Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women[1–3]

Elizabeth A Bell and Barbara J Rolls

ABSTRACT

Background: The results of previous studies indicated that energy density, independent of fat content, influences energy intake. In most studies, however, both fat content and energy density were lower than in typical American diets.

Objective: We examined the influence of energy density on intake when fat content was above, below, or similar to the amount of fat typically consumed and when energy density was closer to that of American diets.

Design: Lean (n = 19) and obese (n = 17) women consumed all meals daily in our laboratory during 6 experimental sessions. The main entrées, consumed ad libitum, were formulated to vary in fat content (25%, 35%, and 45% of energy) and energy density (5.23 kJ/g, or low energy density, and 7.32 kJ/g, or high energy density) but to have similar palatability.

Results: Energy density influenced energy intake across all fat contents in both lean and obese women ($P < 0.0001$). Women consumed less energy in the low (7531 kJ) than in the high (9414 kJ) energy density condition. Despite this 20% lower energy intake, there were only small differences in hunger (7%) and fullness (5%). Women consumed a similar volume, but not weight, of food daily across conditions. Differences in intake by weight, but not volume, occurred because for some versions of manipulated foods, weight and volume were not directly proportional.

Conclusions: Energy density affected energy intake across different fat contents and at levels of energy density comparable with those in typical diets. Furthermore, our findings suggest that cues related to the amount of food consumed have a greater influence on short-term intake than does the amount of energy consumed. *Am J Clin Nutr* 2001;73:1010-8.

KEY WORDS Energy density, fat content, energy intake, food intake, macronutrient composition, obesity, satiation, volume, weight management, women

INTRODUCTION

Over the past several years, interest has increased in the influence of food composition on energy intake and its possible role in both weight gain and obesity. Results from experimental studies showed that when both the fat content and the energy density (kJ/g) of diets are increased, energy intake also increases (1–6). Other investigations separated the effects of fat content and energy density by varying them independently. In studies in which the fat content but not the energy density of diets varied, fat content did not affect energy intake (7–9). Conversely, when energy density was manipulated independent of fat content, energy density directly influenced energy intake (10–12).

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In most studies in which energy density but not fat content was altered, however, both the fat content and energy density were lower than in typical American diets. For example, in one study diets contained ≤5.6 kJ/g with 16% of energy from fat (10), whereas in another study diets contained ≤6.3 kJ/g with 22% of energy from fat (11). Similarly, when the fat content but not the energy density was manipulated, energy density remained relatively low. Diets varied in fat content from 20% to 60% of energy, but contained <5.4 kJ/g (7–9). In comparison, the typical American diet derives ≈34% of energy from fat (13). Data on the energy density of diets is limited, although one study reported that the average energy density of foods in the diet is ≈7.6 kJ/g (14). Thus, the independent influence of energy density and fat content in diets similar to those typically consumed is not understood.

Given the increasing prevalence of obesity in the United States (15), it is also important to determine whether obese individuals respond differently than do lean individuals to changes in dietary energy density and fat content. Only one study examined the responses of lean and obese individuals to such dietary manipulations (16). The results of that study indicated that energy intakes of both lean and obese individuals are affected by the energy density, but not the fat content, of the diet. Some evidence, however, suggests that obese individuals may differ from lean individuals in their ability to adjust their intake to manipulations of energy content and in their preference for high-fat foods (17, 18). Therefore, additional research is needed to determine whether fat content and energy density have different effects on intake in lean and obese individuals.

In the present study, we manipulated the energy density of foods across 3 percentages of dietary fat in the diets of both lean and obese women. Values for energy density were similar to the energy density of food in American diets and percentages of fat were selected to be above, below, or similar to the fat content of typical diets.

[1] From the Nutrition Department, The Pennsylvania State University, University Park.

[2] Supported by NIH grants DK39177 and RR10732.

[3] Address reprint requests to BJ Rolls, Nutrition Department, 226 Henderson Building, The Pennsylvania State University, University Park, PA 16802-6501. E-mail: bjr4@psu.edu.

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TABLE 1
Menus for the breakfast, lunch, dinner, and snack for each session

Breakfast	Lunch	Dinner	Snack
Cheese strata (≈800 g)[1]	Taco salad (≈1200 g)[1]	Pasta bake (≈1200 g)[1]	Apple bake (≈700 g)[1]
Orange juice (185 g)[2]	Peaches, canned (115 g)[2]	Lettuce salad (43 g) with nonfat Italian dressing (15 g)[2]	Water (1000 mL)[3]
Water (1000 mL)[3]	Chocolate chip cookies, reduced-fat, bite-size (9 g)[2]	Dinner roll (34 g)[2]	Tea or coffee (600 mL) with non-energy-containing sweetener[3]
Tea or coffee (600 mL) with non-energy-containing sweetener[3]	Water (1000 mL)[3]	Chocolate mints (10 g)[2]	
		Water (1000 mL)[3]	

[1] Six versions of each main entrée, consumed ad libitum, were served: *1*) low fat, low energy density; *2*) medium fat, low energy density; *3*) high fat, low energy density; *4*) low fat, high energy density; *5*) medium fat, high energy density; and *6*) high fat, high energy density.

[2] Compulsory items were required to be consumed in full and were identical in type and amount across conditions.

[3] Beverages, except orange juice, were consumed ad libitum.

Foods were also formulated to be of similar palatability across conditions. This was important not only because obese individuals may have greater preferences for high-fat foods than do lean individuals but also because the addition of fat may improve the overall palatability of food (19). Thus, in the present experiment, we tested whether energy density, fat content, and body mass index (BMI; in kg/m^2) interacted to influence intake. We also determined the independent influences of each of these factors on intake.

SUBJECTS AND METHODS

Subjects

We recruited women through advertisements in local and university newspapers. When the women responded to the advertisement, they were interviewed by telephone to determine whether they met the general criteria for inclusion in the study: 20–45 y of age, nonsmoking, in good health, not dieting to gain or lose weight, not in training for athletic competition, not pregnant or lactating, not using medication known to affect food intake or appetite, and not having any food allergies or restrictions.

Potential subjects were measured for weight and height and completed several questionnaires in our laboratory, including the Eating Attitudes Test (EAT; possible score: 0–140), which detects aberrant attitudes toward food and eating (20); the Eating Inventory (EI; 21), which measures dietary restraint (possible score: 0–21), perceived hunger (possible score: 0–14), and disinhibition (possible score: 0–16); the Zung Self-Rating Questionnaire (possible score: 20–80), which detects depression (22); and the Questionnaire on Eating and Weight Patterns Revised (QEWP-R; 23), which detects evidence of binge-eating disorders. Women were excluded from participation if they scored ≥ 30 on the EAT, if they scored ≥40 on the Zung Self-Rating Questionnaire, or if their answers on the QEWP-R indicated evidence of an eating disorder. Scores on the EI were not used as inclusion or exclusion criteria. Individuals were classified as lean if their BMI was between 20 and 24.9 or as obese if their BMI was ≥30. Potential subjects were excluded if their BMI was ≤19, >45, or between 25 and 29.9 or if they had lost or gained >4.5 kg in the previous 6 mo. They were also excluded if they reported disliking any of the foods offered during the experiment. Individuals were selected so that the groups of lean and obese women were of similar age and had similar scores for dietary restraint and disinhibition.

Forty-six women (21 lean, 25 obese) were selected for participation in the study. Seven subjects (2 lean, 5 obese) failed to complete the study. Two women (1 lean, 1 obese) were dropped because of scheduling conflicts, 1 obese subject withdrew because of an illness in her family, and 1 lean subject was dropped because of a personal illness. One obese woman was dropped because of low ratings of pleasantness of taste for the manipulated entrées and 2 obese women had inadequate intakes of the manipulated entrées (<350 g) during either the practice session or the first experimental session (see *Test sessions*). In addition, 3 obese subjects were excluded after completion of the study when they were found to be outliers with respect to the weight of food consumed (|studentized residuals| > 3.4; $P < 0.001$). Specifically, the weight of food consumed deviated from expected values for each of these individuals by >430 g in at least one condition. Exclusion of these 3 subjects did not change the results. Thus, 36 women (19 lean, 17 obese) were included in the analyses.

All aspects of the study were approved by the Institutional Review Board of The Pennsylvania State University. To prevent experimental bias, the study consent form indicated that we were measuring the effect of mood on ratings of taste. Subjects were paid for their participation in the study.

Study design

A within-subjects design was used. Subjects participated in 1 practice session and 6 experimental sessions. The order of presentation of the conditions was balanced on the basis of a cyclical Latin-square design across subjects throughout the 6 experimental sessions.

During the sessions, subjects consumed breakfast, lunch, dinner, and an evening snack in our laboratory (**Table 1**). Each meal included one manipulated main entrée that was consumed ad libitum. The main entrées were formulated to vary by percentage of fat [low (LF), medium (MF), and high (HF)] and energy density [low (LED) and high (HED)]. Breakfast, lunch, and dinner also included small portions of other foods. These items were required to be consumed in full (compulsory foods). Thus, the study was designed so that most of the food and energy consumed was from manipulated foods.

Procedures

Physical examinations

Before participating in the study, subjects underwent routine physical examinations, which included a basic blood profile and urinalysis, at Penn State's General Clinical Research Center. Results from the examinations were used to ensure that the women were healthy and physically able to participate in the study.

Physical characteristics

Subjects were weighed in light clothing (ie, T-shirts and shorts) without shoes at the beginning of each scheduled session. Each subject's percentage body fat was measured by using the BOD POD Body Composition System (Life Measurement Instruments, Concord, CA).

Test sessions

Test sessions were separated by ≥5 d. Before the 6 experimental sessions, subjects participated in a practice session to familiarize them with the laboratory, study procedures, and manipulated foods. During the practice session, subjects were allowed to leave the laboratory between meals. Lunch was scheduled >4 h after the start of breakfast, and dinner was scheduled >4 h after the start of lunch. The evening snack was served immediately after the completion of dinner. For all subjects, practice meals consisted of the MF-LED main entrées and the compulsory side dishes.

Data from the practice session and from the first experimental session (described below) were used to determine whether the subjects liked and were able to eat adequate portions of the manipulated entrées. Subjects were excluded from further participation if they rated the pleasantness of taste of ≥3 entrées <35 mm on visual analogue scales (VAS) during either the practice session or the first test session (see *Ratings*). We also excluded subjects who consumed an inadequate amount of food (<500 g in total of the 4 manipulated main entrées) during the practice or first test session.

For the 6 experimental sessions, subjects were housed in our laboratory for 12 consecutive hours (0800–2000). During this time they participated in quiet activities such as reading, watching movies, listening to music, and playing board games. They were not allowed to sleep. Breakfast was served at 0830, lunch at 1230, dinner at 1700, and the evening snack at 1900.

Subjects were asked to keep their evening meals and activity levels on the day before each scheduled session as similar as possible and to refrain from eating or drinking (except water) after 2200. They were instructed to refrain from drinking alcohol on the day before each session and to consume only foods and beverages provided by our laboratory during scheduled sessions. Subjects were asked to record the physical activities they engaged in throughout the day as well as all foods and beverages they consumed after 1500 on the day before scheduled sessions. The records were collected at the beginning of each session and were reviewed by experimenters to ensure compliance with the protocol. Subjects were rescheduled if they did not consume any foods after 1500, if they consumed foods or energy-containing beverages after 2200, or if activity levels deviated markedly from the first day. Before the start of each session, subjects completed a brief questionnaire to assess whether in the past 24 h they had felt ill, consumed alcohol, or taken any medications known to affect appetite or food intake. They were rescheduled if they answered affirmatively to any of these questions. Subjects also reported the days of their menstrual cycles. Menstrual cycle data were reviewed at the completion of the study to determine whether menstrual phases were evenly distributed across conditions.

Test meals

Subjects were seated in individual cubicles for meals and were periodically monitored to assess compliance with the experimental protocol through the use of concealed video cameras. The subjects were not allowed to read during meals. Foods and beverages were weighed (±0.1 g) before and after each meal to obtain the amount consumed. Energy and macronutrient intakes were calculated on the basis of information from manufacturers.

We also estimated the volume (mL) of food served. This is an important measurement because for some similar types of foods, weight and volume are not directly proportional. For example, foods that are high in air content (ie, puffed cereals and snack foods) or are irregularly shaped are often lower in weight per volume than are foods that contain less air or are more evenly shaped. We determined the volume of each food served by marking its height on the side of the bowl or dish in which it was served and then measuring the amount of water (mL) needed to fill the bowl or dish, when empty, with water up to the marked line. This provided an estimate of the volume of each entrée as it was visually perceived by subjects. On the basis of the estimated volume of each food and its corresponding weight (g), we calculated the weight per volume (g/mL) for each entrée . For each subject, volume intake was determined by dividing weighed intake by the calculated weight per volume.

Main entrées

Each meal included one main entrée that varied in fat content and energy density (Table 1). Subjects were instructed to consume as much or as little of the main entrée as desired. The main entrée at breakfast was a warm cheese strata consisting primarily of eggs, Cheddar cheese, bread, milk, and vegetables. For lunch, a cold taco salad with black beans, vegetables, Cheddar cheese, salsa, sour cream, and tortilla chips was served. Dinner included a warm pasta bake with ingredients such as pasta, tomato sauce, a variety of cheeses, and vegetables. A warm apple bake consisting primarily of apple pie filling and granola was served for the evening snack. Large servings of the entrées (breakfast: ≈800 g; lunch: ≈1200 g; dinner: ≈1200 g; and snack: ≈700 g) were provided to ensure that food intake was not limited by the amount of food served. Serving dishes were filled to a similar volume across conditions. Only commercially available ingredients were used in the entrées.

Recipes for the entrées were formulated by using NUTRITIONIST IV (version 3.5; N-Squared Computing, San Bruno, CA) based on information from food labels. Entrées were formulated to contain ≈25% (LF), 35% (MF), or 45% (HF) of energy from fat (**Appendix A**). These values were selected to represent amounts below, similar to, and above the fat content of typical American diets (14). The LED entrées were formulated to contain ≈5.23 kJ (1.25 kcal)/g and the HED entrées were formulated to contain ≈7.32 kJ (1.75 kcal)/g (Appendix A). These energy densities are similar to the energy density of food in American diets and represent a difference in energy density of ≈29% between the HED and LED conditions.

Protein and fiber contents were held constant across conditions for each entrée. Thus, for manipulations of fat content, the fat-to-carbohydrate ratio varied. We altered the fat content of entrées primarily by substituting reduced-fat or fat-free items for their full-fat counterparts. Manipulations in energy density were due primarily to differences in water content, with LED entrées containing more water than HED entrées. Specifically, LED versions contained more low-fiber fruit and vegetables and less pasta and other grain products than did HED versions. Recipes were adjusted to account for loss of moisture during cooking and are available from the corresponding author on request.

Compulsory foods and beverages

In addition to the manipulated main entrée, breakfast, lunch, and dinner also included small portions of low-energy foods or beverages, identical in type and amount across conditions, that were required to be consumed in full (Table 1). Care was taken to ensure that the compulsory items were suitable accompaniments to the main entrées. A detailed listing of compulsory items served, including manufacturers, is available from the corresponding author on request.

TABLE 2
Subject characteristics[1]

	Lean women (n = 19)	Obese women (n = 17)
Age (y)	26.9 ± 1.8	25.8 ± 1.7
Weight (kg)	60.9 ± 1.4	97.9 ± 2.7[2]
BMI (kg/m^2)	22.7 ± 0.3	34.7 ± 0.9[2]
Body fat (%)[3]	25.6 ± 1.0	43.4 ± 1.0[2]
Eating Inventory scores[4]		
Dietary restraint	6.6 ± 0.9	6.4 ± 0.9
Disinhibition	4.0 ± 0.7	6.8 ± 0.9
Hunger	3.0 ± 0.7	5.0 ± 0.7
Depression score[5]	26.8 ± 0.9	28.9 ± 0.8[2]

[1] $\bar{x}$ ± SEM.
[2] Significantly different from lean women, $P < 0.05$.
[3] Measured with the BOD-POD Body Composition System (Life Measurement Instruments, Concord, CA).
[4] Eating Inventory (21).
[5] Zung Self-Rating Questionnaire (22).

Beverages

Chilled water (1 L) was served with all meals. Subjects could also request hot tea or coffee with breakfast and the snack. Subjects were instructed to consume as much or as little of these beverages as desired. To ensure that energy intake from hot beverages did not vary across sessions, tea and coffee were served only with non-energy-containing sweeteners. After breakfast, lunch, and dinner, subjects were given bottled water (340 g) to consume ad libitum between meals. Subjects returned the bottle and any remaining water at the next meal.

Ratings

Before and after each meal, subjects rated their hunger, thirst, nausea, fullness, and prospective consumption (how much food they thought they could eat) on VAS. 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.” The anchors for the question about prospective consumption were “nothing at all” and “a large amount.” At the time each meal was served, subjects rated the pleasantness of taste, pleasantness of texture, fat content, energy content, saltiness (sweetness for the apple bake), and prospective consumption of the main entrée on 100-mm VAS.

Debriefing

At the conclusion of each session, subjects completed a brief questionnaire with open-ended questions about their experiences in the laboratory that day. A discharge questionnaire, provided at the end of the study, asked subjects to state what they believed the purpose of the study to be and whether they noticed any differences in the main entrées across conditions.

Data analyses

Data were analyzed by using SAS for WINDOWS (version 7.0; SAS Institute, Inc, Cary, NC). Data on subject characteristics were analyzed between groups by using t tests adjusted for unequal variance. All other analyses were conducted by using a mixed procedure with subject group (lean and obese), fat content (LF, MF, and HF), and energy density (LED and HED) entered as factors in the model. When significant interactions were found, data were separated for further analyses. Tukey’s honestly significant difference test was used for post hoc comparisons of significant effects for factors with >2 levels (ie, 3 levels of fat). Chi-square analysis was used to determine whether menstrual phase was evenly distributed across conditions. Values are reported as means ± SEMs.

Subject characteristics

Analyses were conducted to determine whether there were differences between groups in scores on the 3 subscales of the EI (dietary restraint, disinhibition, and hunger), the EAT, and the Zung questionnaire and in age, weight, height, BMI, and percentage body fat.

Macronutrient composition and energy density of experimental diets

The macronutrient composition and energy density of the diets were calculated on the basis of each subject’s food intake (in g) of the manipulated main entrées and side dishes. Energy density was calculated for diets *1*) including food only, *2*) including food and energy-containing beverages, and *3*) including food and both energy-containing and non-energy-containing beverages.

Food and energy intakes

Analyses of intake (by weight, volume, and energy) were conducted with and without compulsory foods and with and without beverages for each meal and for the entire day. Session number and subject characteristics such as age, dietary restraint, disinhibition, and hunger were tested as covariates on food and energy intake. Ratings on the VAS for the manipulated entrées (ie, taste and texture) were tested as covariates on intake (in g) of the corresponding entrées.

Visual analogue scale ratings

Ratings of hunger, fullness, prospective consumption, thirst, and nausea before and after each meal were analyzed for differences. In addition, we tested whether there were differences across conditions in average daily ratings and in area under the curve for the ratings over time. Palatability ratings (ie, taste and texture) of the manipulated entrées were analyzed individually for each entrée and as averages across the 4 entrées.

RESULTS

Subjects

Subject characteristics are provided in **Table 2**. The obese women had significantly higher weights, BMIs, and percentages of body fat and higher scores on the Zung questionnaire than did the lean women. Subject characteristics were not significant covariates in any analyses. Chi-square analysis showed that menstrual cycle phase was evenly distributed across conditions.

Diets

The macronutrient composition, energy density, and fiber content of the experimental diets were calculated on the basis of the weight of food and beverages consumed. As shown in **Table 3**, the fat content and energy density of the diets were close to the amounts planned. On average, percentages of energy from fat were 21.5 ± 0.1%, 30.1 ± 0.1%, and 39.4 ± 0.2% for the LF, MF, and HF conditions, respectively. Energy density differed between the LED and HED conditions by 25.3% when calculated on the basis of intake of food only, by 23.7% on the basis of intake of food and energy-containing beverages, and by 21.2% on the basis of intake of food and all beverages. Fiber content differed significantly across conditions. The LED condition (17.1 ± 0.6 g) provided slightly more fiber than did the HED

TABLE 3
Macronutrient content and energy density of the experimental diets[1]

	LED			HED		
	LF	MF	HF	LF	MF	HF
Fat (% of energy)[2]	21.6 ± 0.1	30.9 ± 0.2	39.4 ± 0.2	21.3 ± 0.1	29.3 ± 0.1	39.4 ± 0.2
Carbohydrate (% of energy)[2]	64.6 ± 0.3	56.5 ± 0.4	47.3 ± 0.5	66.5 ± 0.3	58.0 ± 0.3	48.0 ± 0.3
Protein (% of energy)[2]	13.8 ± 0.3	12.6 ± 0.2	13.3 ± 0.4	12.2 ± 0.3	12.7 ± 0.2	12.5 ± 0.2
Energy density[3]						
Food only[4]						
(kJ/g)	4.85 ± 0.01	4.94 ± 0.01	5.19 ± 0.01	6.61 ± 0.04	6.61 ± 0.01	6.74 ± 0.01
(kcal/g)	1.16 ± 0.00	1.18 ± 0.00	1.24 ± 0.00	1.58 ± 0.01	1.58 ± 0.00	1.61 ± 0.00
Food and energy-containing beverages[5]						
(kJ/g)	4.48 ± 0.01	4.56 ± 0.04	4.77 ± 0.04	5.98 ± 0.04	5.98 ± 0.04	6.15 ± 0.04
(kcal/g)	1.07 ± 0.00	1.09 ± 0.01	1.14 ± 0.01	1.43 ± 0.01	1.43 ± 0.01	1.47 ± 0.01
Food and all beverages[6]						
(kJ/g)	2.09 ± 0.08	2.22 ± 0.08	2.22 ± 0.08	3.05 ± 0.12	2.72 ± 0.08	2.89 ± 0.08
(kcal/g)	0.50 ± 0.02	0.53 ± 0.02	0.53 ± 0.02	0.63 ± 0.03	0.65 ± 0.02	0.69 ± 0.02

[1] $\bar{x}$ ± SEM; n = 36 women (19 lean, 17 obese). Manipulated entrées had a low (LED) or high (HED) energy density and a low (LF), medium (MF), or high (HF) percentage of fat.

[2] Values for macronutrient content are based on total daily intakes of manipulated main entrées and compulsory items.

[3] Values for energy density are based on total daily intakes of manipulated main entrées and compulsory items.

[4] Values are based on the intake of manipulated main entrées and compulsory foods.

[5] Values are based on the intake of manipulated main entrées, compulsory foods, and energy-containing beverages.

[6] Values are based on the intake of manipulated main entrées, compulsory foods, and both energy-containing and non-energy-containing beverages.

condition (14.0 ± 0.6 g) and the HF condition (16.1 ± 0.7 g) provided more than did the MF (15.4 ± 0.6 g) and LF (15.2 ± 0.6 g) conditions. These differences in fiber content across conditions, however, were arguably too small to affect food intake (24).

Food and energy intakes

The 3-way interaction of group × energy density × fat and the 2-way interactions of group × fat and group × energy density were not significant in analyses of intake. There was also no effect of subject group (lean or obese) on intake, indicating that lean and obese women had similar responses to dietary manipulations of energy density and fat content. Subsequent data are reported collapsed across the 2 subject groups.

Amount of food and beverages consumed

There were main effects of both energy density and fat content on the total weight of food consumed (**Figure 1**). These effects, however, were explained by differences in the weight of the taco salad

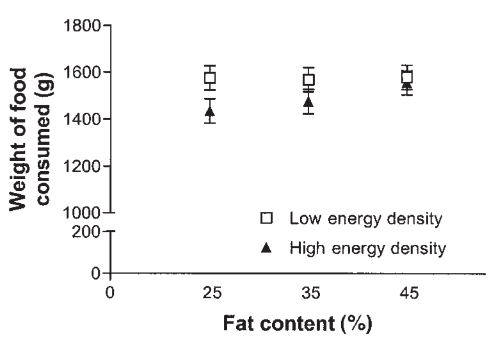

FIGURE 1. Total daily weight of the manipulated main entrées and compulsory items consumed. There were significant main effects of energy density (P < 0.0001) and fat content (P < 0.03). Lean and obese women consumed significantly less food in the low-energy-density than in the high-energy-density condition and less food in the low-fat (25% fat) than in the high-fat (45% fat) condition.

consumed because women ate a similar weight of the cheese strata, the pasta bake, and the apple bake and a similar weight of the compulsory items (410 ± 5 g) across conditions. In fact, intakes of the cheese strata, the pasta bake, and the apple bake varied across conditions by <26, <43, and <31 g, respectively. For the taco salad, however, there were main effects of both energy density (P < 0.0001) and fat content (P < 0.0001) on intake. Women consumed more of the taco salad when served the LED (367 ± 22 g) than the HED (308 ± 22 g) version, and less when served the LF (299 ± 23 g) than the MF (343 ± 23 g) and HF (370 ± 23 g) versions.

When we converted intake of the taco salad from weight to volume, however, there were no significant differences in intake across conditions. Therefore, neither energy density nor fat content affected the volume of taco salad consumed. Intake of the taco salad differed across conditions when measured by weight, but not volume, because the LF-HED and MF-HED versions were lower in weight per unit volume than the other 4 versions. These 2 versions contained a large proportion of tortilla chips, which are lower in weight than is a similar volume of other ingredients in the salad such as black beans, corn, and tomatoes. Therefore, women consumed a similar volume of taco salad across conditions, but the volume consumed weighed less in the LF-HED and the MF-HED conditions than in the other 4 conditions.

When total daily intake of the manipulated entrées was converted from weight to volume, results indicated that intake (in mL) did not differ significantly across conditions (**Table 4**). There were also no significant differences across conditions in the volume of compulsory items consumed or in total daily volume intake, including both manipulated entrées and compulsory items (**Figure 2**). Thus, women did not adjust the volume of entrées consumed in response to manipulations in either the energy density or fat content of the diet.

Other analyses showed that women consumed a similar weight of non-energy-containing beverages (mean intake: 1889 ± 50 g) across conditions and that total daily intake (in g), including all foods and beverages, did not differ significantly across conditions. Therefore, women did not compensate for

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TABLE 4
Intake of manipulated entrées[1]

	Weight consumed[2,3]			Volume consumed			Energy consumed[4,5]		
	LF	MF	HF	LF	MF	HF	LF	MF	HF
		g			*mL*			*kJ*	
LED	1164 ± 51	1160 ± 51	1169 ± 51	1359 ± 62	1262 ± 62	1277 ± 62	1460 ± 79	1463 ± 79	1510 ± 79
HED	1024 ± 51	1064 ± 51	1146 ± 51	1301 ± 62	1264 ± 62	1312 ± 62	1824 ± 79	1914 ± 79	2045 ± 79

[1] $\bar{x}$ ± SEM; n = 36 women (19 lean, 17 obese). Manipulated entrées had a low (LED) or high (HED) energy density and a low (LF), medium (MF), or high (HF) percentage of fat and were consumed by study participants ad libitum.
[2] Weight consumed of LED entrées significantly different from intake of HED entrées, $P < 0.0001$.
[3] Weight consumed of LF entrées significantly different from intake of MF and HF entrées, $P < 0.02$.
[4] Energy intake from LED entrées significantly different from energy intake from HED entrées, $P < 0.0001$.
[5] Energy intake from LF entrées significantly different from energy intake from HF entrées, $P < 0.02$.

the changes in the energy density of the diet by adjusting their intake of beverages. In addition, neither session number nor palatability ratings on the VAS were significant covariates in analyses of the amount (g and mL) of manipulated foods consumed.

Energy consumed

The energy density of the diet significantly affected the total amount of energy consumed daily (**Figure 3**). Lean and obese women consumed less energy in the LED (lean: 7819 ± 415 kJ; obese: 7242 ± 439 kJ) than in the HED (lean: 9816 ± 415 kJ; obese: 9011 ± 439 kJ) condition. These differences reflect an ≈20% reduction in daily energy intake between the HED and LED conditions.

There was also a main effect of fat content on total daily energy intake ($P < 0.002$). This effect of fat content on intake, however, was due to the disproportionate relation between the energy per weight (kJ/g) and the energy per volume (kJ/mL) of the 2 versions (LF-HED and MF-HED) of the taco salad (Appendix A). Thus, there was a significant energy density × fat interaction in analyses of energy intake from the taco salad. Specifically, a main effect of fat content was found when salads were HED, but not LED ($P < 0.0001$). Women consumed significantly more energy from the HF than MF and significantly more energy from the MF than LF versions. There was also a main effect of energy density in the MF and HF conditions, with women consuming more energy from the HED than LED version. For all other entrées, energy density, but not fat content, significantly affected energy intake ($P < 0.0001$).

Energy intake from compulsory items did not differ significantly across conditions (1347 ± 3 kJ), and session number was not a significant covariate in any analyses of energy intake. Thus, differences in total daily energy intake reflected differences in intake (in g) of the manipulated entrées (Table 4).

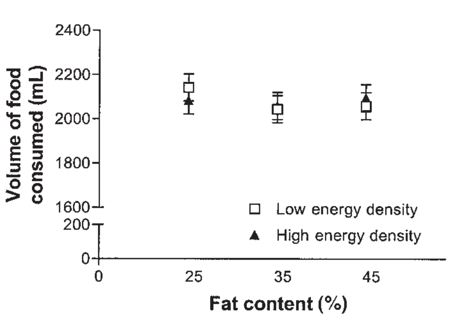

FIGURE 2. Total daily volume of the manipulated main entrées and compulsory items consumed. There were no significant differences across conditions (ie, low or high energy density and low, medium, or high fat content).

Visual analogue scale ratings

Ratings of premeal and postmeal sensations

Analyses indicated that there were some differences in ratings of hunger, fullness, prospective consumption, thirst, and nausea before and after some meals. These differences, however, were small (<5 mm) and were not systematic across conditions.

Energy density significantly affected average daily ratings and areas under the curve for hunger, fullness, and prospective consumption (**Figure 4**), but these differences were small compared with the substantial difference in energy intake (1883 kJ, or 450 kcal) between the LED and HED conditions. Average daily ratings of hunger and prospective consumption were higher in the LED (32 ± 1 and 33 ± 2 mm, respectively) than HED (29 ± 1 mm and 31 ± 2 mm, respectively) condition. Conversely, average daily ratings of fullness were lower in the LED (53 ± 2 mm) than HED (55 ± 2 mm) condition. Values for areas under the curve followed similar patterns with hunger and prospective consumption being ≈7% and 6% greater, respectively, in the LED than HED condition and fullness ≈5% lower in the LED than HED condition.

Ratings of manipulated foods

Significant differences in ratings of pleasantness of taste and texture, prospective consumption, fat content, saltiness (or sweetness), and energy content were found for some of the manipulated entrées. Most differences, however, were small (<5 mm) and were not sys-

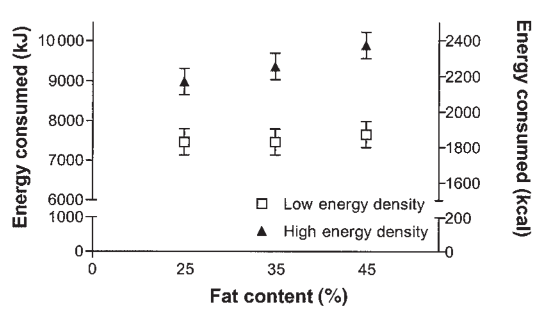

FIGURE 3. Total daily energy consumed from the manipulated main entrées and compulsory items. There were significant main effects of energy density ($P < 0.0001$) and fat content ($P < 0.02$). Lean and obese women consumed significantly less energy in the low-energy-density than in the high-energy-density condition and less energy in the low-fat (25% fat) than in the high-fat (45% fat) condition.

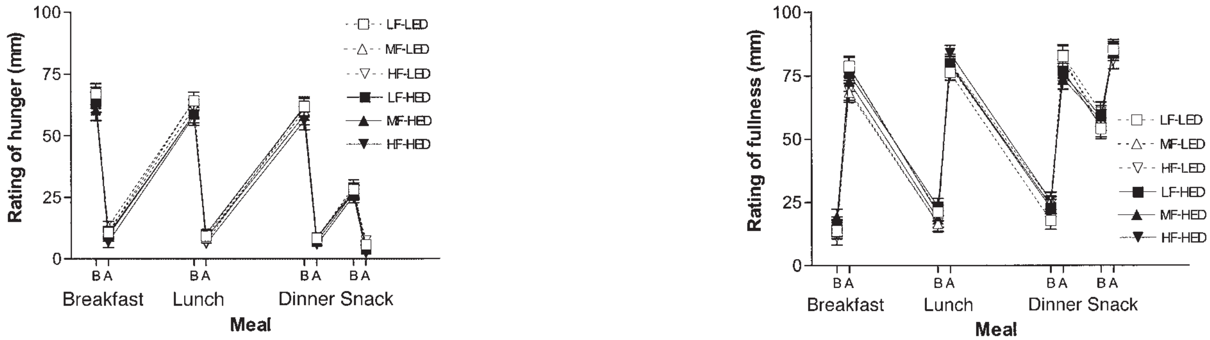

FIGURE 4. Ratings of hunger and fullness before and after meals throughout the day. LF-LED, low-fat diet of low energy density; MF-LED, medium-fat diet of low energy density; HF-LED, high-fat diet of low energy density; LF-HED, low-fat diet of high energy density; MF-HED, medium-fat diet of high energy density; HF-HED, high-fat diet of high energy density; B, before meal; A, after meal. Values for area under the curve for hunger and fullness throughout the day were significantly different between the LED and HED conditions, $P < 0.003$ and $P < 0.01$, respectively.

tematic across levels of fat or energy density or by group. We also calculated average values for each of the ratings across conditions. Again, analyses showed several small, nonsystematic differences. Overall, the entrées were well-liked across conditions (58 ± 2 mm for MF-LED; 59 ± 2 mm for HF-LED; 62 ± 2 mm for LF-LED, LF-HED, and MF-HED; and 63 ± 2 mm for HF-HED).

Analyses also indicated that differences in the energy and fat contents of the entrées were not readily perceived across conditions. There was a main effect of energy density ($P < 0.001$) on ratings of energy content of the entrées, but the difference between conditions was small (LED: 45 ± 3 mm; HED: 48 ± 3 mm). There was also a main effect of fat content on ratings of perceived fat content. Although the women rated HF entrées (42 ± 3 mm) as having higher fat contents than both the MF (37 ± 3 mm) and LF (39 ± 3 mm) entrées, these differences were small compared with the actual differences in fat content between conditions. Furthermore, the LF and MF conditions varied in fat content by 10%, but ratings indicated that neither lean nor obese subjects detected differences in fat content.

Debriefing

Most subjects (61%) indicated that the purpose of the study was to examine the effect of mood on intake or ratings of taste. Six subjects reported that they believed we were examining the effect of the fat or energy content of foods on intake. In addition to the purpose of the study, subjects were asked whether they noticed any differences in the foods across conditions. In response to this question, 5 subjects indicated that the foods varied in fat content. No subjects reported that the foods varied in energy content. Many subjects noted differences in the moisture content of the foods (47%) or differences in the proportions of ingredients (42%) across conditions.

DISCUSSION

The present study extends previous findings by showing that the energy density of foods affects energy intake at levels of fat and energy density comparable with those in typical American diets. Our results show that women consumed 20% less energy daily in the LED than in the HED condition. Despite this substantial reduction (1883 kJ, or 450 kcal) in energy intake, however, differences in ratings of hunger and fullness across conditions were small. These results support earlier findings that energy density, independent of macronutrient composition, affects energy intake (10–12, 16). In those investigations, however, the energy density and fat content of the experimental diets were lower than those of diets typically consumed. Our current findings also show that energy density did not interact with fat content to influence intake and that energy density affected energy intake across different dietary fat percentages in both lean and obese individuals.

Findings from several investigations indicated that individuals tend to consume a constant weight of food regardless of variations in energy density and fat content (1, 4, 5, 7, 8, 10). In one study, investigators reported that lean men partially compensated for changes in energy density by increasing intakes of an LED diet (12). These results, however, may simply reflect differences in palatability of the diets between conditions. In the present study there were also differences in the weight of food consumed across conditions. These differences, however, were not related to differences in palatability, but rather were due to 2 versions of one entrée (taco salad) being lower in weight for a given volume than other versions. When intakes of the manipulated entrées were converted from weight to volume, food intake did not differ significantly across conditions. Thus, within the range of fat content and energy density studied, individuals did not adjust the amount of food consumed in response to differences in energy density.

The present findings also provide preliminary evidence that short-term intake is affected by cues related to not only the weight but also the volume of food consumed. As discussed earlier, the weight and volume of foods are not always proportional. In the current study the LF-HED and MF-HED versions of the taco salad were lower in weight per unit volume than were the other versions. Our results indicated that women consumed a constant volume, but not weight, of the salad across conditions. These findings suggest that cues associated with the volume of food consumed influence the termination of meals and thus food intake.

Evidence supporting a role for food volume in the control of food intake comes from various studies. In 2 studies, increasing the volume of a preload through the addition of water reduced intake at the following meal (25, 26). In those studies, both the volume and weight of the preloads were altered. In one recent study, however, we manipulated the volume of a milkshake served before a self-selected lunch by incorporating air (27). Therefore, the effects of volume were dissociated from those of weight. Results indicated that volume, independent of weight, influenced subsequent energy intake. Other evidence for the influence of volume on intake comes from a recent study that showed that the shape or volume of food (or both) may affect individuals' estimates of the weight of food and thus their perceptions of appropriate portion sizes (28). Further research should characterize the specific effects of food weight and volume on intake. It is challenging, however, to dissociate food weight from food volume while maintaining similar sensory properties and palatability. Additionally, measuring food volume as it is visually perceived at the time of consumption is difficult because most foods are not homogeneous or fluid in nature.

Results from previous studies indicated that fat content does not affect intake when energy density is held constant (7–9). In contrast, the present findings suggest that fat content significantly influenced food (in g) and energy intake. This observed effect of fat content on intake, however, was due to a disproportionate relation between the weight and volume of 2 versions of the taco salad. There was no effect of fat content on food intake when intakes were converted from weight to volume. Thus, these findings indicate that women did not alter the amount of food consumed in response to variations in fat content.

In the present study, there were no significant differences in energy intake between the lean and obese women. We estimated energy needs by using World Health Organization equations for calculating resting energy expenditure and by multiplying the results by age-appropriate activity factors (19–24 y: 1.6; 25–45 y: 1.55) (29). Lean women consumed ≈6% more energy and 15% less energy daily in the HED and LED conditions, respectively, than the estimate for total daily energy needs (9222 ± 180 kJ, or 2204 ± 43 kcal). In both the LED and HED conditions, obese women failed to meet estimated energy needs (12 259 ± 280 kJ, or 2930 ± 67 kcal). It is possible, however, that obese individuals restricted their intakes in the laboratory. Nevertheless, there is no evidence to suggest that the degree of undereating differed between dietary conditions, which was the primary comparison of interest in this experiment.

For both obese and lean individuals, energy intake was reduced when meals included LED entrées. Although there was a substantial reduction in energy intake (1883 kJ, or 450 kcal), women rated their hunger only 7% higher and their fullness only 5% lower in the LED than HED condition. Similarly, in 2 other 14-d studies, men consumed significantly less energy with LED than HED diets. Again, there were only slight, albeit statistically significant, differences in ratings of hunger and fullness (11, 12). In one study, however, there were no differences in women's ratings of hunger and fullness despite a 30% reduction in energy intake (10). These findings indicate that consuming LED foods may be a useful strategy for weight loss and weight management because individuals will consume less energy while experiencing only slight, if any, differences in hunger and fullness. Future studies should consider the longer-term effects of energy density on intake and subjective ratings of hunger and fullness.

The small differences in ratings of the energy and fat content of the entrées, as well as the responses to the discharge questionnaire, indicate that we successfully manipulated the composition of the entrées while holding palatability relatively constant across conditions. Most study participants were not aware of the dietary manipulations or that we were testing how these affected intake. Although several subjects (17%) believed that we were examining the effect of the fat or energy (caloric) content of foods on intake, no subject correctly reported that we varied the energy content or energy density of foods. Further research should determine the influence of energy density on intake when individuals are aware of differences in energy content.

In conclusion, our results indicate that the energy density of food, independent of fat content and palatability, influenced short-term energy intake in both lean and obese women. These results extend previous findings by showing that energy density affected energy intake across multiple dietary fat percentages and at energy densities similar to those of diets commonly consumed. Additionally, our results imply that food intake is influenced by cues related to not only the weight but also the volume of food consumed. It is also possible that energy per volume may be a stronger determinant of energy intake than energy per weight; however, studies are needed to determine the specific roles of food weight and volume on intake. Finally, the large reduction in energy intake in the LED condition accompanied by only slight differences in ratings of hunger and fullness suggests that lowering the energy density of the diet may be a helpful strategy for weight management.

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APPENDIX A

Macronutrient content and energy density of manipulated entrées[1]

	LF-LED	MF-LED	HF-LED	LF-HED	MF-HED	HF-HED
Cheese strata						
Fat (% of energy)	25	35	45	25	35	45
Carbohydrate (% of energy)	49	42	34	53	43	36
Protein (% of energy)	25	23	21	22	22	19
Energy density						
(kJ/g)	5.15	5.23	5.61	7.70	7.70	7.32
(kcal/g)	1.23	1.25	1.34	1.84	1.84	1.75
Energy per volume						
(MJ/L)	3.22	3.56	3.68	4.85	5.06	4.90
(kcal/mL)	0.77	0.85	0.88	1.16	1.21	1.17
Taco salad						
Fat (% of energy)	25	35	45	25	35	45
Carbohydrate (% of energy)	60	50	41	61	51	42
Protein (% of energy)	15	14	14	14	13	13
Energy density						
(kJ/g)	5.23	5.23	5.23	7.32	7.32	7.32
(kcal/g)	1.25	1.25	1.25	1.75	1.75	1.75
Energy per volume						
(MJ/L)	4.18	4.44	4.56	4.69	5.23	5.98
(kcal/mL)	1.00	1.06	1.09	1.12	1.25	1.43
Pasta bake						
Fat (% of energy)	25	35	45	25	35	45
Carbohydrate (% of energy)	61	50	37	62	49	37
Protein (% of energy)	14	15	17	13	16	17
Energy density						
(kJ/g)	5.19	5.19	5.27	7.24	7.45	7.49
(kcal/g)	1.24	1.24	1.26	1.73	1.78	1.79
Energy per volume						
(MJ/L)	5.19	4.94	5.36	7.24	7.32	7.57
(kcal/mL)	1.24	1.18	1.28	1.73	1.75	1.81
Apple bake						
Fat (% of energy)	25	35	45	25	35	45
Carbohydrate (% of energy)	73	63	54	72	62	53
Protein (% of energy)	2	1	1	2	3	2
Energy density						
(kJ/g)	5.48	5.56	5.73	7.70	7.82	7.82
(kcal/g)	1.31	1.33	1.37	1.84	1.87	1.87
Energy per volume						
(MJ/L)	6.36	6.57	6.57	9.16	8.87	8.79
(kcal/mL)	1.52	1.57	1.57	2.19	2.12	2.10

[1] Based on information from manufacturers. Six versions of each entrée were developed: *1*) low fat, low energy density (LF-LED); *2*) medium fat, low energy density (MF-LED); *3*) high fat, low energy density (HF-LED); *4*) low fat, high energy density (LF-HED); *5*) medium fat, high energy density (MF-HED); and *6*) high fat, high energy density (HF-HED).

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