Increasing the volume of a food by incorporating air affects satiety in men[1–3]

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ABSTRACT
Background: Previous research indicated that increasing the volume of food by adding water can lead to reductions in energy intake. However, the addition of water affects not only the volume but also the energy density (kJ/g) of foods. No studies have examined the effect of volume independent of energy density on intake.
Objective: We examined the effect of food volume independent of energy density on satiety.
Design: In a within-subjects design, 28 lean men consumed breakfast, lunch, and dinner in the laboratory 1 d/wk for 4 wk. On 3 d, participants received a preload 30 min before lunch and on 1 d no preload was served. Preloads consisted of isoenergetic (2088 kJ), yogurt-based milk shakes that varied in volume (300, 450, and 600 mL) as a result of the incorporation of different amounts of air. Preloads contained identical ingredients and weighed the same.
Results: The volume of the milk shake significantly affected energy intake at lunch ($P < 0.04$) such that intake was 12% lower after the 600-mL preload (2966 ± 247 kJ) than after the 300-mL preload (3368 ± 197 kJ). Subjects also reported greater reductions in hunger and greater increases in fullness after consumption of both the 450- and 600-mL preloads than after the 300-mL preload.
Conclusions: Changing the volume of a preload by incorporating air affected energy intake. Thus, the volume of a preload independent of its energy density can influence satiety. *Am J Clin Nutr* 2000;72:361–8.

KEY WORDS Air, energy density, energy intake, food intake, obesity, satiety, food volume, men

INTRODUCTION

Results of several recent studies showed that the energy density of foods (in kJ/g) affects both satiety and food intake. For example, the addition of water to a milk-based preload lowers the energy density of the preload and reduces intake by lean men at the next lunch (1). In another study it was shown that adding water to the ingredients of a chicken-rice casserole to make a soup was associated with reduced intake in lean women at the next lunch (2). The addition of water affected not only the energy density of the preloads but also the volume to be consumed. Thus, it was not possible to separate the independent effects of volume and energy density on satiety.

Several other studies have tested the effects of energy density, independent of changes in volume, on satiety. For example, in 2 studies, formulated preloads [yogurt (3) or soup (4)] that varied in energy density but not in volume were served to participants before lunch. Results indicated that the participants did not compensate consistently at lunch for variations in the energy density of similar portions of the preloads. Overall, lean, unrestrained, young men showed better energy compensation than did other subject groups (ie, lean and obese women and obese men) (4, 5).

Although some studies manipulated energy density without varying volume, no studies have tested the effects on satiety of the volume of food consumed independent of changes in energy density. In the present study, we tested the hypothesis that the volume of food consumed affects satiety. The volume of otherwise identical milk shake preloads was varied by incorporating different amounts of air, which adds no weight and thus has no effect on energy density. We hypothesized that adding air would affect the subject's perception of how much food was consumed, and that larger volumes of the milk shake would be associated with more oropharyngeal stimulation and greater gastric distension than smaller volumes (6).

SUBJECTS AND METHODS

Subjects

We recruited 28 male participants through advertisements in local and university newspapers, posters, and mailings. Potential subjects were initially interviewed by telephone to determine that they regularly ate 3 meals daily, did not smoke, did not have any food allergies or restrictions, were not dieting to gain or lose weight, were not athletes in training, 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-40; possible score: 0–117), which detects symptoms of an eating disorder (7); the Eating Inventory (EI; 8), which measures dietary restraint

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TABLE 1
Ingredients and energy and macronutrient contents of the preloads[1]

	Amount
Ingredients (g)	
Whole milk	80.0
Heavy cream[2]	22.0
Nonfat dry milk[3]	17.8
Whipped topping[4]	26.0
Strawberry yogurt[5]	150.0
Fat	
(g)	16.5
(% of energy)	31.0
Carbohydrate	
(g)	65.2
(% of energy)	55.0
Protein	
(g)	15.6
(% of energy)	13.0
Energy	
(kJ)	2088
(kcal)	499
Energy density	
(kJ/g)	7.1
(kcal/g)	1.7

[1] The preloads had the same energy and macronutrient contents but varied in volume (300, 450, and 600 mL) as a result of the incorporation of different amounts of air (*see* Methods).

[2] Foodhold USA, Inc, Atlanta.

[3] Nestlé USA, Inc, Solon, OH.

[4] Dream Whip; Kraft Foods, Inc, White Plains, NY.

[5] Yoplait USA, Inc, Minneapolis.

(possible score: 0–21), perceived hunger (possible score: 0–14), and disinhibition (possible score: 0–16); the Beck Depression Inventory (9; possible score 0–63) and the Zung Self-Rating Questionnaire (10; possible score: 20–80), both of which detect depression; a detailed demographic inquiry; and a family weight-history questionnaire. Weight and height measurements were taken at that time. Individuals were included in the study only if their body mass index (BMI; in kg/m^2) was between 20 and 25. They were excluded if they scored ≥40 on the Zung, ≥10 on the Beck, ≥30 on the EAT-40, or >8 on the cognitive restraint subscale of the EI. Finally, individuals were asked whether they disliked any of the food items to be offered in the experimental meals. Potential subjects were excluded if they disliked the preload (strawberry milk shake) or ≥2 of the main food items to be served in any of the test meals.

All aspects of the study were approved by the Institutional Review Board of The Pennsylvania State University and subjects were compensated for their participation. The subjects were informed that the purpose of the study was to examine the effects of milk shakes on taste but were not told that we were assessing how food volume affects subsequent food and energy intakes.

Design

The experiment included 4 conditions in a counterbalanced, within-subjects design. On 4 separate days, subjects came to the laboratory to eat breakfast, lunch, and dinner. On 3 of the days, subjects received a preload before lunch that varied in volume (300, 450, and 600 mL) and on 1 d no preload was served (control condition). We compared lunch intakes after each condition to investigate whether systematically increasing the volume of a food, while keeping the energy density constant, affected satiety. Test days were separated by ≥1 wk.

Procedures

Subjects were asked to keep their evening meal and their activity level as similar as possible on the day before each test session and to refrain from eating or drinking (except water) after 2200. Subjects were also asked to refrain from drinking alcohol on the day before and throughout each test day. On the evening before each test session, subjects completed food and activity diaries that experimenters reviewed to ensure compliance with the study protocol.

On each test day subjects consumed breakfast 4 h before the start of the lunch meal. At that time, food and activity diaries were collected, subjects were weighed without shoes, and subjects completed a brief questionnaire to assess whether they felt well, had consumed alcohol in the previous 24 h, or had taken any medications known to affect appetite or food intake. The experimenters reviewed the diaries and questionnaires and subjects were rescheduled if their evening meals or activity levels deviated markedly from those of the first test day. Subjects were also rescheduled if they had consumed alcohol, were ill, or had taken any medications known to affect appetite or food intake. Subjects were instructed not to consume any foods or energy-containing beverages in the interval between breakfast and 1 h before their scheduled lunch. They were allowed to consume water ad libitum during that time. During the hour before their scheduled lunch, subjects were instructed to refrain from eating or drinking anything, including water.

At the start of the lunch session, subjects completed a brief questionnaire to determine whether they felt well, had taken any medications, or had consumed any foods or beverages since breakfast. Subjects then tasted and rated a sample of the preload or were notified that they would not be given a milk shake on that day (control condition). On days when a preload was served, subjects were given preset timers to pace their consumption of the preload over 15 min. Lunch was served 15 min after completion of the preload or 30 min after arrival for the control condition. Subjects were permitted to read magazines before lunch except during consumption of the preload. In the control condition, subjects were permitted to read magazines during the 30-min interval before lunch. Magazines were screened to exclude any articles pertaining to food, weight loss, or body image. Finally, subjects returned to the laboratory for dinner between 4 and 5 h after the start of lunch. Subjects were asked not to consume any foods or energy-containing beverages outside the laboratory in the interval between lunch and dinner. They were permitted to consume water ad libitum during that interval. Before dinner, questionnaires were administered to ensure compliance. During all meals, subjects were tested alone in private cubicles.

Preloads

Three strawberry-flavored milk shakes were formulated at our laboratory for use as preloads. All milk shakes contained identical ingredients (**Table 1**). In all conditions, strawberry yogurt was blended in an industrial, high-powered blender (Vita-Mix Corp, Cleveland) for 1.5 min. To vary the volume of the preloads, a commercially available whipped topping mix (Dream Whip; Kraft Foods, Inc, White Plains, NY) was included in the formulation. This product enables air to be incorporated into foods. Differences in volume of the milk shakes were achieved by varying the length of time the whipped topping mix was whipped with the other ingredients (whole milk, heavy cream, and nonfat dry milk). For the 300-mL preload, the whipped topping mix was gently incorporated into the whole milk, heavy cream, and nonfat dry milk with a wire whisk until blended. For the 450- and 600-mL preloads, the above ingredients were whipped in a commercial mixer (KitchenAid, Inc, Greenville, OH) for 2.5 and 5 min, respectively. Finally, the blended strawberry yogurt was incorporated into the whipped topping mixture. Hence, the preloads had the same energy and macronutrient contents but varied in volume (300, 450, and 600 mL) as a result of the incorporation of different amounts of air. The preloads were chilled (3°C, or 38°F) and presented to the subjects in a large, clear glass with a straw.

Test meals

Subjects selected their breakfast beverage or beverages (coffee, tea, orange juice, or milk) before the beginning of the study. At the start of each test day, subjects received the same breakfast of toasted bagels, cream cheese, strawberry jam and grape jelly, and their preselected beverages. Breakfast was consumed ad libitum.

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 differed in energy and macronutrient contents to allow subjects to vary intakes of both energy and macronutrients. Chilled water (4°C, or 39°F) that could be consumed ad libitum was the only beverage available during lunch and dinner. 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, breaded chicken fillets, broccoli, rolls, butter, pound cake, chocolate bars, and mixed fruit cups. At both meals, various condiments were served. To avoid the possibility of subjects eating to "clean their plates," we presented more food than they were likely to consume.

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 tenth of a gram. Energy and macronutrient intakes were calculated by using information from the manufacturers and from Bowes and Church's *Food Values of Portions Commonly Used* (11).

Visual analogue scales

Subjects rated their hunger, thirst, nausea, fullness, and prospective consumption (how much food they thought they could eat) on visual analogue scales. For example, hunger was rated on a 100-mm line preceded by the question, "How hungry are you right now?" and anchored by "not at all hungry" on the left and "extremely hungry" on the right. Other anchors consisted of the phrases "not at all" and "extremely" combined with the adjectives "thirsty," "nauseated," and "full." Ratings were completed before and after breakfast, before and after the preload (or at equivalent times in the control condition), before and after lunch, hourly for 3 h after lunch, and before and after dinner.

Before each preload was served, subjects rated 15-mL samples of the preload on 100-mm visual analogue scales. The following attributes were rated: pleasantness of taste, perceived "caloric" content, thickness, sweetness, creaminess, and prospective consumption. After they completed the ratings, subjects were served the preload (300, 450, or 600 mL). On completion of the preload, subjects again received a 15-mL sample and were asked to rate the above attributes.

Debriefing

Subjects completed a debriefing questionnaire at the end of the study. Specifically, they were asked the purpose of the study, whether there were any factors that affected their responses, and whether they noticed any differences between the test days. The questionnaire also asked whether the subjects had eaten any foods between meals that were unreported and if the amount of milk shake served was appropriate. This questionnaire was used principally to determine whether any subject correctly discerned the study's purpose.

Statistical analyses

Data were analyzed by using SAS-PC for WINDOWS (version 6.11; SAS Institute Inc, Cary, NC). Analysis of variance was performed by using the general linear models (GLM) procedure. The residuals for energy intake at lunch were examined for normality and equal variance by using the univariate procedure and were also examined for the presence of outliers. Observations with $P < 0.001$ for the studentized residual and $|\text{DFFITS}| > 2$ were considered to be significant outliers. The influence of each observation on the regression function was examined by using DFFITS (an approximation of the number of SDs that a fitted value changes when a particular observation is removed from the data set). Percentage of energy from macronutrients was analyzed by using an equivalent multivariate analysis of variance procedure. Tukey's honestly significant difference test was used for post hoc comparisons of significant effects. To compare each condition with the control condition, all conditions were included in the analyses and the GLM procedure was used with a Dunnett post hoc test to examine differences between means. Results were considered significant at the $P < 0.05$ level. Post hoc power analyses were conducted by using the ANALYST program provided in SAS-PC for WINDOWS (version 7.0; SAS Institute Inc). Values in the text are reported as means ± SEMs unless reported otherwise.

Food intake

Energy (kJ) and food (g) intakes (with and without water) and percentages of energy from macronutrients were analyzed for breakfast, lunch, and lunch plus dinner, with and without the preload. Analyses excluding the control condition were also performed.

Satiating efficiency

The satiating efficiency of the preloads, based on Kissileff et al's model (12), was also examined. A satiating efficiency of 1 represents a reduction in lunch intake of 1 unit per unit preload. A satiating efficiency >1 represents a reduction in lunch intake of >1 unit per unit preload and a satiating efficiency <1 represents a reduction in lunch intake of <1 unit per unit preload. We calculated the negative of the slope generated by plotting the hypothetical energy content of the preloads (kJ) against the average amount consumed at lunch (kJ). 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; thus, volume was an indicator of the energy content of the preload (ie, energy content

TABLE 2
Intakes of food and water[1]

	Condition			
	Control	300 mL	450 mL	600 mL
Breakfast				
Energy (kJ)	2874 ± 126[2]	2711 ± 142	2787 ± 146	2715 ± 155
Amount (g)	736 ± 50	704 ± 56	754 ± 55	733 ± 51
Preload				
Energy (kJ)	0	2088	2088	2088
Amount (g)	0	295.8	295.8	295.8
Lunch				
Energy (kJ)	4201 ± 192	3368 ± 197^{a}[3]	3146 ± 180^{a,b}[3]	2966 ± 247^{b}[3]
Amount (g)	981 ± 55	836 ± 57[3]	822 ± 56[3]	788 ± 58[3]
Food (g)	500 ± 23	412 ± 26^{a}[3]	386 ± 24^{a,b}[3]	351 ± 30^{b}[3]
Water (g)	481 ± 45	425 ± 42	435 ± 41	437 ± 40
Dinner				
Energy (kJ)	7556 ± 351	7109 ± 364	7657 ± 433	7401 ± 393
Amount (g)	1372 ± 62	1344 ± 48	1386 ± 68	1414 ± 65
Food (g)	800 ± 34	773 ± 31	813 ± 41	817 ± 42
Water (g)	572 ± 46	571 ± 40	573 ± 43	598 ± 47
Total (preload + lunch + dinner)				
Energy (kJ)	11 753 ± 439	12 565 ± 477	12 891 ± 485[3]	12 456 ± 490
Amount (g)	2353 ± 104	2476 ± 90	2503 ± 110[3]	2498 ± 104[3]
Food (g)	1300 ± 44	1481 ± 47[3]	1495 ± 48[3]	1464 ± 52[3]
Water (g)	1053 ± 82	995 ± 71	1008 ± 79	1034 ± 78
Fat (% of energy)	25 ± 0.8	25 ± 0.8	26 ± 0.8	26 ± 0.8
Carbohydrate (% of energy)	61 ± 0.9	60 ± 0.7	60 ± 0.8	60 ± 0.8
Protein (% of energy)	14 ± 0.2	15 ± 0.3	15 ± 0.2	14 ± 0.3

[1] Data were analyzed with and without data from the control condition. Values within a row with different superscript letters were significantly different when models did not include the control condition ($P < 0.05$).

[2] $\bar{x}$ ± SEM; $n = 28$.

[3] Significantly different from the control condition, $P < 0.05$.

increased as volume increased). By using the drink for which the best energy compensation was observed (ie, the 600-mL preload), we calculated the hypothetical energy content of the 300-mL preload to be 50% (1044 kJ) of that of the 600-mL preload (2088 kJ) and the hypothetical energy content of the 450-mL preload to be 75% (1566 kJ) of that of the 600-mL preload.

Visual analogue scale ratings

Subjective ratings of hunger, fullness, thirst, nausea, and prospective consumption were analyzed. In addition, changes in ratings due to preload consumption were calculated for each participant by subtracting the ratings taken before preload consumption from ratings taken immediately after preload consumption (15 min later) as well as just before lunch. A negative value indicated a decline whereas a positive value indicated an increase in these subjective sensations. Sensory ratings of the preloads, completed both before and after consumption, were also analyzed.

RESULTS

Subjects

All subjects completed the study and none were excluded for having outlying values. Thus, the final sample consisted of 28 lean men aged 20–33 y ($\bar{x}$: 23 ± 0.6 y) who weighed 75.4 ± 1.4 kg, were 1.8 ± 0.01 m tall, and had a BMI of 23.5 ± 0.3. According to the EI, the men had low ratings for restraint (3.4 ± 0.4), perceived hunger (5.0 ± 0.6), and disinhibition (3.5 ± 0.5). In addition, the EAT-40 indicated no signs of an eating disorder (mean score: 7.0 ± 0.6). Scores were low on the assessments of depression by the Zung Self-Rating Questionnaire (mean score: 27.5 ± 0.9) and the Beck Depression Inventory (mean score: 2.2 ± 0.5).

Energy intake

Mean intakes at each meal are presented in **Table 2**. Energy intakes at breakfast were not significantly different across all conditions. Subjects consumed significantly less energy at lunch after consumption of the preloads than in the control condition ($P < 0.0001$). When energy from the preloads was added to lunch intake, there was still a main effect of condition ($P < 0.0001$). Subjects overate compared with the control condition (4199 ± 193 kJ) in the 300-mL (5456 ± 196 kJ), 450-mL (5233 ± 180 kJ), and 600-mL conditions (5054 ± 246 kJ) (**Figure 1**). When the control condition was excluded from the analysis, the volume of the preload significantly affected energy intake at lunch ($P < 0.04$) such that intake was reduced 12% more (402 kJ) after consumption of the 600-mL preload than after the 300-mL preload.

Intakes at dinner were not significantly different across conditions. When lunch and dinner energy intakes were combined, subjects consumed significantly less energy after consumption of the preloads than in the control condition ($P < 0.001$). When the control condition was excluded from the analysis, we found that subjects consumed similar amounts of energy for lunch and dinner combined after each of the preloads. Because no significant differences in energy intake were found for dinner, these results

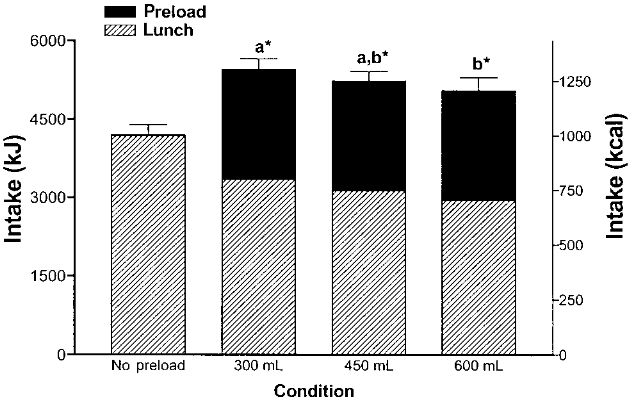

FIGURE 1. Mean (±SEM) energy intake at lunch in each condition (n = 28). Within the 3 preload conditions, means with different letters were significantly different ($P < 0.05$). *Significantly different from the control condition, $P < 0.05$.

indicate that subjects did not adjust intake at dinner to compensate for differences in intake across conditions at lunch.

Satiating efficiency

As shown in **Figure 2**, a satiating efficiency of 1.0 would result if subjects assumed that changes in energy content of the preload occurred in direct proportion to changes in volume of the preload and adjusted their energy intake at lunch accordingly. A satiating efficiency of 0.0 would result if subjects relied solely on energy cues (ie, all preloads would reduce energy intake at lunch by the same amount). A satiating efficiency of 0.39 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 0.39 kJ for every kJ of hypothetical preload.

Weight of food consumed and macronutrient intake

Amounts of food and water consumed at each meal are presented in Table 2. Relative to the control condition, subjects consumed less food (in g) at lunch in the 3 preload conditions ($P < 0.0001$). When the weight of the preload (295.8 g), however, was added to lunch intake (in g), a greater amount of food was consumed in the 3 preload conditions than in the control condition ($P < 0.0001$). With exclusion of the control condition, subjects consumed less food at lunch after the 600-mL preload (351 g) than after the 300-mL preload (412 g) ($P < 0.008$). The percentages from fat, carbohydrate, and protein consumed at lunch were not significantly different across all preload conditions. Across all conditions, subjects consumed similar amounts of food at breakfast and dinner.

Visual analogue scale ratings

Subjective sensations

Across all conditions, no significant differences were found in subjective ratings of hunger, fullness, nausea, or prospective consumption before the preload was served. Subjects reported greater reductions in hunger and prospective consumption, as well as a greater increase in fullness, immediately after consumption of the 450- and 600-mL preloads than after the 300-mL preload. By the time lunch was served, ratings of hunger and prospective consumption remained significantly lower in the 600-mL condition than in the 300-mL condition. At that time, ratings of fullness were significantly greater in the 600-mL condition than in the 300- and 450-mL conditions. Also, immediately before lunch, ratings of hunger and prospective consumption were significantly greater and ratings of fullness were significantly lower in the control condition than in each of the preload conditions.

Differential changes in subjective ratings were also analyzed. After consumption of the preload, changes in hunger, prospective consumption, and fullness were significantly greater in the 450- and 600-mL conditions than in the 300-mL condition (**Table 3**). Immediately before lunch, changes in hunger and prospective consumption remained significantly different between the 600- and 300-mL conditions. At this time, there was a greater change in fullness in the 600-mL condition than in the 300- and 450-mL conditions. Subjects reported a significantly greater change in nausea immediately after consumption of the 600-mL preload than after consumption of the 300-mL preload, but by the time lunch was served there were no significant differences.

Preload ratings

Ratings of the milk shakes completed before the preloads were served indicated that overall the preloads were well liked (mean taste rating: 73 mm). These ratings also indicated that subjects perceived the milk shakes to be similar in thickness and creaminess but significantly different in taste, sweetness, and perceived caloric (energy) content (**Table 4**). After consumption of the preloads, ratings of perceived caloric (energy) content and sweetness were not significantly different, but ratings of taste, thickness, and creaminess were. None of the ratings, completed

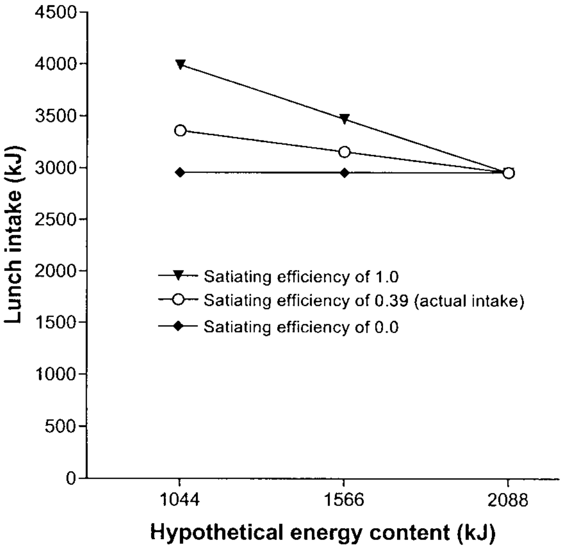

FIGURE 2. Satiating efficiency of volume consumed. For each regression line, intake at lunch (kJ) was regressed against the hypothetical energy content of the preloads, which was calculated on the basis of the energy content estimates that would result if subjects equated changes in volume with changes in energy content. With use of the 600-mL drink as a reference, the hypothetical energy content of the 300-mL drink was calculated to be 50% (1044 kJ) and that of 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.

TABLE 3

Change in visual analogue scale scores after preload consumption and before lunch[1]

	Condition		
	300 mL	450 mL	600 mL
		mm	
After preload[2]			
“How hungry are you right now?”	-10.3 ± 3.3^{a}	-24.3 ± 4.0^{b}	-28.5 ± 4.4^{b}
“How thirsty are you right now?”	-9.0 ± 2.5	-4.0 ± 4.1	-12.5 ± 5.6
“How much food do you think you could eat right now?”	-6.4 ± 2.5^{a}	-20.0 ± 3.6^{b}	-24.6 ± 4.0^{b}
“How nauseated are you right now?”	2.2 ± 1.7^{a}	$7.9 \pm 3.1^{a,b}$	12.7 ± 4.8^{b}
“How full are you right now?”	12.7 ± 4.0^{a}	29.4 ± 4.2^{b}	39.0 ± 4.2^{b}
Before lunch[3]			
“How hungry are you right now?”	-8.8 ± 3.5^{a}	$-15.5 \pm 3.5^{a,b}$	-21.3 ± 3.6^{b}
“How thirsty are you right now?”	-8.2 ± 3.3	-4.0 ± 4.1	-12.0 ± 4.9
“How much food do you think you could eat right now?”	-9.5 ± 3.0^{a}	$-13.9 \pm 3.3^{a,b}$	-21.3 ± 3.5^{b}
“How nauseated are you right now?”	-0.3 ± 0.8	2.1 ± 2.0	4.8 ± 3.0
“How full are you right now?”	13.9 ± 4.0^{a}	21.9 ± 4.1^{a}	31.9 ± 3.6^{b}

[1] $\bar{x}$ ± SEM; $n = 28$. Values within a row with different superscript letters are significantly different, $P < 0.05$.

[2] Change determined by subtracting the value before the preload from the value immediately after the preload.

[3] Change determined by subtracting the value before the preload from the value before lunch.

either before or after the preload, were found to be significant covariates in the analysis of lunch intake. Thus, any differences in ratings did not affect interpretation of results.

Power analyses

We conducted analyses on current data to determine whether we had sufficient power to detect meaningful changes in lunch intake between the 3 experimental conditions. We used the hypothetical changes in intake that would result if subjects equated the change in volume with a change in energy (Figure 2). With the current sample size, the power to detect a difference in intake of 522 kJ was 0.83 for comparisons between the 600- and 450-mL conditions as well as for comparisons between the 450- and 300-mL conditions. For comparisons of the 300- and 600-mL conditions, the power was >0.99 to detect the hypothetical difference in lunch intake of 1055 kJ.

Debriefing

Sixty-eight percent of the subjects reported noticing a difference in the amount of milk shake that was served. Fifty percent of the subjects stated that the purpose of the study was to examine whether consumption of a milk shake affected appetite.

DISCUSSION

Our results show that the volume of food consumed, independent of energy density, affects satiety. Consistent with the effects on food intake, the volume of the preload consumed affected ratings of hunger, fullness, and the amount of food that subjects desired to eat. In this study we tested only lean, unrestrained young men, a group shown in previous studies to be sensitive to the energy content of preloads (3, 5). The current data show that the effect of the energy content of a preload can be modulated by the volume of food consumed.

The participants consumed ≈400 kJ less at lunch after the 600-mL milk shake than after the 300-mL milk shake, a reduction of 12%. They did not make up this difference in lunch intake by eating more at dinner. After all 3 volumes of the milk shakes, subjects showed incomplete compensation for the energy in the shakes, as indicated by the significantly greater energy intakes in the preload conditions than in the control condition. This overconsumption was likely due in part to the relatively high energy content of the preloads. A recent analysis of 7 preloading studies showed that in lean men the best compensation for the energy in preloads occurs when the preloads contain ≈32% of the energy content of a baseline lunch intake (13). Thus, the fact that the energy content of the preloads in the current study was 50% of energy intake in the control condition may explain why subjects did not compensate for the energy content of the preloads.

The present study was designed to be similar to a previous study in which milk-based drinks varying in volume, as a result of the addition of water, were served before a self-selected lunch (1). In that study, in which both the volume and the energy density of the preloads varied, energy intake at lunch was suppressed by 16.7% more after the 600-mL drink than after the 300-mL drink. Because the current study was conducted independently of that investigation, the 2 studies cannot be compared statistically. It does appear, however, that adding water both to increase the volume and to reduce the energy density of a drink may have a greater effect on satiety than does just increasing the volume by adding air. Specifically, the results of the 2 studies indicated that lean men reduced energy intake at lunch by ≈5% more after the incorporation of water into the 600-mL milk drink (1) than after the incorporation of air into the 600-mL milk shake.

In both studies, calculations of the satiating efficiency of the preloads showed that subjects were responsive to volume cues and that these cues partially overrode cues related to energy content. Again, it appears that increasing volume via the addition of water may be more effective for reducing energy intake than is increasing volume via the incorporation of air. Specifically, the satiating efficiency of the milk drinks in the first study (1), in which water content varied, was 0.54 kJ for every 1 kJ of the hypothetical preload compared with 0.39 kJ for the milk shakes in the present study. Further studies are required to compare these effects directly and to determine the mechanisms through which satiety is influenced by the volume and energy density of foods.

The volume of food consumed may affect satiety in several ways. First, added air or water can affect the perception of how

TABLE 4

Sensory and prospective consumption visual analogue scale scores[1]

	Condition		
	300 mL	450 mL	600 mL
		mm	
Palatability scores before preload			
“How pleasant is the taste of this food?”	79 ± 2.8^{a}	72 ± 3.7^{a,b}	69 ± 4.5^{b}
“How many calories do you think this food has?”	58 ± 3.9^{a}	56 ± 4.2^{a}	45 ± 4.6^{b}
“How thick is this food?”	54 ± 4.6	59 ± 4.5	63 ± 4.9
“How much of this food do you think you could consume?”	62 ± 3.4	54 ± 4.1	60 ± 4.0
“How sweet does this food taste?”	75 ± 3.1^{a}	70 ± 2.5^{a,b}	62 ± 4.0^{b}
“How creamy is this food?”	71 ± 4.1	78 ± 3.6	77 ± 4.1
Palatability scores after preload			
“How pleasant is the taste of this food right now?”	61 ± 3.6^{a}	49 ± 5.1^{a,b}	40 ± 5.2^{b}
“How many calories do you think this food has?”	55 ± 3.5	54 ± 4.6	52 ± 4.9
“How thick is this food?”	55 ± 4.8^{a}	69 ± 3.7^{b}	78 ± 3.4^{b}
“How much of this food do you think you could consume?”	42 ± 4.1^{a}	27 ± 3.9^{b}	18 ± 4.0^{c}
“How sweet does this food taste?”	69 ± 3.6	66 ± 4.0	60 ± 4.5
“How creamy is this food?”	65 ± 4.2^{a}	77 ± 3.3^{a,b}	71 ± 4.8^{b}

[1] $\bar{x}$ ± SEM; $n = 28$. Values within a row with different superscript letters are significantly different, $P < 0.05$.

much food is being consumed. In fact, we served the drinks in clear glasses to ensure that subjects could see that the drinks differed in volume. It is likely that seeing the bigger volume led to the perception that more energy was consumed. This is supported by the ratings of the energy content of a small portion (15 mL) of the milk shakes completed after consumption of the preload. Specifically, these ratings indicated that subjects perceived the energy content per portion to be similar for the 3 drinks.

Typically, more time is required to consume foods that are larger in volume than those that are smaller in volume. In the current study, however, the time required for consumption of the milk shakes was kept constant across conditions (15 min) to ensure that time needed for consumption did not influence the results. Nevertheless, the amount of oral stimulation varied with the volume of the drinks. This affected the pleasantness of the taste of the preloads so that after consumption, the high-volume milk shake tasted significantly less pleasant than the low-volume milk shake. Subjects also reported a significantly greater decline in the amount of the 600-mL drink that they wanted to consume after consumption of the preloads. Thus, the results indicated that simply adding air to a food can influence subjective responses related to hunger and appetite.

Because air was incorporated into the milk shakes, it is likely that the greater the volume of the preload, the greater the gastric distension experienced by the subjects (14). This probably accounts for the significantly larger ratings of fullness after the 600-mL preload than after the 300-mL preload. In both animals and humans, gastric distension is known to affect food intake (6, 14, 15). It is possible that the incorporation of air into the milk shakes affected gastric emptying, although studies are needed to confirm this. Gastrointestinal effects of the milk shakes could account for the increase in nausea immediately after consumption (16). It is unlikely that the effect of air in the milk shake on lunch intake was due to nausea, however, because ratings of nausea immediately before lunch in all conditions were low and did not differ significantly.

These results show that increasing the volume of a food consumed as a preload can affect satiety and food intake independent of changes in energy density. This finding indicates that energy density alone cannot be used as an index of satiety and that the volume or portion of a food can also have an effect. In practice, foods with similar energy densities may have serving sizes that vary widely in volume as a result of differences in air content. Thus, it is possible that foods such as popcorn and puffed cereals that contain relatively large amounts of air will be more satiating than similar foods without added air.

The results from this study suggest that consuming high-volume foods can lead to reductions in short-term energy intake. Volume, however, is only one of many factors that may affect satiety. Further understanding of these multiple influences on food intake may lead to strategies for controlling hunger while reducing energy intake. Future studies should determine whether the effects of volume on intake and satiety are sustained when high-volume foods are regularly incorporated into the diet.

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