

ARTICLE

Effects of Decreasing Sugar-Sweetened Beverage Consumption on Body Weight in Adolescents: A Randomized, Controlled Pilot Study

Cara B. Ebbeling, PhD^a, Henry A. Feldman, PhD^{a,b}, Stavroula K. Osganian, MD, ScD^{a,b}, Virginia R. Chomitz, PhD^c, Sheila J. Ellenbogen, MBA^a, David S. Ludwig, MD, PhD^a

From the ^aDivision of Endocrinology, Department of Medicine, and ^bClinical Research Program, Children's Hospital Boston, Boston, Massachusetts; and ^cInstitute for Community Health, Cambridge, Massachusetts

The authors have indicated they have no financial relationships relevant to this article to disclose.

ABSTRACT

AQ: A

OBJECTIVE. The role of sugar-sweetened beverages (SSBs) in promoting obesity is controversial. Observational data link SSB consumption with excessive weight gain; however, randomized, controlled trials are lacking and necessary to resolve the debate. We conducted a pilot study to examine the effect of decreasing SSB consumption on body weight.

METHODS. We randomly assigned 103 adolescents aged 13 to 18 years who regularly consumed SSBs to intervention and control groups. The intervention, 25 weeks in duration, relied largely on home deliveries of noncaloric beverages to displace SSBs and thereby decrease consumption. Change in SSB consumption was the main process measure, and change in body mass index (BMI) was the primary end point.

RESULTS. All of the randomly assigned subjects completed the study. Consumption of SSBs decreased by 82% in the intervention group and did not change in the control group. Change in BMI, adjusted for gender and age, was 0.07 ± 0.14 kg/m² (mean \pm SE) for the intervention group and 0.21 ± 0.15 kg/m² for the control group. The net difference, -0.14 ± 0.21 kg/m², was not significant overall. However, baseline BMI was a significant effect modifier. Among the subjects in the upper baseline-BMI tertile, BMI change differed significantly between the intervention (-0.63 ± 0.23 kg/m²) and control ($+0.12 \pm 0.26$ kg/m²) groups, a net effect of -0.75 ± 0.34 kg/m². The interaction between weight change and baseline BMI was not attributable to baseline consumption of SSBs.

CONCLUSIONS. A simple environmental intervention almost completely eliminated SSB consumption in a diverse group of adolescents. The beneficial effect on body weight of reducing SSB consumption increased with increasing baseline body weight, offering additional support for American Academy of Pediatrics guidelines to limit SSB consumption. Large-scale trials aimed at evaluating the effects of

www.pediatrics.org/cgi/doi/10.1542/peds.2005-0983

doi:10.1542/peds.2005-0983

Key Words

beverages, adolescent obesity, weight loss, body mass index, diet

Abbreviations

SSB—sugar-sweetened beverage

El_{SSB}—energy intake from sugar-sweetened beverages

Accepted for publication Jun 30, 2005

Address correspondence to David S. Ludwig, MD, PhD, Department of Medicine, Children's Hospital, 300 Longwood Ave, Boston, MA 02115. E-mail: david.ludwig@childrens.harvard.edu

PEDIATRICS (ISSN Numbers: Print, 0031-4005; Online, 1098-4275). Copyright © 2006 by the American Academy of Pediatrics

decreasing SSB consumption over the long-term in the heaviest adolescents are needed.

A RAPID INCREASE in the consumption of sugar-sweetened beverages (SSBs) among adolescents in the United States¹ has occurred concomitantly with the escalating pediatric obesity epidemic,² raising the possibility of a causal relationship. Soft drinks are readily available in homes, fast food and other restaurants, vending machines, and school cafeterias.³ Moreover, the soft drink industry uses aggressive advertising campaigns directed toward young consumers.^{4,5} Based on data from a nationally representative sample of youth, a remarkable 73% of adolescent boys and 62% of adolescent girls consume carbonated soft drinks on any given day, of which the vast majority contain sugar rather than non-nutritive sweeteners.³ Those who consume soft drinks obtain 10% to 11% of their total energy intake from these beverages.³ Not surprisingly, soft drinks are the leading source of added sugars in the diets of adolescents.⁶

The role of SSBs in promoting obesity has been debated extensively in recent years. The American Academy of Pediatrics^{7,8} and the current *Dietary Guidelines for Americans*⁹ advocate reducing SSB consumption as a weight-control strategy based on available prospective data from cohort studies.¹⁰⁻¹² However, the American Beverage Association argues that available evidence for a causal relationship between soft drink consumption and obesity is inadequate to justify a change in their marketing practices.¹³ A recent executive summary put forth by food and nutrition scientists also contends that there is no convincing evidence linking obesity with intake of high-fructose corn syrup,¹⁴ the primary sweetener and major source of calories in soft drinks.¹⁵ Although prospective data linking SSB consumption with excessive weight gain are compelling,¹⁰⁻¹² randomized, controlled trials are undeniably lacking and necessary to evaluate causality.

In the only pediatric trial to date, James et al¹⁶ reported a significant decrease in the incidence of obesity after 1 year among 7- to 11-year-old children who received an intervention to decrease carbonated beverages compared with a control group. However, change in mean body mass index (BMI) did not differ between groups, possibly because of methodological issues. The intervention consisted of only 4 school-based educational sessions aimed at reducing consumption of all carbonated beverages containing either sugar or nonnutritive sweeteners. Moreover, baseline SSB consumption was very low in this young cohort (ie, ~1 glass every 3 days), leaving minimal opportunity for the intervention to have a significant impact on beverage intake and, ultimately, BMI. The decrease in consumption of all carbonated beverages for the intervention group was

only 150 mL over 3 days, with no significant change in SSB consumption. These issues highlight a need for trials of more powerful interventions with youth who frequently consume SSBs.

Environmental variables, such as ready availability of SSBs, often seem to undermine educational and behavioral strategies that focus largely on personal responsibility for making healthful choices based on expert recommendations.¹⁷ The purpose of this randomized, controlled pilot study was to test the hypothesis that a simple environmental intervention will significantly decrease SSB consumption and BMI among adolescents. We further hypothesized that the effects will be greatest in the heaviest adolescents; for this reason, we stratified the cohort by baseline-BMI status. Although access to soft drinks from many sources has increased over the last 2 decades, adolescents still obtain nearly 50% of their beverages at home.³ Thus, we implemented a novel intervention that relied on delivery of noncaloric beverages to the homes of adolescents, in combination with telephone-administered behavioral counseling, to displace SSBs and thereby decrease consumption.

METHODS

Subjects

We enrolled 103 adolescents (47 males and 56 females), aged 13 to 18 years, who reported consuming at least 1 serving (ie, 360 mL or 12 fl oz) per day of SSB (ie, soft drinks, juice drinks containing <100% juice, punches, lemonades, iced teas, and sports drinks). Each subject lived predominantly in 1 household (ie, no more than 1 weekend every 2 weeks in a secondary household). We excluded those who were currently dieting for the purpose of weight loss or taking prescription medications that might affect body weight. We also did not enroll those who reported smoking at least 1 cigarette in the past week or were diagnosed as having a major medical illness or eating disorder. To decrease the likelihood of enrolling individuals with eating disorders or undernutrition, we excluded those with a BMI below the 25th percentile.¹⁸ During telephone conversations with parents, we collected demographic data including gender, race and ethnicity, date of birth, total annual household income, and street address. Recruitment and screening of subjects were conducted in collaboration with a local high school that provided mailing lists and space for obtaining measurements. Packets containing an invitation letter and informed consent and assent documents were sent to parents of all students enrolled at the school. Parents were instructed to contact staff members by telephone, if interested, to obtain more information about the study protocol. The study director supervised the evaluation of eligibility criteria and enrollment.

The study protocol was approved by the institutional

review board at Children’s Hospital Boston. Written informed consent and assent were obtained from parents and subjects, respectively. Eligible subjects were entered sequentially onto a list of random group assignments prepared in advance by the study statistician, stratified by gender and BMI (<85th percentile for gender and age, ≥85th percentile).¹⁸ The sequence of random assignments was permuted within stratum in blocks of 2, 4, and 6. To avoid any bias in the enrollment procedure, personnel conducting recruitment were masked to sequence. All of the subjects assigned to a group were available for follow-up measurements (Fig 1), and there were no serious adverse events or adverse effects among adolescents in the intervention group. Each subject received a \$100 gift certificate to a local shopping mall at the end of the study. The study, known as Beverages and Student Health, was conducted during the 2003–2004 academic year.

Intervention

The intervention group received weekly home deliveries of noncaloric beverages for 25 weeks. The target number of individual beverage servings (ie, 360 mL or 12 fl oz per referent serving) delivered to each home was based on household size: 4 servings per day for the subject and 2 servings per day for each additional member of the household. This extra allotment was provided to avoid competition between the subject and family members for the beverages. We distributed an order form to each household for selecting beverage preferences from a wide variety of options (eg, bottled water and “diet” beverages including soft drinks, iced teas, lemonades, and punches). The beverage order form listed options in units, based on manufacturer packaging. The units contained bundles of 4 to 6 cans or bottles, with volumes ranging from 300 to 720 mL (10–24 fl oz) per can or bottle. The target number of delivered servings, specified

above, was approximately equal to 5 units per week for the subject and 3 units per week for each additional member of the household. A regional supermarket delivery service filled the orders and delivered the beverages, with research staff coordinating and monitoring the process.

We instructed subjects to drink the noncaloric beverages delivered to their homes and not to buy or drink SSBs. In addition, we offered advice on how to choose noncaloric beverages when not at home. Written instructions regarding beverage consumption were mailed to subjects at the beginning of the intervention period. We also contacted each household by telephone during the first week of the intervention to speak with the subject and a parent. This telephone contact provided an opportunity to reinforce instructions, answer questions, and address concerns. Thereafter, we contacted each subject by telephone on a monthly basis throughout the intervention period to assess satisfaction with beverage choices and deliveries, discuss beverage consumption, and provide motivational counseling. Beverage orders were revised on request to increase the likelihood that subjects would drink the delivered products. On a monthly basis, we also mailed refrigerator magnets to subjects, with each magnet conveying a message under the theme of “Think Before You Drink.” The messages provided data-based information with regard to the possible effects of SSBs in promoting excess energy intake,¹¹ weight gain,¹⁰ tooth decay,¹⁹ and hunger.²⁰ An additional message cautioned subjects to beware of misleading beverage labels and advertisements.

We asked subjects in the control group to continue their usual beverage consumption habits throughout the 25-week intervention period. They received weekly home deliveries of noncaloric beverages for 4 weeks after completion of follow-up measurements, as a benefit for having participated in the study.

Primary End Point

The change in BMI from baseline to follow-up was the primary end point. Weight and height were measured by using an electronic scale (model TBF-300A; Tanita, Arlington Heights, IL) and stadiometer (model PE-AIM-101; Perspective Enterprises, Portage, MI), respectively. Subjects removed shoes and heavy outerwear before weight measurements. We measured height in duplicate, with the subject stepping away from the stadiometer between measurements. BMI was calculated as total mass (kilograms) divided by height (meters) squared.

Dietary and Physical Activity Recall Interviews

Two 24-hour dietary and physical activity recall interviews were conducted over the telephone at baseline and another 2 at the end of the intervention period. Telephone calls were unannounced so that the subject did not know the exact dates of the interviews in ad-

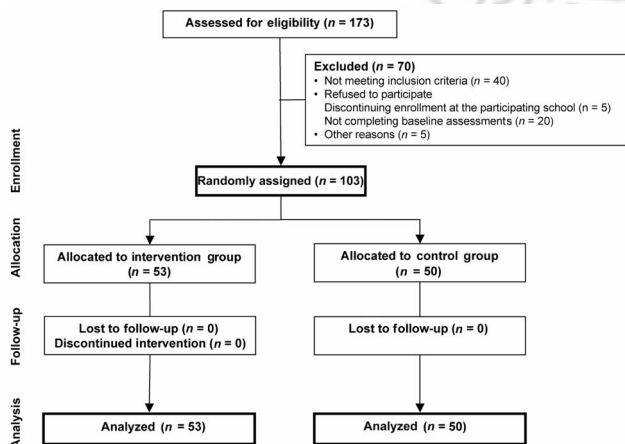


FIGURE 1
Flow of participants through each stage of the trial.

vance. The interviewer was masked to group assignment.

Dietary intake was assessed by a multiple-pass method using the Nutrition Data System for Research Software (NDS-R 4.06; Nutrition Coordinating Center, University of Minnesota, Minneapolis, MN). We prompted the subject to list in sequence the foods and beverages consumed during the previous day, identify omissions in the initial list, and then provide details (eg, portion sizes and brand names) concerning each reported item. Intake was reviewed and confirmed at the end of each recall. Energy intake from SSBs (EI_{SSB}) was the variable of primary interest for this report. We also quantified the volumetric consumption of all noncaloric beverages.

Immediately after the dietary recall portion of the interview, we prompted the subject to recall physical activity and inactivity, including sleep, using a protocol modeled after validated methodology.^{21,22} The subject was asked to recall the activity performed most during respective 15-minute time blocks throughout the preceding day (12:00 AM to 11:59 PM) and then to rate the relative intensity of each reported activity as light, moderate, hard, or very hard.²² A metabolic equivalent was assigned to each activity to calculate a physical activity factor (kilojoules/kilogram per hour). As points of reference, resting has a metabolic equivalent level of 1.0, and brisk walking has a level of 5.0.²³ In addition to conducting the 24-hour physical activity recall interview, we asked subjects to estimate the usual number of hours per day spent watching television, using a computer (for purposes other than doing homework), and playing video games.

Before the first telephone interview, we held in-person group training sessions focusing on how to estimate food and beverage portion sizes and how to describe the intensity of physical activity. Teaching aids included food models, measuring cups and spoons, common kitchen items (ie, plates, bowls, cups, and glasses), and familiar packaging (ie, beverage containers and snack food wrappers). In addition, we presented cartoons illustrating examples of physical activities performed at varying intensity levels. Each subject practiced recalling dietary intake and physical activity during the training session.

Process Evaluation

To obtain additional process data for informing the design of a future large-scale trial, we administered questionnaires at the end of the study. Using 10-cm visual analog scales with appropriate verbal anchors, subjects responded to a series of questions regarding adherence to instructions, beverage delivery logistics, and overall enjoyment of participation.

Statistical Methods

The study was designed to provide 80% power to detect an effect size of 0.51 (mean change \div SD of change), using a 5% type I error rate. Historical data on intersubject variability and intrasubject correlation of BMI in children, drawn from the American Academy of Pediatrics' Community Access to Child Health (CATCH) study,²⁴ indicated that our detectable effect size corresponded with a 3.1% mean change in BMI. Posthoc power calculations, taking into account the attained sample size ($n = 103$) and precision of the overall net difference between the intervention and control groups, indicated that the detectable effect in practice was 0.57 kg/m² or 2.2% of mean baseline BMI.

We compared baseline demographic, anthropometric, and behavioral characteristics between the intervention and control groups by Student's *t* test for continuous measures and Fisher's exact test for discrete variables. The primary analysis was conducted by multiple linear regression with individual BMI change as the dependent variable, group as an indicator independent variable, and gender and age as obligatory covariates. The influence of covariates was tested by adding them to the regression model, both singly and in combination. Effect modification by baseline BMI was evaluated by adding a group \times baseline BMI interaction term to the primary analytic model. To quantify the net effect of the intervention among the heaviest adolescents, we categorized subjects using baseline-BMI tertiles as cut points in a secondary model of effect modification. We used $P < .05$ as a criterion for statistical significance of covariates and effect modifiers. Computations were performed with SAS software (SAS Institute, Inc, Cary, NC).

RESULTS

Baseline Measures

Baseline subject characteristics are presented in Table 1. There were no significant group differences between intervention and control subjects in demographics (gender, race, ethnicity, age, household income, and household size) or anthropometrics (weight, height, and BMI). Likewise, the groups did not differ in baseline levels of EI_{SSB} , noncaloric beverage intake, physical activity, television viewing, or total media time (Table 2).

Process Measures

We completed all of the 6 possible monthly telephone contacts with 83.0% of the subjects in the intervention group (44 of 53 subjects), for an average of 5.8 ± 0.6 (mean \pm SD) counseling calls per subject. Problems with beverage deliveries were reported during only 1.3% of the completed telephone contacts (4 of 306 contacts). As shown in Table 2, EI_{SSB} decreased by 82% for the intervention group ($P < .0001$) and did not change for the control group. There were no changes in physical activ-

AQ: B

T2

TABLE 1 Baseline Characteristics of Subjects in the Intervention and Control Groups

Characteristic	n (%) or Mean ± SD		P ^a
	Intervention	Control	
No. subjects	53 (100)	50 (100)	
Gender			
Male	24 (45)	23 (46)	1.0 ^b
Female	29 (55)	27 (54)	
Race			
White	18 (34)	19 (38)	.69
Non-white	35 (66)	31 (62)	
Ethnicity			
Hispanic	11 (21)	7 (14)	.44
Non-Hispanic	42 (79)	43 (86)	
Age, y	16.0 ± 1.1	15.8 ± 1.1	.37
Weight, kg	72.1 ± 20.5	69.6 ± 19.2	.53
Height, cm	167 ± 9	167 ± 9	.88
BMI, kg/m ²	25.7 ± 6.3	24.9 ± 5.7	.51
Weight status			
BMI <85th percentile	28 (53)	29 (58)	.69 ^b
BMI ≥85th percentile	25 (47)	21 (42)	
Household income			
<\$30 000 ^c	19 (38)	20 (41)	.97
\$30 000 to \$59 999	16 (32)	14 (29)	
≥\$60 000	15 (30)	15 (31)	
Residing in subsidized housing	10 (19)	7 (14)	.60
Household size (family members)	3.1 ± 1.1	3.2 ± 1.1	.96

^a Comparing intervention and control groups by independent-sample *t* test (continuous measures) or Fisher's exact test (discrete variables).

^b Balanced by stratified randomization.

^c Three nonrespondents in the intervention and 1 in the control group.

TABLE 2 EI_{SSB} Physical Activity, Television Viewing, and Total Media Time in the Intervention and Control Groups

Variable	Mean ± SD		P ^a
	Intervention	Control	
No. of subjects	53	50	
EI _{SSB} , kJ			
Baseline	1465.8 ± 781.2	1596 ± 1108.8	.50
Change	-1201.2 ± 835.8 ^b	-184.8 ± 945	<.0001
Noncaloric beverage intake, mL			
Baseline	254 ± 304	170 ± 245	.12
Change	396 ± 493 ^b	78 ± 523	.002
Physical activity, metabolic equivalent			
Baseline	1.74 ± 0.35	1.63 ± 0.23	.08
Change	-0.12 ± 0.37	-0.03 ± 0.32	.18
Television viewing, h			
Baseline	2.17 ± 1.36	2.62 ± 1.75	.14
Change	0.05 ± 1.56	-0.19 ± 1.85	.47
Total media time, h ^c			
Baseline	4.57 ± 2.42	5.28 ± 3.38	.22
Change	-0.50 ± 2.56	-0.31 ± 3.33	.75

^a From independent *t* test comparing intervention and control groups.

^b Significant change from baseline, *P* < .0001.

^c Sum of time spent watching television, using a computer (for purposes other than doing homework), and playing video games.

ity, television viewing, or total media time for either group. Questionnaire data are presented in Table 3 and suggest a high level of self-reported compliance.

Outcome Measures

Change in BMI, adjusted for gender and age, was 0.07 ± 0.14 kg/m² (mean ± SE) for the intervention group and 0.21 ± 0.15 kg/m² for the control group. The net difference, -0.14 ± 0.21 kg/m², was not significant overall but varied considerably over the range of baseline BMI (Fig 2). As an effect modifier in regression analysis, baseline BMI was significant at *P* = .016. The trend in weight loss (Fig 2) was an additional BMI decrease of

0.08 kg/m² for every 1 kg/m² at baseline (Fig 2A), compared with a negligible trend in the controls (Fig 2B). The intervention effect was significant for baseline BMI >30 kg/m² (Fig 2C) in the primary analysis. Moreover, among the subjects in the upper baseline-BMI tertile (BMI ≥ 25.6 kg/m²), BMI change differed markedly between the intervention (-0.63 ± 0.23 kg/m²) and control (+0.12 ± 0.26 kg/m²) groups, a net effect of -0.75 ± 0.34 kg/m² (*P* = .03), whereas no significant group difference was seen for the subjects in the middle and lower tertiles (*P* = .04 for interaction).

Adjusting the analysis for the demographic and behavioral covariates listed in Tables 1 and 2, either singly or in combination, did not change the results. Among the covariates, only baseline EI_{SSB} exerted an independent effect on the trial end point, amounting to an additional 0.14 kg/m² decrease in BMI per 420 kJ per day consumed. However, baseline EI_{SSB} was not a sig-

TABLE 3 Adherence to Instructions, Beverage Delivery Logistics, and Overall Enjoyment of Participation

Question	Descriptor Range ^a	Mean ± SD
Intervention group (n = 53)		
How well did you follow the study instructions to drink the BASH beverages delivered to your home?	Not at all (0) to very well (10)	8.4 ± 1.7
How well did you follow the study instructions to not buy or drink SSBs?	Not at all (0) to very well (10)	8.1 ± 2.1
How was the number of beverages that you received each week?	Too few (0) to too many (10)	6.4 ± 1.9
How was the frequency (1 time per wk) of beverage deliveries?	Not often enough (0) to too often (10)	5.4 ± 1.5
Did you enjoy participating in the BASH study?	Not at all (0) to very much (10)	8.6 ± 1.9
Control group (n = 50)		
How well did you follow the study instructions to continue your usual beverage habits until June 2004?	Not at all (0) to very well (10)	8.1 ± 1.9
Are you enjoying the BASH study? ^b	Not at all (0) to very much (10)	7.6 ± 1.9

BASH indicates Beverage and Student Health study.

^a On 10-cm visual analog scale.

^b Present tense; control group had not yet received beverage deliveries (provided as a benefit after completion of the study) when the questionnaire was administered.

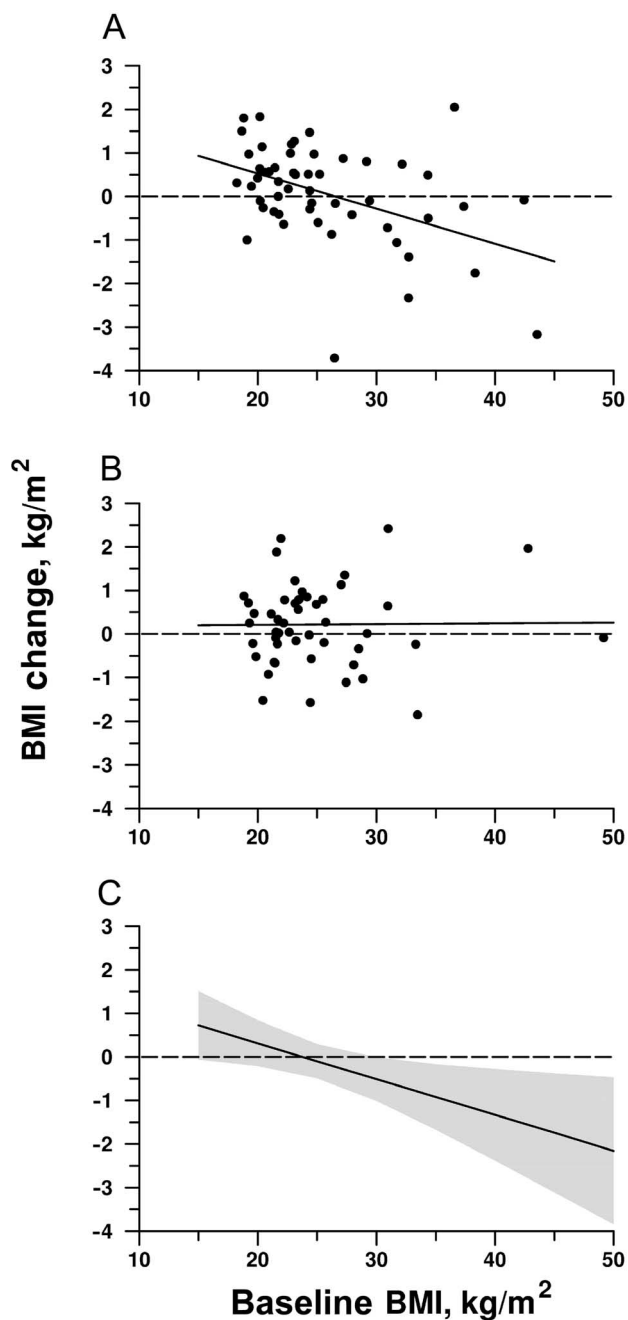


FIGURE 2
 BMI trends over 25 weeks for the intervention (A, slope = -0.081 kg/m²; $P = .0005$) and control (B, slope = 0.002 kg/m²; $P = .95$) groups as a function of baseline BMI. The intervention effect was significant, as shown by 95% confidence band on difference between study groups (C) for baseline BMI >30 kg/m².

nificant effect modifier ($P > .75$) and did not attenuate the effect modification of baseline BMI, which remained statistically significant at $P = .028$ when adjusted for baseline EI_{SSB} .

DISCUSSION

Public health interventions to prevent and treat overweight in children have generally taken a comprehen-

sive approach, targeting multiple behaviors believed to promote positive energy balance.^{17,25} Conceptually, such an approach could be more efficacious than an intervention focused on just 1 behavior. However, most comprehensive programs have not had a substantial effect on body weight despite some success in promoting behavior change,¹⁷ perhaps because the behaviors targeted in these interventions are not key determinants of body weight, or because the selected educational and behavioral strategies lack sufficient intensity. In the present study, we focused specifically on SSB consumption, a single dietary behavior that may have a particularly large impact on body weight in adolescents. Moreover, we used a novel environmental intervention, in combination with telephone-administered behavioral counseling, to penetrate homes and thereby foster behavior change.

We found that decreasing SSB consumption had a beneficial effect on body weight that was strongly linked with baseline BMI. Net BMI change was -0.75 ± 0.34 kg/m² in the intervention compared with the control group among subjects in the upper baseline-BMI tertile; BMI changes did not differ significantly between groups among subjects with lower baseline body weight. Moreover, the effect was greater among the subjects who drank more SSBs at baseline, presumably because of greater displacement of SSBs by noncaloric beverages. We observed that BMI decreased by -0.14 kg/m² for every 420 kJ per day from SSBs at baseline. Because each 360-mL (12-fl oz) serving of SSBs contains ~ 630 kJ, and total SSB consumption was reduced by 82% in the intervention group, we calculate that BMI decreased on average by 0.26 kg/m² for every serving per day of SSB that was displaced ($[0.14$ kg/m² per 420 kJ per day from SSB] \times [630 kJ per serving] \div [82% reduction in SSB consumption]). For comparative purposes, a prospective observational study found that BMI increased by 0.24 kg/m² for every additional serving of SSB consumed per day.¹⁰ The results of our pilot study were not materially affected by gender, race or ethnicity, age, household income, household size, physical activity, or television viewing.

Several previous studies provide a physiological basis for interpreting these findings. Sugar seems to be less satiating when provided in liquid compared with solid form, thus contributing to incomplete energy compensation.^{26–31} For example, DiMeglio and Mattes²⁷ observed exact energy compensation under free-living conditions when ingested sugar was obtained from jelly beans but not when an equal amount of sugar was obtained from a beverage. Moreover, St-Onge et al³¹ found that a beverage containing only sugar was less satiating than one with mixed nutrients, while controlling for energy content and volume. The sugary beverage also had an attenuated thermogenic effect, indicating less nutrient oxidation and greater energy storage. Taken together, these

studies suggest that both the physical (liquid versus solid) and chemical (exclusively sugar versus mixed nutrient) characteristics of SSBs have an adverse effect on short-term energy intake and metabolism. Decreasing SSB consumption may elicit adaptations, involving satiety and thermogenesis, that facilitate long-term weight control.

The greater impact of the intervention among the heaviest adolescents is particularly striking. Although published data indicate that overweight adolescents obtain a larger percentage of their total energy intake from soft drinks than their lean peers,³² the greater weight loss with increasing baseline BMI in the present study was not simply because of a greater decrease in energy intake from SSBs. Perhaps some individuals are inherently more susceptible than others to the adverse effects of SSBs on body weight. If so, these individuals would be more likely to become overweight in an environment characterized by high levels of SSB consumption; similarly, they would also tend to lose more weight with reduction in consumption. In any event, the mechanisms underlying susceptibility remain speculative and likely involve complex interactions among genetic predispositions, psychological factors, and environmental stimuli.³³

Our data are consistent with previous studies. In a 1-year retrospective cohort study, Welsh et al³⁴ noted that preschool children who were overweight or at risk of overweight were ~2 times more likely to remain or become overweight if they consumed SSBs. There was no significant association between SSB consumption and weight gain in children who were not at risk. In an intervention study, Tordoff and Alleva³⁵ reported that provision of 4 servings per day of noncaloric beverages caused a decrease in body weight over 3 weeks, relative to a control period, in adults who were overweight on average. Similarly, Raben et al³⁶ noted that obese subjects lost weight when given supplements containing nonnutritive sweeteners primarily in the form of beverages for 10 weeks, whereas those who were given sucrose primarily in the form of soft drinks gained weight.

Pediatricians and parents often express concern regarding the possible adverse health effects of nonnutritive sweeteners, such as aspartame or sucralose, in many noncaloric beverages. However, these sweeteners have been approved by the US Food and Drug Administration and are considered safe for children.³⁷ In this pilot study, we provided a wide range of noncaloric beverage options, including varieties containing nonnutritive sweeteners, to maximize the likelihood that the adolescents would identify products that satisfied their preferences and thereby displace SSBs with the products delivered to their homes. Nevertheless, we encouraged the subjects to order only bottled water if they or their parents had any safety concerns regarding nonnutritive sweeteners. It seems prudent for pediatricians to take a similar approach when counseling families to remove SSBs from

their homes and self-select noncaloric beverages from available options as a weight-control strategy.

The strengths of this study include a novel intervention, a demographically diverse sample, and a 100% completion rate among randomly assigned subjects. An environmental intervention is particularly attractive for adolescents who often desire increasing autonomy, resist adult authority, express ambivalence regarding dietary change and, thus, may not respond to conventional nutrition education and behavioral counseling.^{38,39} Based on process data, the intervention had the anticipated effect in significantly decreasing SSB consumption, and subjects seemed to enjoy participation in the study. Moreover, the diversity and high retention rate of the study cohort enhance the generalizability of the results. Limitations of the study include a relatively small sample size and short intervention period. Reliance on self-report for dietary assessment and process evaluation is another limitation, as in all studies of free-living subjects. Finally, we did not stage pubertal status. Although puberty could be an effect modifier, randomization likely precluded any systematic bias associated with this variable.

In the context of a research study, we used an expensive environmental intervention to evaluate the efficacy of decreasing SSB consumption as a weight-control strategy. However, it should be relatively simple to translate this intervention into a pragmatic public health approach. For example, schools could make noncaloric beverages available to students by purchasing large quantities at low costs. Assuming a unit price of 10¢, an intervention designed to provide 2 servings of noncaloric beverages per day (more than the amount associated with a BMI decrease of 0.75 kg/m² among the heaviest adolescents in our study) would cost approximately \$35 per student over 25 weeks. This cost would compare favorably with that of other weight-loss interventions for adolescents.

CONCLUSIONS

Decreasing the consumption of SSBs seems to be a promising strategy for the prevention and treatment of overweight adolescents. Large-scale trials are needed to evaluate the effects of this strategy over the long term, focusing specifically on the heaviest adolescents. Pending completion of such trials, this study offers additional support for American Academy of Pediatrics guidelines that recommend limiting SSB consumption.^{7,8} Pediatricians and public health professionals are well-positioned to publicize and implement these guidelines.

ACKNOWLEDGMENTS

This study was supported by grants R01 DK63554 and K01 DK62237 from the National Institute of Diabetes and Digestive Kidney Diseases, the Charles H. Hood Foundation, and grant M01 RR02172 awarded by the

National Institutes of Health to support the General Clinical Research Center at Children's Hospital Boston.

The study could not have been completed without the help of Robert McGowan, who facilitated school-based activities, and Susan Burke, who supervised beverage deliveries from the MIT Star Market in Cambridge, Massachusetts. We also thank Michelle Castaneda, Erica Garcia-Lago, Inger Hustrulid, Michael Leidig, Lenard Lesser, Linda Seger-Shippee, and Kelly Sinclair for contributions to subject enrollment, data collection, or telephone counseling.

REFERENCES

- Nielsen SJ, Popkin BM. Changes in beverage intake between 1977 and 2001. *Am J Prev Med.* 2004;27:205-210
- Ogden CL, Flegal KM, Carroll MD, Johnson CL. Prevalence and trends in overweight among US children and adolescents, 1999-2000. *JAMA.* 2002;288:1728-1732
- French SA, Lin BH, Guthrie JF. National trends in soft drink consumption among children and adolescents age 6 to 17 years: prevalence, amounts, and sources, 1977/1978 to 1994/1998. *J Am Diet Assoc.* 2003;103:1326-1331
- Kraak V, Pelletier DL. How marketers reach young consumers: implications for nutrition education and health promotion campaigns. *Fam Econ Nutr Rev.* 1998;11:31-41
- Fried EJ, Nestle M. The growing political movement against soft drinks in schools. *JAMA.* 2002;288:2181
- Guthrie JF, Morton JF. Food sources of added sweeteners in the diets of Americans. *J Am Diet Assoc.* 2000;100:43-51
- Krebs NF, Jacobson MS. Prevention of pediatric overweight and obesity. *Pediatrics.* 2003;112:424-430
- American Academy of Pediatrics, Committee on School Health. Soft drinks in schools. *Pediatrics.* 2004;113:152-154
- US Department of Health and Human Services. US Department of Agriculture. *Dietary Guidelines for Americans.* 2005. Available at: www.healthierus.gov/dietaryguidelines/index.html. Accessed January 12, 2005
- Ludwig DS, Peterson KE, Gortmaker SL. Relation between consumption of sugar-sweetened drinks and childhood obesity: a prospective, observational analysis. *Lancet.* 2001;357:505-508
- Berkey CS, Rockett HR, Field AE, Gillman MW, Colditz GA. Sugar-added beverages and adolescent weight change. *Obes Res.* 2004;12:778-788
- Schulze MB, Manson JE, Ludwig DS, et al. Sugar-sweetened beverages, weight gain, and incidence of type 2 diabetes in young and middle-aged women. *JAMA.* 2004;292:927-934
- Crowley RDJ. From foes of soft drinks, an empty case [op-ed]. *The Boston Globe.* December 28, 2004
- Hein GL, Storey ML, Lineback DR. Highs and lows of high fructose corn syrup. In: Executive summary: Ceres workshop on the highs and lows of high fructose corn syrup. Available at: www.ceresnet.org/images/Misc/HFCS.Executive.Summary.pdf. Accessed March 1, 2005
- Bray GA, Nielsen SJ, Popkin BM. Consumption of high-fructose corn syrup in beverages may play a role in the epidemic of obesity. *Am J Clin Nutr.* 2004;79:537-543
- James J, Thomas P, Cavan D, Kerr D. Preventing childhood obesity by reducing consumption of carbonated drinks: cluster randomised controlled trial. *BMJ.* 2004;328:1237-1239
- Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet.* 2002;360:473-482
- Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, et al. CDC growth charts: United States. *Adv Data.* 2000;314:1-27
- Shenkin JD, Heller KE, Warren JJ, Marshall TA. Soft drink consumption and caries risk in children and adolescents. *Gen Dent.* 2003;51:30-36
- Spitzer L, Rodin J. Effects of fructose and glucose preloads on subsequent food intake. *Appetite.* 1987;8:135-145
- Weston AT, Petosa R, Pate RR. Validation of an instrument for measurement of physical activity in youth. *Med Sci Sports Exerc.* 1997;29:138-143
- Pate RR, Ross R, Dowda M, Trost SG, Sirard JR. Validation of a 3-day physical activity recall instrument in female youth. *Pediatr Exerc Sci.* 2003;15:257-265
- Ainsworth BE, Haskell WL, Whitt MC, et al. Compendium of physical activities: an update of activity codes and MET intensities. *Med Sci Sports Exerc.* 2000;32:S498-S504
- Luepker RV, Perry CL, McKinlay SM, et al. Outcomes of a field trial to improve children's dietary patterns and physical activity: the Child and Adolescent Trial for Cardiovascular Health (CATCH). *JAMA.* 1996;275:768-776
- Baranowski T, Cullen KW, Nicklas T, Thompson D, Baranowski J. School-based obesity prevention: a blueprint for taming the epidemic. *Am J Health Behav.* 2002;26:486-493
- De Castro JM. The effects of the spontaneous ingestion of particular foods or beverages on the meal pattern and overall nutrient intake of humans. *Physiol Behav.* 1993;53:1133-1144
- DiMeglio DP, Mattes RD. Liquid versus solid carbohydrate: effects on food intake and body weight. *Int J Obes Relat Metab Disord.* 2000;24:794-800
- Harnack L, Stang J, Story M. Soft drink consumption among US children and adolescents: nutritional consequences. *J Am Diet Assoc.* 1999;99:436-441
- Holt SH, Sandona N, Brand-Miller JC. The effects of sugar-free vs sugar-rich beverages on feelings of fullness and subsequent food intake. *Int J Food Sci Nutr.* 2000;51:59-71
- Mattes RD. Dietary compensation by humans for supplemental energy provided as ethanol or carbohydrate in fluids. *Physiol Behav.* 1996;59:179-187
- St-Onge MP, Rubiano F, DeNino WF, et al. Added thermogenic and satiety effects of a mixed nutrient vs a sugar-only beverage. *Int J Obes Relat Metab Disord.* 2004;28:248-253
- Troiano RP, Briefel RR, Carroll MD, Bialostosky K. Energy and fat intakes of children and adolescents in the United States: data from the National Health and Nutrition Examination Surveys. *Am J Clin Nutr.* 2000;72(5 suppl):1343S-1353S
- Rosenbaum M, Leibel RL. The physiology of body weight regulation: relevance to the etiology of obesity in children. *Pediatrics.* 1998;101:525-539
- Welsh JA, Cogswell ME, Rogers S, Rockett H, Mei Z, Grummer-Strawn LM. Overweight among low-income preschool children associated with the consumption of sweet drinks: Missouri, 1999-2002. *Pediatrics.* 2005;115(2). Available at: www.pediatrics.org/cgi/content/full/115/2/e223
- Tordoff MG, Alleva AM. Effect of drinking soda sweetened with aspartame or high-fructose corn syrup on food intake and body weight. *Am J Clin Nutr.* 1990;51:963-969
- Raben A, Vasilaras TH, Moller AC, Astrup A. Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. *Am J Clin Nutr.* 2002;76:721-729
- American Dietetic Association. Position of the American Dietetic Association: use of nutritive and nonnutritive sweeteners. *J Am Diet Assoc.* 2004;104:255-275
- Story M, Neumark-Sztainer D, Ireland M, Evans T. Adolescent health and nutrition: a survey of perceived knowledge and skill competencies and training interests among dietitians working with youth. *J Am Diet Assoc.* 2000;100:362-364
- Story M, Neumark-Sztainer D, French S. Individual and environmental influences on adolescent eating behaviors. *J Am Diet Assoc.* 2002;102(3 suppl):S40-S51

AQ: C