Female	Male	Female	Male
HOMA-IR[d]	0.07 (0.03)e	0.04 (0.02)	-0.0001 (0.0001)	-0.0004 (0.0001)e	-1.38 (0.69)	-1.51 (0.29)e
TC, mg/dL	-0.18 (0.39)	-0.02 (0.26)	-0.002 (0.001)	-0.001 (0.002)	-7.91 (9.19)	-3.91 (7.17)
HDL-C, mg/dL	-0.73 (0.15)e	-0.35 (0.08)e	0.001 (0.0005)	0.001 (0.0005)	3.31 (2.90)	5.08 (2.16)e
LDL-C, mg/dL[d]	-0.03 (0.54)	0.19 (0.26)	-0.003 (0.002)	-0.005 (0.001)e	-14.33 (14.78)	-14.04 (7.45)
TG, mg/dL[d]	2.25 (1.09)e	0.47 (1.01)	-0.01 (0.002)e	-0.01 (0.003)e	-47.01 (30.34)	-28.88 (12.87)e
SBP, mm Hg	0.38 (0.13)e	0.05 (0.08)	0.0002 (0.001)	-0.00002 (0.0003)	-1.40 (2.06)	-1.67 (1.68)
DBP, mm Hg	0.07 (0.12)	-0.02 (0.08)	0.001 (0.0005)	-0.0004 (0.0004)	0.75 (2.09)	-0.17 (2.60)
WC, cm	0.75 (0.19)e	0.29 (0.10)e	-0.0004 (0.001)	-0.001 (0.001)e	-3.90 (3.64)	-3.47 (2.73)
BMI percentile	0.84 (0.35)e	0.78 (0.23)e	0.0003 (0.001)	-0.0002 (0.001)	2.60 (7.97)	-2.31 (5.40)

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); DBP, diastolic blood pressure; HDL-C, high-density lipoprotein cholesterol; HOMA-IR, homeostasis model assessment of insulin resistance; LDL-C, low-density lipoprotein cholesterol; PA, physical activity; SBP, systolic blood pressure; SE, standard error; SSB, sugar-sweetened beverage; TC, total cholesterol; TG, triglyceride; WC, waist circumference.

SI conversions: To convert total, LDL, and HDL cholesterol to millimoles per liter, multiply by 0.0259; to convert TG to millimoles per liter, multiply by 0.0113.

[a] Low SSB intake defined as the lowest quintile of the sum of the number of serving equivalents of caloric soft drinks, colas, sugar-sweetened fruit drinks, or other SSBs consumed per day; medium defined as the second through fourth quintile; high SSB intake defined as the highest quintile. β (SE) are for the number of serving equivalents of SSBs consumed per day, adjusting for amount of physical activity performed per day, age, sex, race, menarche (for female adolescents), and energy intake (in kilocalories).

[b] Low PA defined as the lowest quintile of the sum of the mean number of times a subject did activity per day × the average duration of each time × metabolic equivalent score; medium defined as the second through fourth quintile; high PA defined as the highest quintile. β (SE) are for the sum of the mean number of times a subject did activity per day × the average duration of each time × metabolic equivalent score of activity, adjusting for the number of serving equivalents of SSBs consumed per day, age, sex, race, menarche (for female adolescents), and energy intake (in kilocalories).

[c] β (SE) are for SSB intake and PA level compared with high SSB intake and low PA level, adjusting for age, sex, race, menarche (for female adolescents), and energy intake (in kilocalories).

[d] Fasting subsample.

[e] $P<.05$.