

Sugars and satiety: does the type of sweetener make a difference?¹⁻³

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ABSTRACT

Background: Widespread use of high-fructose corn syrup (HFCS) in beverages has been linked to rising obesity rates. One hypothesis is that HFCS in beverages has little satiating power.

Objective: The objective of the study was to compare the relative effect of commercial beverages containing sucrose or HFCS on hunger, satiety, and energy intakes at the next meal with the use of a within-subject design.

Design: Thirty-seven volunteers (19 men, 18 women) aged 20–29 y consumed isocaloric cola beverages (215 kcal) sweetened with sucrose, HFCS 42, or HFCS 55. HFCS 42 contains 42% fructose, and HFCS 55 contains 55% fructose. Diet cola (2 kcal), 1%-fat milk (215 kcal), and no beverage were the control conditions. The 5 beverages were consumed at 1010 (2 h after a standard breakfast). Participants rated hunger, thirst, and satiety at baseline and at 20-min intervals after ingestion. A tray lunch (1708 kcal) was served at 1230, and energy intakes were measured. The free sugars content of sucrose-sweetened cola was assayed at the time of the study.

Results: We found no differences between sucrose- and HFCS-sweetened colas in perceived sweetness, hunger and satiety profiles, or energy intakes at lunch. The 4 caloric beverages tended to partially suppress energy intakes at lunch, whereas the no-beverage and diet beverage conditions did not; the effect was significant ($P < 0.05$) only for 1%-fat milk. Energy intakes in the diet cola and the no-beverage conditions did not differ significantly.

Conclusion: There was no evidence that commercial cola beverages sweetened with either sucrose or HFCS have significantly different effects on hunger, satiety, or short-term energy intakes. *Am J Clin Nutr* 2007;86:116–23.

KEY WORDS Beverages, sucrose, fructose, high-fructose corn syrup, HFCS, sweetness, hunger, fullness, satiety, energy intakes

INTRODUCTION

The introduction of corn sweeteners into the US food supply is said to have contributed to the current obesity epidemic (1–3). High-fructose corn syrup (HFCS) began to replace sucrose in soft drinks at approximately the same time that obesity rates in the United States began their sharp increase (2, 4). However, temporal parallels between HFCS consumption patterns and body-weight trends are not sufficient to show causality. Obesity has also increased sharply in countries where beverage consumption is lower than in the United States and HFCS is not a common sweetener (5).

One of the criteria for establishing causality in evidence-based medicine is a biologically plausible mechanism. Attempts to

establish a causal link between soft drink consumption and rising obesity rates have therefore relied on the notion that caloric beverages in general (6), and HFCS-sweetened beverages in particular (2, 7), lack satiating power. Research reports have suggested that liquids were less satiating than were solids (8); that sugars were less satiating than was either protein or fat (9); and that HFCS blunted the satiety response more than did other sweeteners (2, 10, 11). The metabolic and endocrinologic processes associated with the ingestion of free fructose have featured prominently in arguments that HFCS-sweetened beverages are the principal culprit in the obesity epidemic (2, 6, 7).

However, satiety-related arguments based on the ingestion of pure fructose or fructose-rich stimuli (12, 13) may not apply to sweetened beverages, given that the 2 most common forms of HFCS—HFCS 55 and HFCS 42—contain 55% and 42% free fructose, respectively, and the remainder is free glucose. Furthermore, the sharp distinctions made between HFCS-sweetened and sucrose-sweetened beverages (2, 14) may be incorrect. The low pH of carbonated soft drinks favors the breakdown of sucrose into free glucose and free fructose before consumption (15), and the rate of hydrolysis is dependent on storage variables, temperature, and time (16). Perhaps most important, the short-term satiating power of foods and beverages may have little to do with the long-term regulation of body weight (13, 17).

The present study was a direct test of the hypothesis that HFCS-sweetened carbonated soft drinks differ significantly from sucrose-sweetened soft drinks and from low-fat milk in their effect on satiety. Aiming to approximate naturalistic conditions of soft drink use, we compared the effect of commercially available cola beverages, sweetened with sucrose or with 2 types of HFCS (HFCS 42 and HFCS 55), on hunger, satiety, and energy intakes (EIs) at the test meal. Because so much has been made of the metabolic differences between free fructose and fructose bound within disaccharide sucrose molecules (2, 14), we sent samples of the sucrose-sweetened beverage to be analyzed for free sugars content at the time of the experiment.

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SUBJECTS AND METHODS

Participants

Thirty-seven participants (19 M, 18 F) aged 20–29 y were recruited at the University of Washington with the use of advertisements and flyers. A telephone-administered screening interview was used to verify eligibility criteria. Eligible participants were normal-weight to overweight [body mass index (BMI; in kg/m²): 18–30], regularly consumed breakfast, did not smoke, and were not following a diet to gain or lose weight. Persons with food allergies or food restrictions; those who disliked ≥ 2 of the foods or beverages in the study; those taking prescription medications that were likely to affect taste, smell, or appetite; athletes in training; pregnant or lactating women; and persons reporting recent weight loss or weight cycling were excluded. Potential candidates were invited to report to the laboratory for a brief session, during which their weight and height were measured. The Eating Disorder Inventory (18) and the cognitive restraint subscale of the Eating Inventory (19) were administered as screening instruments to exclude persons with indications of eating disorders or restrained eating patterns. Persons who met all eligibility criteria were invited to participate and were given a reminder card stating the dates and times for the study sessions. To minimize variability, each participant was asked to report to the laboratory on the same day of the week throughout the study, to keep evening meals and activity levels on the day before each test as similar as possible, to refrain from drinking alcohol the day before each test, and to have a standardized breakfast at ≈ 0800 on the mornings when they were scheduled to have a test. The participants' standardized breakfasts were consumed at home and were composed of specified servings of hot or cold cereals with milk along with a medium-sized apple, orange, or banana or a specified serving of low-fat yogurt along with a medium-sized fruit.

All participants provided written informed consent. The study protocol was approved by the Institutional Review Board at the University of Washington. All 37 subjects completed the study and were compensated for their time.

Study design

The study followed a repeated-measures within-subject design, in which each participant returned for 6 separate test sessions. The sessions lasted from 0930 to 1310 and were spaced at least a week apart. The order of presentation of the 5 preloads and the no-beverage condition was counterbalanced. The same lunch foods were offered on all 6 testing occasions. The magnitude of the energy manipulation (0 or 215 kcal) was based on a review of previous studies in this area (20). Power analysis indicated that, with a power of 80% and an alpha of 0.05, a sample of 35 subjects was sufficient to detect a minimum difference of 150 kcal in compensation (21).

Beverage stimuli

The 5 beverages were cola sweetened with HFCS 42 (Sam's Choice Cola; Cott Beverages, Toronto, Canada), cola sweetened with HFCS 55 (Coca-Cola Classic; Coca-Cola Co, Atlanta, GA), cola sweetened with sucrose (Coca-Cola Classic), cola sweetened with aspartame (Diet Coke; Coca-Cola Co), and 1%-fat milk (Darigold; Wesfarm Foods, Seattle, WA). All preload beverages with the exception of the diet cola (2 kcal) were isoenergetic (894 kJ or 215 kcal) and of comparable sweetness, but they

TABLE 1

Energy and macronutrient composition of the preloads¹

Preload	Sugar composition (fructose/glucose)				Sugars	Protein	Fat	Serving	Energy	
	%/%	g	g	g					mL	kcal
HFCS 42	42/58	57.3	0.0	0.0	475	214	0.45			
HFCS 55	55/45	57.7	0.0	0.0	525	213	0.44			
Sucrose	50/50	54.7	0.0	0.0	525	213	0.44			
Aspartame	0/0	0.0	0.0	0.0	475	2	0.00			
1%-fat Milk	0/50 ²	27.2	16.7	5.2	495	213	0.43			

¹ HFCS 42 and HFCS 55, High-fructose corn syrup-sweetened cola containing 42% and 55% fructose, respectively; sucrose, sucrose-sweetened cola; aspartame, aspartame-sweetened cola. Data were from ESHA software (FOOD PROCESSOR version 8.1; Salem, OR) and manufacturers' specifications.

² Lactose in milk is a disaccharide made up of 1:1 glucose:galactose.

differed in sugar composition. To keep both sweetness and energy constant, the preload volume was allowed to vary within narrow limits (from 475 to 525 mL). The composition and energy density of the 5 beverage preloads are shown in **Table 1**. All beverages were coded and were served chilled, without ice, in opaque containers with a lid and a straw. Participants were asked to consume the entire amount within 15 min.

Samples of the sucrose-sweetened beverage were analyzed at regular intervals during the data collection phase. The analyses, conducted by the Analytic Chemistry Department of the Coca-Cola Company, used samples from the same production run (25 May 2005) of Coca-Cola Classic and were conducted at the same time as the data collection phase of the present study.

Motivational ratings and hedonic evaluations

Participants used computerized, semi-anchored visual analogue scales (VASs) to rate their hunger, fullness, thirst, nausea, and desire to eat. The VAS software was custom-written by using the LABVIEW graphic programming software (version 6.1; National Instruments, Austin, TX) that was running on 10 identical Macintosh G3 computers (Apple Computers, Cupertino, CA). Motivational scales were presented one at a time (ie, one scale per screen) on the computer monitor. Each participant used a mouse to position a cursor along the 100-mm bar displayed on a flat-panel LCD computer monitor. The VAS bars were anchored at each extreme with the labels "not at all . . ." and "extremely . . ." (22). A semi-anchored VAS was also used for quantifying several sensory and hedonic attributes of each beverage. Each sensory attribute scale also was anchored with the labels "not at all . . ." and "extremely . . .". Hedonic ratings and ratings along 11 sensory attribute scales were obtained for each beverage.

Test meal

A lunch meal served on a tray was provided at 1230. Identical meals were provided on each occasion. The set meal was 7120 kJ (1708 kcal) and included a variety of foods, both savory and sweet. Each lunch consisted of a selection of 2 grains, 2 types of fruit, 2 vegetables, 2 cheeses, 2 meats, 2 candies, 1 yogurt, 1 ice cream cup, hummus, chips, and water. A large cup containing 591 mL (20 fl oz) still water was provided with the test lunch. Participants were told that they could have as much or as little as



TABLE 2
Energy and nutrient composition of foods provided at lunch¹

Food	Carbohydrate	Protein	Fat	Sugar	Fiber	Portion	Energy
	g	g	g	g	g		kcal
Reduced-fat crackers	21	3	3		3	7 pieces	120
Pita bread	36	7	2	1	3	1 piece	190
Banana, medium-sized	26.7	1.2	0.6		1.8	1 piece	105
Apple slices	8	0	0	6	0	1 bowl	35
Baby carrots	9	1	0	6	2	1 bowl	38
Sugar snap peas	7	2	0	3	2	1 bowl	40
Cheddar cheese	0	5	7	0	0	1 slice	90
Havarti cheese	0	6	10	0	0	1 slice	110
Yogurt (99% fat-free)	33	5	1.5	27	0	1 pack	170
Ham	2	10	1	2	0	2 slice	60
Turkey	0	20	1	0	0	2 slice	90
Hummus	24	8	16	0	0	8 tbsp	240
Chocolate candies	15	1	4.5	13	1	1 pack	100
Marshmallow snack bar	18	1	2	8	0	1 pack	90
Potato chips	12	1	10	0	0	1 pack	140
Vanilla ice cream and orange sherbet blend	15	1	3	13	0	1 pack	90
Totals	226.7	72.2	61.6	79	12.8	—	1708

¹ Information was obtained from the food label or ESHA software (FOOD PROCESSOR version 8.1; Salem, OR).

they would like of any food or water and that they could request unlimited additional portions. All foods and water were weighed at the time of serving. Plate waste was collected and weighed by the experimenters. Food energy and nutrient values were calculated with FOOD PROCESSOR software (version 8.1; ESHA Research, Salem, OR) and from the manufacturer's food labels. The nutrient composition of the meal is shown in **Table 2**.

Procedures

Participants were asked to consume a standard breakfast at home starting at 0800. They arrived at the laboratory at 0930 and were seated in separate cubicles. They remained there for the duration of the session and were allowed to read, listen to music with earphones, or use their portable computers. They were allowed to leave the room briefly to stretch or use the restroom. Participants were also asked to record all foods and beverages they had consumed for breakfast earlier that morning and to note the time of consumption. Motivational ratings were first obtained 10 min after arrival (baseline or time 0) and every 20 min thereafter until lunchtime (times 1 through 8). The preload was provided in the laboratory at 1010, and lunch was provided at 1230. The last set of ratings was obtained after lunch (time 9), after which participants left the laboratory.

Data analyses and statistical tests

We used SPSS for WINDOWS software [version 11.1 (23)] for all analyses. Normality was determined by the Kolmogorov-Smirnov test (normal if $P > 0.05$). Analyses of motivational ratings used a nested repeated-measures analysis of variance (ANOVA) with beverage type and time after ingestion (times 2–8) as the within-subjects factors and sex as the between-subjects factor. Analyses were conducted for all 6 conditions together and separately for the 3 sweetener conditions (sucrose, 42% HFCS, and 55% HFCS) and the 3 comparison conditions (aspartame, 1%-fat milk, and no beverage). Univariate tests of within-subject effects were subject to Huynh-Feldt correction

when the sphericity assumption was violated. Bonferroni-adjusted pairwise comparisons were made when ANOVAs were significant. Because there were no significant main effects or sex-related interactions ($P > 0.05$ for all tests), the data were combined by sex for each beverage condition. Analyses of EIs and the weight of foods and water consumed at lunch used a repeated-measures ANOVA with beverage type as the within-subject factor and sex as the between-subjects factor. The strength of the association between pre-lunch (time 8) appetite ratings and energy or water intakes at lunch was tested by using Pearson's correlation coefficients. Pre-lunch appetite ratings were computed by averaging 3 proxies for appetite according to a method similar to that of Anderson et al (11): hunger, desire to eat, and the inverse of fullness (ie, 100 – fullness). Sweetness intensity and hedonic ratings were analyzed by repeated-measures ANOVA.

RESULTS

Participants and beverage stimuli

Mean (\pm SD) age was 22.6 ± 4.0 y for men and 23.4 ± 2.8 y for women. Mean body weight was 77.5 ± 10.7 kg for men and 60.2 ± 9.1 kg for women. Body mass index (BMI; in kg/m^2) values were 23.4 ± 1.8 for men and 21.9 ± 2.7 for women.

Analysis of sweetness ratings for the 4 cola beverages found a significant ($F_{3, 99} = 11.1, P < 0.001$) main effect of beverage type. However, that was entirely due to the aspartame-sweetened cola, which was perceived as significantly less sweet than the 3 sugar-sweetened colas ($P < 0.01$ for all 3 comparisons). Cola beverages sweetened with sucrose, HFCS 55, and HFCS 42 did not differ significantly in perceived sweetness ratings. Milk (1% fat) was not perceived as sweet. All 5 beverages (including milk) were rated as equally palatable by the participants. The analysis of hedonic preference ratings showed no significant main beverage effect ($F_{41, 32} = 2.5$).

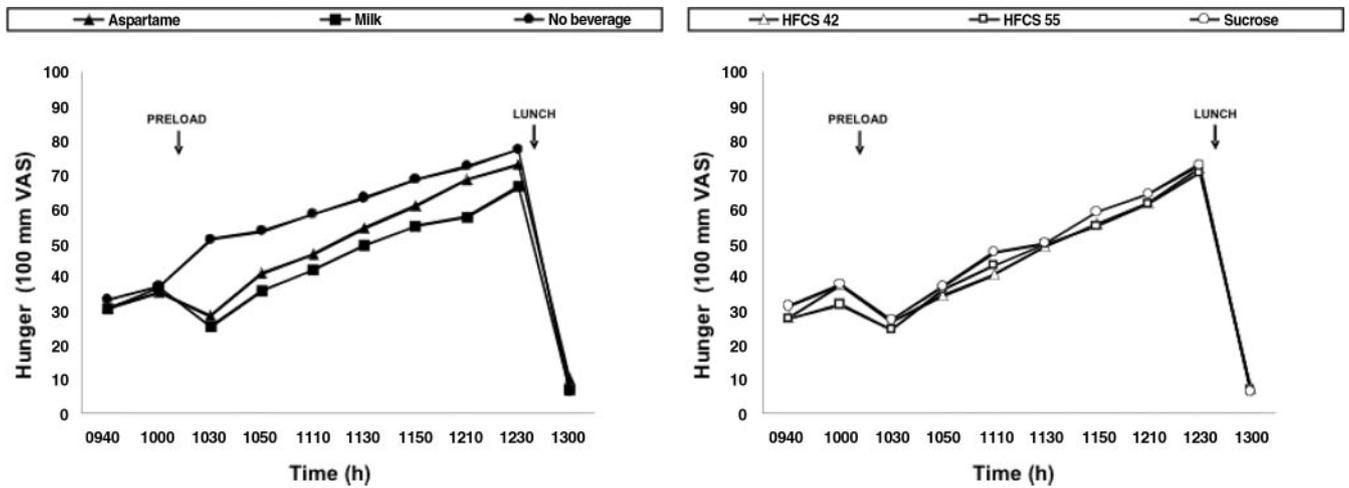


FIGURE 1. Temporal profiles of mean hunger ratings as a function of preload condition for control beverages (left) and sugar-sweetened carbonated beverages (right). $n = 37$. VAS, visual analogue scale; HFCS 42 and 55, high-fructose corn syrup containing 42% and 55% fructose, respectively. The no-beverage control was associated with higher hunger levels than were the milk and aspartame-sweetened diet cola controls ($P < 0.005$), and the beverage \times time interaction was significant ($P < 0.005$). Hunger ratings for the 3 sugar-sweetened beverages did not differ significantly.

Motivational ratings

All 5 beverages (caloric and not) led to lower hunger ratings during the initial 20 min after ingestion than were seen in the no-beverage condition. Repeated-measures ANOVA showed significant main effects of both beverage type and time and a significant beverage \times time interaction ($P < 0.001$ for all). Separate analyses were then conducted for the 3 colas and the 3 comparison conditions.

The time course of energy and volume effects on short-term hunger is shown in **Figure 1** (left). In the first 60 min after their ingestion, equal volumes of 1%-fat milk and noncaloric diet cola had comparable effects on perceived hunger. However, hunger ratings rose more rapidly in the diet cola condition than in the milk condition, and a separation in hunger ratings was visible before lunch. ANOVA found a significant ($P < 0.001$) main effect of beverage type and a significant ($P < 0.005$) beverage \times time interaction.

In contrast, the 3 sugar-sweetened cola beverages, although different from the no-beverage condition, did not differ significantly from each other (**Figure 1**, right). There was no significant main beverage effect or beverage \times time interaction.

ANOVA of fullness ratings found significant main effects of beverage type and time ($P < 0.001$ for both) and a significant beverage \times time interaction ($P < 0.005$). As shown in **Figure 2** (left), milk and diet cola had different effects on fullness ratings, depending on the time after ingestion. The beverage effect and the beverage \times time interaction were significant ($P < 0.01$ for both). In contrast, the sucrose- and the HFCS-sweetened colas differed significantly ($P < 0.001$) from the no-beverage condition but not from each other. The beverage \times time interaction was not significant (**Figure 2**, right).

Analysis of the desire-to-eat ratings found significant main effects of beverage type and time ($P < 0.001$ for both) and a significant beverage \times time interaction ($P < 0.01$). It can be seen

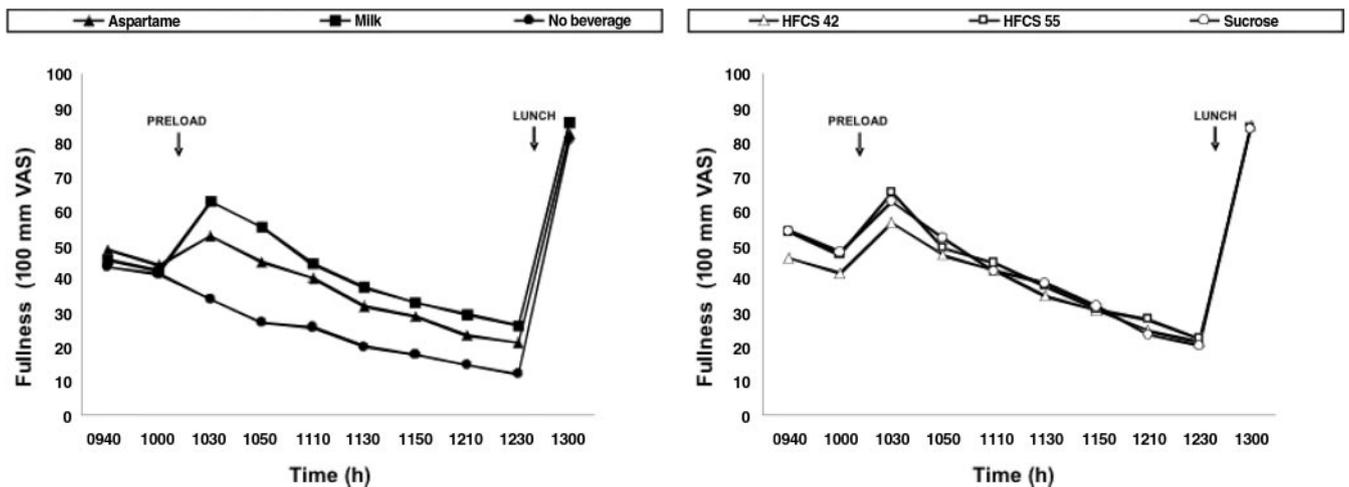


FIGURE 2. Temporal profiles of mean fullness ratings as a function of preload condition for control beverages (left) and sugar-sweetened carbonated beverages (right). $n = 37$. VAS, visual analogue scale; HFCS 42 and 55, high-fructose corn syrup containing 42% and 55% fructose, respectively. The no-beverage control was associated with significantly lower fullness ratings than were the milk and aspartame-sweetened diet cola controls ($P < 0.001$ for both). Diet cola was associated with significantly lower fullness ratings than was milk ($P < 0.05$), and the beverage \times time interaction was significant ($P < 0.01$). Fullness ratings for the 3 sugar-sweetened beverages did not differ significantly.

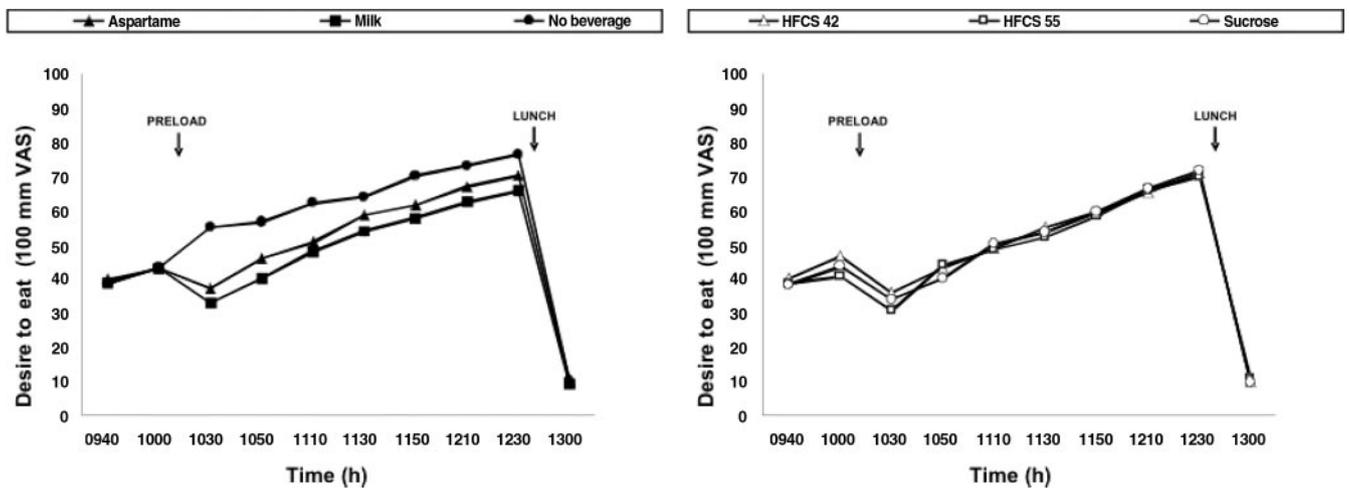


FIGURE 3. Temporal profiles of the mean desire to eat as a function of preload condition for control beverages (left) and sugar-sweetened carbonated beverages (right). $n = 37$. VAS, visual analogue scale; HFCS 42 and 55, high-fructose corn syrup containing 42% and 55% fructose, respectively. The no-beverage control was associated with a significantly greater desire to eat than were the milk and aspartame-sweetened diet cola controls ($P < 0.005$), and the beverage \times time interaction was significant ($P < 0.05$). Desire-to-eat ratings for the 3 sugar-sweetened beverages did not differ significantly.

in **Figure 3** (left) that 1%-fat milk and diet cola had different effects on the desire to eat, depending on the time after ingestion. The effect of beverage type was significant ($P < 0.001$), as was the beverage \times time interaction ($P < 0.05$). Again, the sucrose- and the HFCS-sweetened colas did not differ significantly from each other (**Figure 3**, right).

Analysis of thirst ratings (**Figure 4**) found significant main effects of beverage type and time ($P < 0.001$ for both). The beverage \times time interaction also was significant ($P < 0.01$). Subjects in the no-beverage condition reported significantly higher thirst ratings than did those in the other 5 conditions ($P < 0.05$ for all comparisons). The 5 beverages did not differ significantly from each other in thirst ratings. Participant nausea ratings did not vary significantly by preload condition, and nausea did not vary significantly as a function of time.

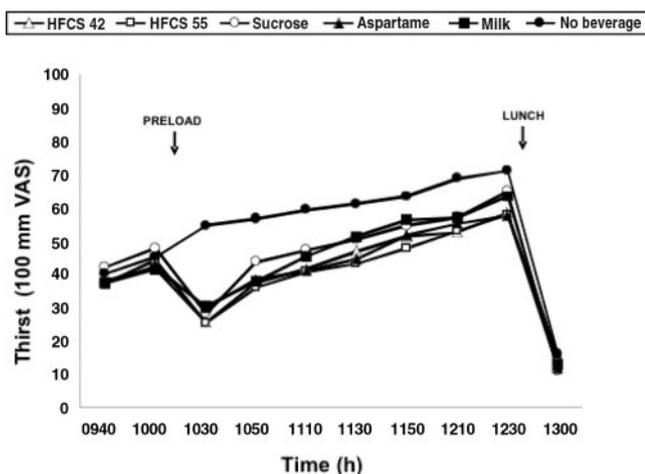


FIGURE 4. Temporal profiles of mean thirst ratings as a function of preload condition for all 6 preload conditions. $n = 37$. VAS, visual analogue scale; HFCS 42 and 55, high-fructose corn syrup containing 42% and 55% fructose, respectively. The no-beverage control was associated with significantly greater thirst than were the milk and aspartame-sweetened diet cola controls ($P < 0.001$), and the beverage \times time interaction was significant ($P < 0.05$). Thirst ratings for the 3 sugar-sweetened beverages did not differ significantly.

Energy and nutrient intakes

For each condition, energy and water intakes at lunch, as well as the weight of all foods consumed, are shown in **Table 3**. Across all 6 conditions, men consumed an average of 1077 kcal at lunch, whereas women consumed an average of 862 kcal. Whereas this effect of sex on EIs was significant ($P < 0.005$), the beverage type \times sex interaction was not.

The 4 caloric beverages partially suppressed EIs at lunch as compared with the EIs in the no-beverage condition. The main effect of beverage type on EIs was significant ($P < 0.05$). However, pairwise comparisons showed that the effect was significant only for the 1%-fat milk preload ($P < 0.05$). EIs in the no-beverage condition and in the diet cola condition did not differ significantly, which indicated that preload volume had no effect on EIs by the time the test lunch was served (120 min after preload ingestion).

The combined energy content of the preload and the lunch also showed significant main effects of beverage type ($P < 0.001$). Pairwise comparisons showed that the 3 sugar conditions did not differ significantly from each other or from milk. However, all 4 caloric beverages differed significantly from both the diet cola and the no-beverage conditions.

Beverage type significantly affected the weight of food and the amount of water consumed at lunch ($P < 0.001$ for both). Participants in the no-beverage condition consumed significantly more water at lunch than did subjects in all of the other preload conditions except for the diet cola condition. The nutrients consumed in association with each beverage condition are shown in **Table 4**. Beverage type did not significantly affect the nutrient composition of the lunch meal. Overall, the meals selected and consumed by the participants provided 51.2% of energy as carbohydrate, 17.2% of energy as protein, and 32.8% of energy as fat. The nutrient composition of lunch did not differ significantly by sex.

Motivational ratings and energy intakes

A composite score of appetite was calculated by using the method of Anderson et al (11). The correlation between appetite ratings and EIs at lunch was significant for women ($r = 0.33$,

TABLE 3Energy and water intakes and the weight of foods and beverages consumed at lunch for each preload condition¹

Preload condition	Energy at lunch	Energy at lunch + preload	Volume of water at lunch	Weight of food at lunch without water
	<i>kcal</i>	<i>kcal</i>	<i>mL</i>	<i>g</i>
HFCS 42	979 ± 40	1193 ± 40 ²	415 ± 29	1004 ± 44 ²
HFCS 55	969 ± 41	1182 ± 41 ²	418 ± 27	1003 ± 39 ²
Sucrose	957 ± 41	1170 ± 41 ²	427 ± 31	1009 ± 44 ²
Aspartame	1009 ± 39	1011 ± 39	437 ± 28	1033 ± 40
1%-fat Milk	916 ± 41 ²	1129 ± 41 ²	423 ± 26	961 ± 42 ²
No beverage	1008 ± 40	1008 ± 41	522 ± 36 [‡]	1125 ± 44

¹ All values are $\bar{x} \pm \text{SEM}$; $n = 37$. HFCS 42 and HFCS 55, high-fructose corn syrup-sweetened colas containing 42% and 55% fructose, respectively; sucrose, sucrose-sweetened cola; aspartame, aspartame-sweetened cola.

² Significantly different from aspartame and no-beverage conditions, $P < 0.05$ (Bonferroni-corrected post hoc pairwise comparison).

³ Significantly different from all beverage conditions except aspartame, $P < 0.05$ (Bonferroni-corrected post hoc pairwise comparison).

$P < 0.001$) but not for men ($r = 0.17$, NS). In contrast, the correlation between prelunch thirst ratings and water consumption at lunch was significant for both women ($r = 0.39$, $P < 0.001$) and men ($r = 0.2$, $P < 0.05$).

Free sugar content of sucrose-sweetened beverage

The progressive hydrolysis of sucrose in cola beverages over the course of the study is shown in **Figure 5**. Each point is based on the analysis of 3 samples. As sucrose hydrolyzed, its concentration declined from 36% of total sugars on June 30 to just above 10% on August 24, or ≈ 3 mo after the beverages were manufactured (May 25). Free fructose increased from 32% to $\approx 44\%$. Free glucose (not shown) followed the same course as fructose. During the time of the satiety study (period indicated by the shaded bar), the principal sugars in the sucrose-sweetened cola were free fructose and glucose. Dashed reference lines at 50.6% and 6.4% indicate concentrations of sucrose present in samples from a separate lot of sucrose-sweetened cola measured 10 d and 1 y after manufacture.

DISCUSSION

The argument that HFCS-sweetened beverages play a causal role in the obesity epidemic (24) rests, in part, on the notion that free fructose blunts the satiety response more strongly than do other sweeteners (2, 11, 13). Bray et al (14) made a sharp distinction between “free” and bound fructose in soft drinks, arguing further that HFCS-containing beverages could “never” have the same sweetness as sucrose-sweetened ones.

TABLE 4Macronutrient intakes at lunch¹

Preload condition	Protein	Carbohydrate	Sugar	Fat
	<i>kcal</i>	<i>kcal</i>	<i>kcal</i>	<i>kcal</i>
HFCS 42	165 ± 8	507 ± 21	181 ± 11	319 ± 17
HFCS 55	169 ± 9	503 ± 23	179 ± 10	310 ± 16
Sucrose	171 ± 9	482 ± 23	173 ± 12	315 ± 15
Aspartame	181 ± 9	504 ± 21	183 ± 10	338 ± 16
1%-fat Milk	156 ± 10	466 ± 22	161 ± 12	307 ± 15
No Beverage	166 ± 10	524 ± 21	195 ± 12	334 ± 15

¹ All values are $\bar{x} \pm \text{SEM}$; $n = 37$. HFCS 42 and HFCS 55, high-fructose corn syrup-sweetened colas containing 42% and 55% fructose, respectively; sucrose, sucrose-sweetened cola; aspartame, aspartame-sweetened cola.

As the present study shows, the 3 cola beverages, which were sweetened with sucrose, HFCS 55, or HFCS 42, were perceived as equally sweet and significantly sweeter than diet cola. All 3 beverages showed identical temporal profiles of motivational ratings, which were different from the no-beverage condition. There were no differences between the reported temporal profiles for hunger, satiety, and the desire to eat obtained after the ingestion of HFCS- or sucrose-sweetened colas. Compared with the EIs under the no-beverage condition, the 3 colas and 1%-fat milk weakly suppressed EIs at lunch, whereas the diet cola did not. However, the effect was significant only for 1%-fat milk.

The present study used the conventional preload paradigm (25–27) and commercially available colas and 1%-fat milk. The statistical power was similar to that used in past research (9, 25). The study design was thus able to separate the effects of preload energy and preload volume. As had been noted in previous reports, diet cola suppressed hunger immediately after ingestion, but hunger ratings recovered sooner than did those after ingestion of caloric 1%-fat milk. Preload volume alone had no effect on EIs 120 min later. The amount of food consumed at lunch in the diet

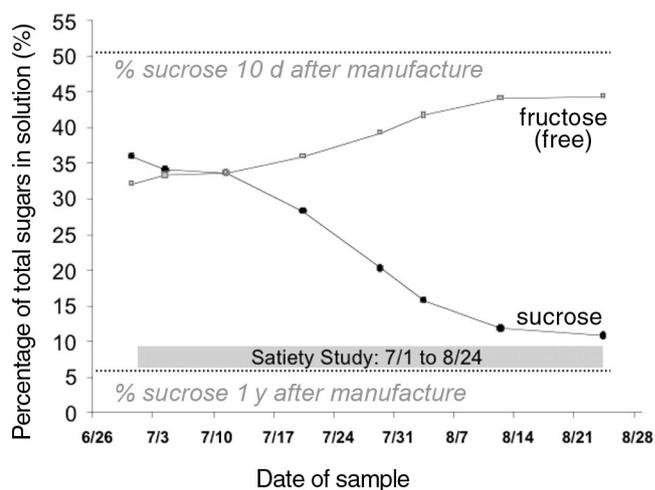


FIGURE 5. Timeline of sucrose inversion in the sucrose-containing cola used in this study. Each data point represents the mean of 3 samples taken from the same lot on the indicated date. As sucrose hydrolyzed over the weeks of the study, its concentration declined from 36% of total sugars to just above 10%. Free fructose increased from 32% to $\approx 45\%$ of total sugar.

cola condition did not differ significantly from that in the no-beverage condition.

The notion that HFCS-sweetened beverages differ substantially from sucrose-sweetened beverages (2, 14) seems to have been based on the incorrect assumption that sucrose in solution remains stable. As documented by multiple laboratory assays conducted over the course of the present study, the sucrose content of the cola beverage dropped from 35% to 10%, whereas the free fructose content rose from 32% to 44% of total sugars. Other hydrolysis data indicate that 50% of the sucrose in carbonated beverages is hydrolyzed within 10 d of manufacture and that $\approx 90\%$ is hydrolyzed within 3 mo. Given the time lag between production and consumption, it is likely that most sugars in sucrose-sweetened beverages are already in the form of free fructose and glucose by the time the beverages are consumed (16).

Previous laboratory studies of sugars and satiety in humans, most often conducted with aqueous solutions of pure sugars (11, 12), produced inconsistent results. One early study did not find differences between glucose and fructose in hunger ratings or EIs (12). A study in 16 women showed that 50 g fructose in 500 mL water significantly reduced lunch intakes as compared with a water control (28). A study of different glucose-fructose mixtures showed that high-glucose (80%) stimuli elevated blood glucose concentrations more than did high-fructose stimuli (80%), but that the 2 mixtures had similar effects on appetite (T Akhavan and GH Anderson, unpublished observations, 2005). The same study showed that high-fructose stimuli (65% and 80%) were associated with lower short-term food intake than was sucrose.

The putative effect of HFCS on satiety hormones awaits further research. In a recent study, 30 lean women consumed cola beverages at lunch served at 1300 h, and blood samples were drawn before the meal and 30 min and 60 min afterward (29). There were no significant differences between plasma glucose, insulin, leptin, or ghrelin after the ingestion of HFCS- or sucrose-sweetened cola. It is possible that the responses to sucrose- and HFCS-sweetened cola beverages were similar because the sugar content of the stimuli was, in fact, much the same. Studies of the human response to sweetened liquids should assess the stimulus sugar composition at the time of testing.

The present study does not resolve the underlying question of whether liquids differ from solids in their satiating power. Past studies found no difference in satiating power between liquid cola and solid fat-free cookies (30) or between a drinkable liquid yogurt and the same yogurt that was eaten with a spoon (9). A review (20) showed that, whereas some studies found that liquids were less satiating than solids, other studies showed the opposite. Most recently, a study showing that apple juice had higher satiating power when it was called a "soup" attributed the difference to cognitive rather than physiologic factors (31).

In the present study, conducted with liquids only, a slightly but significantly different degree of compensation as compared with the no-beverage condition was obtained for 1%-fat milk only. This finding is of interest because 2 previous studies observed no differences in EIs among regular cola, orange juice, or 1%-fat milk, no matter whether the beverages were consumed 135 min before lunch (32) or with lunch (27). On the other hand, yogurts were associated with higher fullness ratings than were either dairy- or fruit-based drinks (9), possibly because of their higher protein content.

Although laboratory studies conducted with pure sugar solutions provide valuable data on fructose metabolism (12, 13), not all observations can be extrapolated to the human food supply. The hydrolysis of sucrose in soft drinks before consumption suggests that the substitution of HFCS for sucrose did not have the dramatic effects that had been claimed (2). The emerging view voiced in the scientific literature (33) and in the news media (34) is that any potential contribution of sugars to obesity is unlikely to be mediated by metabolic effects that are unique to HFCS.

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