Volume of food consumed affects satiety in men[1–3]

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ABSTRACT This study tested the hypothesis that the amount (weight or volume) of food consumed affects the satiating potency of a food, independent of its energy content. Normal-weight young men (n = 20) were tested in a within-subjects design. Subjects were served a milk-based drink or no drink (control), followed 30 min later by a self-selected lunch and > 4 h later by a self-selected dinner. Milk drinks were equal in energy content (2088 kJ, or 499 kcal) and had similar proportions of fat (30.3%), carbohydrate (54.7%), and protein (15%) across three volumes: 300, 450, and 600 mL. Ratings of palatability, sensory properties, and energy content of the drinks and of hunger completed before consumption of the preloads were not significantly different among conditions. The results showed that preload volume affected energy intake at lunch ($P \leq 0.009$) such that energy intake was less after the 600-mL preload than after the 300-mL preload. This effect was still present when energy intake at dinner was included ($P \leq 0.022$). At lunch, including energy from the preload, subjects overate relative to the control condition (4323 ± 322 kJ) after the 300- (5263 ± 321 kJ) and 450-mL (5011 ± 300 kJ) preloads but not after the 600-mL (4703 ± 353 kJ) preload. Thus, the best adjustment for the energy in the preloads was with the largest, least energy-dense drink. Consistent with the effects on intake, the volume of the drinks affected ratings of hunger and fullness. These results indicate that the volume consumed is an important determinant of satiety after milk drinks under these conditions. *Am J Clin Nutr* 1998; 67:1170–77.

KEY WORDS Energy density, humans, food intake, hunger, satiety, volume, Eating Attitudes Test, Beck Depression Inventory, Zung Self Rating Questionnaire

INTRODUCTION

The high incidence of obesity in affluent societies indicates that many individuals are consuming more energy than they are expending. Food intake is affected by a variety of factors, including environmental influences and those related to the psychologic or physiologic characteristics of the individual. In particular, attributes of the available food, such as palatability (1), energy or macronutrient content (2), or energy density (3), can affect intake.

We showed previously in a series of studies that some people, especially lean young men, can adjust their intake in response to the energy content of a preload that is either ingested (4, 5) or infused intragastrically (6) before a meal. The type of macronutrients, ie, fat or carbohydrate, in the preload did not affect subsequent energy compensation, a measure of satiety, in the lean men (2, 4–6). In these experiments, the sensory properties and the weight or volume of the preload were held constant while the energy or macronutrient content, or both, varied. The purpose of the present study was to explore further the properties of food that can affect satiety by keeping the sensory properties and the energy and macronutrient contents of preloads constant and systematically varying the volume or weight consumed.

The volume consumed could affect satiety through mechanoreceptors or chemoreceptors in the oropharyngeal or gastrointestinal tracts (7). Additionally, the volume of a preload could affect satiety by affecting the perception of how much has been consumed (3). People may equate portion size with energy content and adjust subsequent intake accordingly. The present study was the first to test directly the effects of volume consumed on satiety in humans when the energy and macronutrient contents and the sensory properties of the preloads are similar.

SUBJECTS AND METHODS

Design

The experiment used four conditions in a counterbalanced, within-subjects design. Subjects came to the laboratory on 4 separate days to eat breakfast, lunch, and dinner. On three of the days, subjects received a milk-based preload before lunch and on 1 d no preload was served. Test days were separated by ≥1 wk.

Subjects

We recruited participants through advertisements in local and university newspapers, posters, and mailings. Potential subjects

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were initially screened through a telephone interview to determine whether they ate breakfast regularly, were regular milk drinkers, did not smoke, did not have any food allergies or restrictions, were not athletes in training, were not dieting to gain or lose weight, and were not taking any medications or dietary supplements that could affect appetite. Potential subjects completed the following questionnaires in our laboratory: the Eating Attitudes Test (EAT; possible score: 0–140), which detects symptoms of an eating disorder (8); the Eating Inventory (EI; 9), which measures dietary restraint (possible score: 0–21), perceived hunger (possible score: 0–14), and disinhibition (possible score: 0–16); the Beck Depression Inventory (10; possible score: 0–63) and the Zung Self Rating Questionnaire (11; possible score: 20–80), both of which detect depression; a detailed demographic questionnaire; and a family weight-history questionnaire. Weight, height, waist, and hip measurements were taken at this time. Subjects were included in the study only if their body mass index (BMI; in kg/m^2) was between 20 and 25. Subjects were excluded if they scored > 40 on the Zung Self Rating Questionnaire, > 10 on the Beck Depression Inventory, > 30 on the EAT, or > 10 on the cognitive restraint subscale of the EI. Finally, subjects were excluded from the study if they disliked two or more of the foods to be served in any of the test meals. All aspects of the study were approved by the Institutional Review Board of Pennsylvania State University.

Procedures

Subjects were asked to keep their evening meals and activity levels on the day before each test day as similar as possible. Subjects were also asked to refrain from drinking alcohol on the day before each test day and throughout each test day. Food and activity diaries were used to monitor compliance. On each test day, subjects consumed breakfast ≥ 3 h before the start of the lunch meal. Subjects were instructed to not consume any food or beverages, except water, in the interval between breakfast and 1 h before their scheduled lunch. During the hour before their lunch, subjects were instructed to refrain from eating or drinking any foods, including water.

At the start of the lunch session, subjects tasted and rated a sample of the preload or were notified that there would be no milk drink served on that day. On days when a preload was served, subjects were instructed to consume the preload over a 15-min period. Preset timers were given to assist subjects in pacing their consumption of the preload. Subjects were permitted to read magazines before lunch, except when consuming the preload. Magazines were screened to exclude any articles pertaining to food, weight loss, or body image. Lunch was served 30 min after the presentation of the preload or 30 min after arrival for the no-preload condition. Finally, subjects returned to the laboratory for dinner ≥ 4 h after lunch began. Subjects were asked to not consume any foods or energy-containing beverages outside the laboratory during the experimental day until after dinner. During all meals, subjects were tested alone in private cubicles.

Preloads

Three vanilla-flavored, milk-based drinks were developed for use as preloads. Initial formulation and testing of the drinks was conducted in the Department of Food Science at Pennsylvania State University. After these initial tests, we recruited men and women (n = 18) to taste and rate samples of the final formulations in our laboratory. These subjects were excluded from participation in the current preload study. No differences were found for ratings of perceived energy content of the food, pleasantness of taste, creaminess, sweetness, thickness, or how much subjects were willing to consume. The preloads were equal in energy and macronutrient contents but varied in volume (300, 450, or 600 mL) (**Table 1**). The preloads were chilled (3 °C, 37 °F) and presented to the subjects in a large, clear glass with a straw.

Test meals

Subjects selected their breakfast foods before the study began. They chose either bagels (served with an assortment of jelly, jam, and cream cheese) or cereal (there were a variety of choices) and their beverages (coffee, tea, orange juice, or milk). Subjects received the same breakfast at the start of each test day.

Lunch and dinner were individual, buffet-style, self-selected meals that allowed participants to choose ad libitum from a variety of meal-appropriate foods. The foods varied in fat, carbohydrate, and protein contents to allow subjects to vary their energy intake and proportions of macronutrients. The lunch consisted of sliced turkey breast, bologna, American cheese slices, bread, lettuce, tomato slices, potato chips, pretzels, applesauce, and cookies. Dinner included cooked pasta shells, meatless spaghetti sauce,

TABLE 1
Ingredients and macronutrient and energy contents of preloads

	Preload condition[1]		
	300 mL	450 mL	600 mL
Ingredients (g)			
Skim milk[2]	110.0	110.0	110.0
Instant nonfat dry milk[3]	20.0	20.0	20.0
Sweet cream, 40%[2]	39.5	39.5	39.5
Total milk protein[4]	9.0	9.0	9.0
Corn syrup solids (36 DE)[5]	30.0	30.0	30.0
Maltose[6]	20.5	14.5	8.3
Polydextrose-K[7]	0.0	24.0	49.0
Water	100.0	222.0	352.0
Fat			
(g)	16.8	16.8	16.8
(% of energy)	30.3	30.3	30.3
Carbohydrate			
(g)	68.3	68.3	68.3
(% of energy)	54.7	54.7	54.7
Protein			
(g)	18.7	18.7	18.7
(% of energy)	15.0	15.0	15.0
Energy			
(kJ)	2088	2088	2088
(kcal)	499	499	499
Energy density			
(kJ/g)	6.3	4.5	3.4
(kcal/g)	1.5	1.1	0.8

[1] The preloads were pasteurized in a high-temperature, short-time pasteurizer at 80 ºC for 25 s and homogenized in a two-stage homogenizer at 6.9 MPa in the first stage and 3.45 MPa in the second stage. In the 450-mL and 600-mL drinks, 0.02% carrageenan (SeaKem IC 611; FMC Food Ingredients, Philadelphia) was used. Guar gum (Germantown International, Broomall, PA) was used in the 450- (0.13%) and 600-mL (0.18%) drinks.
[2] The Pennsylvania State University Creamery, University Park, PA.
[3] Maryland and Virginia Milk Producers Association Inc, Laurel, MD.
[4] Milk Pro800; American Dairy Specialties Ltd, Burlington, NJ.
[5] Cerestar USA Inc, Hammond, IN. DE, dextrose equivalents.
[6] US Biochemical Corporation, Cleveland
[7] Litesse (4.2 kJ/g); Pfizer Chemical Division, New York.

breaded chicken fillets, broccoli, rolls, butter, pound cake, chocolate bars, and mixed fruit cups. At both meals, a variety of condiments and chilled water were served. To avoid the possibility of subjects eating to "clean their plates," we presented more food than they were likely to consume. More information about the foods offered at breakfast, lunch, and dinner is available from the corresponding author on request. During all meals, subjects were instructed to eat as much or as little of any food item as they desired and to ask for more if desired. All food items were weighed before and after consumption to obtain the amount consumed to the nearest 0.1 g. Energy and macronutrient intakes were calculated by using information from the manufacturers and from *Bowes & Church's Food Values of Portions Commonly Used* (12).

Visual analogue scales

Subjects rated their hunger, thirst, nausea, fullness, and prospective consumption (ie, how much food they thought they could eat) on visual analogue scales (VAS; in mm) (13). For example, hunger was rated on a 100-mm line preceded by the question, "How hungry are you right now?" and anchored on the left by "not at all hungry" and on the right by "extremely hungry." Other anchors consisted of the phrases "not at all…" and "extremely…" combined with the adjectives "thirsty," "nauseated," and "full." Ratings were performed before and after breakfast, before and after the preload (or at equivalent times in the no-preload condition), before and after lunch, hourly for 3 h after lunch, and before and after dinner.

Subjects also rated samples of each preload on 100-mm VAS. The following attributes were rated: pleasantness of taste, perceived energy content, sweetness, creaminess, thickness, and prospective consumption. Ratings were performed before consumption of the preload. Subjects were given a 15-mL sample of the preload to taste and rate. After the ratings were completed, subjects were served their preload.

Debriefing

Subjects completed a debriefing questionnaire at the end of the study. They were asked to state the purpose of the study, whether they noticed any differences between the test days, and whether there were any factors that affected their responses. They were also asked whether they noticed any differences in the milk drinks in terms of color, smell, fat content, energy content, amount, taste, texture, and other qualities.

Statistical analyses

Data were analyzed by using SAS-PC for Windows (version 6.10; SAS Institute Inc, Cary, NC). One-way analysis of variance was performed by using the general linear model (GLM) procedure. The percentage of energy from macronutrients was analyzed by using an equivalent multivariate analysis of variance procedure with condition entered as a within-subjects factor. Tukey's honestly significant difference test was used for post hoc comparisons of significant effects. Results were considered significant at the $P < 0.05$ level. Power analyses were conducted by using the statistical package nQuery Advisor (version 2.0; Statistical Solutions, Ltd, Los Angeles) with alpha set to 0.05.

Food intake

Energy intakes (kJ) and amounts consumed (g), with and without water, and the percentage of energy from macronutrients from lunch and from lunch plus dinner, with and without the preload, were analyzed. Analyses were also performed excluding the no-preload (control) condition. The percentage of energy compensation at lunch was calculated by dividing the energy intake at lunch in the control condition by the energy intake at lunch (including energy from the preload) in each of the preload conditions and multiplying by 100. The percentage energy compensation over the rest of the day was calculated by dividing energy intake at lunch and dinner in the control condition by the energy intake at lunch and dinner in each of the preload conditions and multiplying by 100. For these calculations, values > 100% indicated overcompensation (undereating) and values < 100% indicated undercompensation (overeating). Individual t tests were used to test whether percentage energy compensation scores were different from 100%. For these tests, results were considered significant at $P < 0.025$, based on a modified Bonferroni correction for multiple comparisons.

Satiating efficiency

The satiating efficiency of the preloads based on Kissileff's model (14) was also examined. We calculated the negative of the slope generated by plotting attributes related to preload size (kJ or g) against the average amount consumed at lunch (kJ or g). A satiating efficiency of 1 represents a reduction in lunch intake of 1 unit per unit of preload, a satiating efficiency > 1 represents a reduction in lunch intake of > 1 unit per unit of preload, and a satiating efficiency < 1 represents a reduction in lunch intake of < 1 unit per unit of preload. Two attributes of the preloads were used in these analyses: weight and hypothetical energy content. The hypothetical energy content of the preload is the estimated energy content that would result if subjects assumed that a different volume of the same drink was served on each occasion and thus volume was an indicator of the energy content (ie, that the energy density of the drinks remained constant). Using the drink in the condition in which the best energy compensation was observed (ie, the 600-mL condition), we calculated the hypothetical energy content of the 300-mL drink to be 50% (1044 kJ) of that of the 600-mL drink, and the hypothetical energy content of the 450-mL drink to be 75% (1566 kJ) of that of the 600-mL drink (2088 kJ).

Visual analogue scale ratings

Subjective ratings of hunger, fullness, thirst, nausea, and prospective consumption made before the preload was consumed were analyzed to ensure that systematic differences did not exist between test days. Changes in ratings due to preload consumption were calculated for each participant by subtracting the ratings taken before preload consumption from the ratings taken immediately after preload consumption (15 min later). A negative value indicates a decline in these subjective sensations, whereas a positive value indicates an increase. Ratings of the preloads, completed before consumption, were analyzed to confirm that subjects could not detect differences between preloads.

RESULTS

Subjects

Twenty-four subjects were selected; however, four were dropped from the study: one subject failed to report to the laboratory on the first day of the study, one subject did not follow the experimental procedures, one subject reported gastrointestinal disturbance (unrelated to the study protocol), and one subject reported increased nausea after consuming the preloads. The final sample consisted of 20 lean men aged 22–42 y (mean age: 28 ± 1.5 y). They weighed 75.4 ± 2.2 kg, were 1.8 ± 0.02 m tall, had a BMI of 23.3 ± 0.3, and had a waist-to-hip ratio of 0.9 ± 0.01. According to the EI, subjects scored low in restraint (4.9 ± 0.7), perceived hunger (3.8 ± 0.6), and disinhibition (3.3 ± 0.4). In addition, the EAT indicated no signs of an eating disorder (mean score: 6.9 ± 0.6). The two tests used to assess depression indicated low scores: the Zung Self Rating Questionnaire (mean score: 27.3 ± 1.0) and the Beck Depression Inventory (meanscore: 08 ± 0.2).

Energy intake

Mean energy intakes at each meal are presented in **Table 2**. Subjects consumed significantly less energy at lunch after consumption of the preloads than in the no-preload condition ($F_{[3,57]} = 19.86$, $P < 0.0001$). When energy from the preloads was added to lunch intake, there was still a main effect of condition ($F_{[3,57]} = 5.48$, $P < 0.002$). Subjects overate, compared with the no-preload condition (4323 ± 322 kJ), in the 300-mL (5263 ± 321 kJ) and 450-mL (5011 ± 300 kJ) conditions but not in the 600-mL condition (4703 ± 353 kJ) (**Figure 1**). When the control condition was excluded from the analysis, the volume of the preload significantly affected energy intake at lunch ($F_{[2,38]} = 5.33$, $P < 0.009$) such that intake was reduced 17.6% more after consumption of the 600-mL preload than after the 300-mL preload. These results indicate that the volume ingested affected satiety.

When energy intakes at lunch and dinner were combined, subjects consumed significantly less energy after consumption of the preloads than in the no-preload condition ($F_{[3,57]} = 15.83$, $P < 0.0001$). When energy intake from the preload was added to energy intakes at lunch and dinner, no differences were detected among the four conditions. When the no-preload condition was excluded from the analysis we found that subjects ate significantly more at lunch and dinner combined after the 300-mL preload (10309 ± 537 kJ) than after the 600-mL preload (9410 ± 588 kJ). Because no significant differences in energy intake were found for dinner when the no-preload condition was excluded, these results indicate that subjects did not adjust their energy intake at dinner to compensate for differences among the three preload conditions at lunch.

Energy compensation after the preloads

At both lunch and dinner, energy compensation after the 300-mL preload was significantly different from energy compensation after the 600-mL preload. At lunch, energy compensation after the 300-mL (84%) and 450-mL (88%) preloads was significantly different from 100% ($P < 0.008$ and 0.02, respectively). However, energy compensation after the 600-mL preload (96%) was not significantly different from 100%. At dinner, compensation scores were not significantly different from 100% after any of the preloads (95%, 99%, and 104% after the 300-mL, 450-mL, and 600-mL preloads, respectively).

Satiating efficiency

The satiating efficiency of preload weight was 0.30 for food intake at lunch and 0.35 for water intake at lunch. The satiating efficiency for intake of food and water combined was 0.64. Thus, adjustments in lunch intake for preload weight were not made on a strictly one-to-one basis. For each gram of preload consumed, subjects reduced their intake of food and water at lunch by 0.64 g. As shown in **Figure 2**, a satiating efficiency of 1.0 would result if subjects assumed that changes in energy content of the preloads occurred in direct proportion with changes in volume (ie, volume cues override energy cues) and adjusted their energy intake

TABLE 2
Intakes of food and water[1]

	No preload	Preload condition 300 mL	450 mL	600 mL
Breakfast				
Energy intake (kJ)	2658 ± 194	2761 ± 181	2827 ± 180	2676 ± 187
Preload				
Energy intake (kJ)	NA	2088	2088	2088
Amount consumed (g)	NA	329	469	618
Lunch				
Energy intake (kJ)	4323 ± 322[a]	3175 ± 321[b]	2923 ± 300[b]	2615 ± 353[b,2]
Amount consumed (g)[3]	588 ± 35[a]	452 ± 34[b 4]	423 ± 32[b,c,4]	366 ± 37[c]
Water consumed (g)	552 ± 70[a]	496 ± 53[a,b]	469 ± 55[a,b]	396 ± 57[b,2]
Dinner				
Energy intake (kJ)	5405 ± 362[a]	5046 ± 338[a,b]	4752 ± 261[b]	4708 ± 300[b]
Amount consumed (g)[3]	814 ± 48	782 ± 46	744 ± 42	726 ± 45
Water consumed (g)	578 ± 55	578 ± 68	538 ± 52	495 ± 70
Total (preload + lunch + dinner)				
Energy intake (kJ)	9728 ± 627	10309 ± 537	9763 ± 518	9410 ± 588[2]
Amount consumed (g)[3]	1402 ± 76[a]	1563 ± 65[b]	1635 ± 64[b,c]	1711 ± 73[c,2]
Water consumed (g)	1131 ± 120[a]	1073 ± 118[a]	1007 ± 100[a,b]	891 ± 123[b,2]
Fat (% of energy)	22 ± 1.2	22 ± 0.8	22 ± 0.9	23 ± 1.0
Carbohydrate (% of energy)	65 ± 1.4	64 ± 0.9	65 ± 1.1	65 ± 1.1
Protein (% of energy)	13 ± 0.5	14 ± 0.4	14 ± 0.5	13 ± 0.4

[1] Data were analyzed with and without data from the no-preload condition. Values within a row with different superscript letters are significantly different when models included the no-preload condition, $P < 0.05$. NA, not applicable.

[2] Significantly different from 300 mL when the no-preload condition was excluded, $P < 0.05$.

[3] Amount consumed excluding water.

[4] Significantly different from 600 mL when the no-preload condition was excluded, $P < 0.05$.

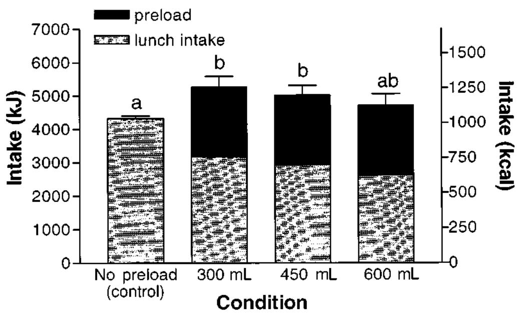

FIGURE 1. Mean (± SEM) energy intake at lunch in each of the four conditions (n = 20). Means with different letters are significantly different, $P < 0.05$.

accordingly. A satiating efficiency of 0.0 would result if subjects relied on energy cues only, ie, all preloads would reduce intake at lunch by the same amount (kJ). A satiating efficiency of 0.54 was found when the hypothetical energy content of the preload was regressed against actual energy intake at lunch. Thus, subjects reduced their energy intake at lunch by 0.54 kJ for every kJ of hypothetical preload. These results indicate that volume cues partially override energy cues.

Macronutrient energy intake and weight of food consumed

There were no significant differences in the macronutrient composition of lunch and dinner. Consumption of the preload reduced both food and water intakes at lunch (Table 2). Subjects consumed less food (g) in the three preload conditions than in the control condition ($F_{[3,57]} = 23.5$, $P < 0.0001$). Subjects consumed less food and water at lunch after the 600-mL preload than after the 300-mL preload. Effects of volume were also noted when the weight of the preload was added to the weight of food and water intakes at lunch. Subjects consumed a greater total weight of food and water in the 450- and 600-mL conditions than in the control condition, and consumed more food and water (g) in the 600-mL condition than in the 300-mL condition.

VAS ratings

Subjective sensations

No significant differences were found for subjective ratings of hunger, fullness, thirst, nausea, or prospective consumption reported before the preload was served. Thus, subjects did not differ systematically across conditions. Differential changes in ratings due to condition were detected in the interval between when the preload and lunch were served (**Table 3**). Subjects reported greater reductions in hunger and prospective consumption and greater increases in fullness after consumption of the 600-mL preload than after consumption of the 300-mL preload. These results show a clear effect of volume consumed on subjective ratings of satiety. No effect of condition was noted for changes in ratings of nausea. Ratings were low before preloads were served (between 3.2 and 2.2 mm) and changed little after the preloads were consumed (Table 3).

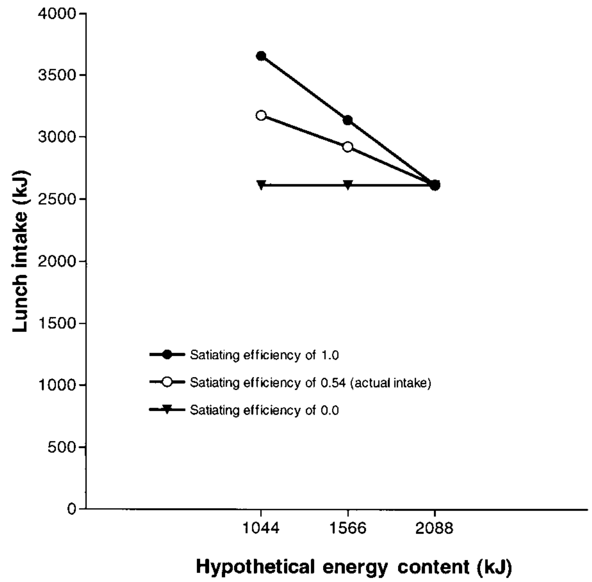

FIGURE 2. Satiating efficiency of volume consumed. For each regression line, intake at lunch (kJ) was regressed against the hypothetical energy content of the preloads, which was calculated on the basis of the energy content estimates that would result if subjects equated changes in volume with changes in energy content. Using the 600-mL drink as a reference, we calculated the hypothetical energy content of the 300 mL drink to be 50% (1044 kJ) of and the 450-mL drink to be 75% (1566 kJ) of the energy content in the 600 mL drink (2088 kJ). Theoretically, a satiating efficiency of 1.0 would result if lunch intake was adjusted in direct proportion to changes in volume, and a satiating efficiency of 0.0 would result if no adjustments were made.

Preload ratings

Ratings of the preloads, completed on each test day before subjects were aware of the volume to be consumed, were not

TABLE 3
Change in visual analogue scale (VAS) scores after preload consumption[1]

	No preload	Preload condition 300 mL	450 mL	600 mL
		mm		
"How hungry are you right now?"	5.1 ± 3.3^{a}	-9.5 ± 4.1^{b}	$-17.9 \pm 3.4^{b,c}$	-28.5 ± 3.4^{c}
"How thirsty are you right now?"	3.8 ± 3.5^{a}	$-11.6 \pm 5.2^{a,b}$	-12.8 ± 5.0^{b}	-17.8 ± 5.9^{b}
"How much food do you think you could eat right now?"	2.1 ± 3.4^{a}	$-8.6 \pm 2.5^{a,b}$	-12.5 ± 3.2^{b}	-26.0 ± 3.5^{c}
"How nauseated are you right now?"	0.2 ± 0.5	1.5 ± 0.8	1.2 ± 1.0	3.5 ± 1.9
"How full are you right now?"	-0.4 ± 2.4^{a}	$11.9 \pm 4.6^{a,b}$	23.2 ± 3.8^{b}	39.7 ± 3.8^{c}

[1] Values within a row with different superscript letters are significantly different, $P < 0.05$. $\bar{x} \pm$ SEM. Change determined by subtracting the value before the preload from the value 15 min after the preload.

TABLE 4
Sensory and prospective consumption visual analogue scale (VAS) scores before preload consumption[1]

	300 mL	450 mL	600 mL
		mm	
"How pleasant is the taste of this food right now?"	67.5 ± 2.9	66.1 ± 4.3	67.6 ± 4.6
"How many calories do you think this food has?"	59.6 ± 4.1	59.5 ± 4.1	55.7 ± 4.2
"How sweet does this food taste?"	71.6 ± 3.4	70.4 ± 3.7	70.8 ± 4.8
"How creamy does this food taste?"	66.7 ± 3.6	68.5 ± 4.2	68.4 ± 4.5
"How thick is this food?"	57.6 ± 5.2	67.4 ± 3.7	54.4 ± 4.3
"How much of this food could you eat right now?"	49.8 ± 4.1	54.1 ± 5.2	50.6 ± 4.7

[1] $\bar{x}$ ± SEM. There were no significant differences.

significantly different among conditions (**Table 4**). This indicates that the sensory properties of the milk drinks were well-matched and confirmed the results of the sensory testing performed during formulation of the drinks.

Power analyses

We conducted analyses based on current data to determine whether sufficient power was obtained to detect meaningful differences in energy intake at lunch. We estimated the power to detect differences in lunch intake in a situation in which subjects adjusted their intake in response to a hypothetical preload amount (Figure 2). The power to detect a difference of 522 kJ (the hypothetical difference in energy content between preloads) was 0.74 for comparisons between the 600- and 450-mL conditions and between the 450- and 300-mL conditions. The estimated power to detect a difference of 1044 kJ between the 600- and 300-mL conditions was 0.99.

We also conducted analyses to ensure that the sample size was sufficient to detect meaningful differences in ratings of the preloads. We found that differences of 7 mm between the 300- and 450-mL preloads and between the 450- and 600-mL preloads would result in power estimates ≥ 0.80 for ratings of pleasantness of taste, energy content, creaminess, sweetness, thickness, and prospective consumption. These results indicate that failure to detect differences in ratings of the milk drinks was not due to a lack of statistical power.

Debriefing

Forty percent of the subjects correctly stated that the purpose of the study was to examine intake after consumption of drinks differing in volume. Two subjects failed to notice a difference in the amount that was served. Most subjects (70–90%) reported no differences in the milk drinks with respect to color, fat content, temperature, energy content, smell, sweetness, texture, or taste, confirming the results obtained with VAS ratings.

DISCUSSION

The results show clearly that the weight or volume of a liquid food affects satiety independent of its sensory properties or its energy or macronutrient content. Consistent with the effects on food intake, the volume consumed in the preload affected ratings of hunger, fullness, and the amount subjects wanted to eat. In this study we tested only lean, nondieting young men, a group that was shown in previous studies to be sensitive to the energy content of preloads (4, 5). However, the visual, cognitive, and physiologic cues from the volume consumed were sufficient to modulate the effect of energy content on satiety in these young men.

The three formulations of milk drinks were matched for total energy content and macronutrient composition (percentage of energy). The main difference in the drinks was in water content (Table 1). Because the energy content of the drinks was held constant and the volume was varied by adding water, energy density (kJ/g) also varied. Thus, we could not separate the effects of volume from the effects of energy density. This result was obviously unavoidable because total energy content and energy density cannot be controlled for simultaneously while varying volume. Small amounts of carrageenan (0.02% in the 450-mL and 600-mL drinks) and guar gum (0.13% in the 450-mL drink and 0.18% in the 600-mL drink) were added to maintain thickness in the more dilute drinks. These small amounts of thickener were unlikely to have affected satiety (15).

Differences in sensory properties and palatability were not confounding variables in this study because no significant differences in pleasantness of taste, sensory qualities, and prospective consumption were detected among the three versions of the drink. Thus, we specifically tested the effects of the volume of the drinks because the sensory properties, palatability, and energy and macronutrient contents were controlled for. Furthermore, we showed that the number of subjects tested in this study was adequate to detect meaningful differences between drinks; therefore, the failure to detect differences between ratings was not due to a lack of statistical power.

Several previous studies examined the role of volume or weight of food consumed in the control of food intake (16–18). Holt et al (16) compared preloads of isoenergetic servings of 38 different foods and found that serving weight was the factor most positively correlated with ratings of satiety and subsequent food intake in a test meal. However, in another study, De Graaf and Hulshof (17) investigated the relative effects of weight and energy content of preloads of dairy products on intake 2 h after they were consumed and found that the effect of energy content was greater than that of the weight of the preloads. The results of these studies, although provocative, do not directly indicate an effect of weight or volume of food on satiety because other qualities of the preloads varied. For example, in these previous studies the preloads were not matched for palatability and macronutrient content (16, 17). Also, the test meal was not given for several hours after the preload, although one would expect the effects of volume on satiety to peak some time during the first hour after consumption, when cognitive cues, oropharyngeal stimulation, and gastrointestinal distension are greatest (19).

One way in which the volume consumed could affect satiety is via receptors in the gastrointestinal tract. Several studies in animals that examined the influences of gastric fullness or distension and the modulatory effects of gastric emptying suggest that mechanical and nutrient stimulation of gastric and postgastric compartments can play an important role in the regulation of food intake (20, 21). In humans, this hypothesis is supported by the results of studies in which the level of gastric distension was manipulated, usually through the use of gastric balloons, and subsequent intake was examined. The findings showed that expansion of a gastric balloon to a volume of 400 mL reduced subsequent food intake (22). It is not clear in humans how sensitive the stomach is to volume cues, although a recent study in rats showed that the stomach is sensitive to its contents when it contains only a small proportion of its capacity (23). Future studies should examine further the role of gastrointestinal factors in the effects of volume on satiety by intubating directly into the stomach drinks similar to those consumed in the present study.

It is of interest that in the present study the best compensation for the energy in the drinks was seen after consumption of the drink with the largest volume and lowest energy density, ie, the 600-mL preload. There are many possible explanations for this. One is that the 600-mL drink may have been the one to best conform to the participants' expectations of the energy content. Another is that the more concentrated drinks of lower volume (300 and 450 mL) may have been below a threshold required to stimulate volume receptors. It could be that there is an optimal energy density of foods for the maintenance of energy balance and that consumption of foods with higher energy density will contribute to the development of obesity, whereas those of lower energy density will aid in weight loss.

Kissileff (14) proposed calculating satiating efficiency as a means for comparing the satiating potency of different foods. Numerous attributes of foods that are postulated to affect satiety, can be evaluated by comparing the magnitude of the chosen attribute of a preload with intake of a subsequent test meal. We used this strategy in a previous study to compare the satiating effects of preloads varying in macronutrient content and found that fat in yogurt was slightly less satiating than was carbohydrate in some individuals (5). However, lean, nondieting young men compensated remarkably well for the energy content of preloads regardless of the macronutrient composition: satiating efficiency scores were close to 1.0 for both high-fat and high-carbohydrate preloads (5).

Although satiating efficiency is often used to relate energy content in a preload to energy consumed at lunch (24), it is also possible to relate other attributes of preloads, such as weight or the perceived energy content, to lunch intake (14). We calculated how much energy the subjects should have consumed if the energy density of the drinks had remained constant and the volume actually reflected the energy content of the drinks, ie, the hypothetical energy content. The resulting satiating efficiency (0.54) indicated that subjects were responsive to volume cues but not on a one-to-one basis. That is, the reduction in intake was ≈50% less than what may have been expected if the subjects equated the doubling in volume to a doubling in energy content. These results suggest that for lean, young men, cues related to volume only partially override cues related to energy content in the short term. Further research is warranted to investigate how volume may affect intake in other populations and over longer time periods. For example, we showed that obese men and women and individuals highly concerned with diet and body weight (ie, restrained eaters) are less responsive to the energy content of preloads than are lean, young men (5). We also showed that women are highly responsive to cognitive cues about food (25). Thus, it is conceivable that the satiating efficiency of volume may be greater in these groups because they have been shown to be less responsive to energy cues than the young men tested in this study.

The present study was designed to maximize the effects of volume on satiety rather than to distinguish any separate effects of visual, cognitive, and physiologic cues related to the volume of the drinks. Several studies showed that beliefs about the energy or fat content of a preload can affect satiety (25, 26). Because we emphasized the visual differences in the drinks by serving them in clear glasses, both visual and cognitive cues could have affected the results. We did not ask subjects how much energy they thought they had consumed in the drinks because we did not want to draw their attention to the energy content of the preloads. However, it is likely that they thought that the volume of the drinks was related to total energy content because the sensory properties such as thickness and creaminess were perceived to be similar. Also, when the subjects were asked to rate the energy content of the drinks based on the 15-mL sample tasted at the start of lunch, they indicated no significant differences between the drinks.

In the present study, we showed that the effect of a given level of energy in a preload on satiety can be affected by adding water and thickeners to increase the volume while maintaining the sensory characteristics. The finding that the volume of food ingested can affect satiety has important health implications. Because of the high incidence of obesity in the United States, strategies are needed to help individuals reduce their energy intake. The results from this study showed that the amount eaten after consumption of isoenergetic preloads varied with the volume of the preload. In addition, eating a food of high volume helped to suppress hunger and to increase fullness. The reduction in energy intake at lunch after the high-volume preload was not compensated for by an increased intake at dinner. Clearly, it is of interest to conduct a longer-term study in which a high-volume, low-energy preload precedes every meal over a longer time period to determine whether this would be an effective strategy for weight loss. Increasing the volume consumed by adding water or foods with a high water content, such as fruit or vegetables, to the diet can be a safe and easy approach to controlling hunger and reducing food intake.

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