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Comparison of three methods to reduce energy density: effects on daily energy intake

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Abstract

Reductions in food energy density can decrease energy intake, but it is not known if the effects depend on the way that energy density is reduced. We investigated whether three methods of reducing energy density (decreasing fat, increasing fruit and vegetables, and adding water) differed in their effects on energy intake across the day. In a crossover design, 59 adults ate breakfast, lunch, and dinner in the laboratory once a week for four weeks. Across conditions, the entrées were either standard in energy density or were reduced in energy density by 20% using one of the three methods. Each meal included a manipulated entrée along with unmanipulated side dishes, and all foods were consumed *ad libitum*. Reducing the energy density of entrées significantly decreased daily energy intake compared to standard entrées (mean intake 2667±77 kcal/day; 11,166±322 kJ/day). The mean decrease was 396±44 kcal/day (1658±184 kJ/day) when fat was reduced, 308±41 kcal/day (1290±172 kJ/day) when fruit and vegetables were increased, and 230±35 kcal/day (963±147 kJ/day) when water was added. Daily energy intake was lower when fat was decreased compared to the other methods. These findings indicate that a variety of diet compositions can be recommended to reduce overall dietary energy density in order to moderate energy intake.

Keywords

Energy intake; Food intake; Energy density; Obesity; Human; Adult

INTRODUCTION

Given the current rates of obesity, it is critical to determine dietary approaches that can moderate the over-consumption of energy. One strategy that has been promoted by government and health organizations is to reduce dietary energy density (ED; kcal/g or kJ/g), because reductions in ED have robust effects on energy intake (Division of Nutrition, Physical Activity and Obesity, 2008; Pérez-Escamilla et al., 2012). Several different

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DISCLOSURE

None of the authors had a conflict of interest.

methods can be used to reduce ED including decreasing the fat content, increasing the proportion of fruit and vegetables, adding water, and using sugar or fat substitutes; all of these methods have been shown to decrease energy intake (Blatt, Roe, & Rolls, 2011a; Duncan, Bacon, & Weinsier, 1983; Hill et al., 1998; Lissner, Levitsky, Strupp, Kalwarf, & Roe, 1987; Rolls, Hetherington, & Laster, 1988; Rolls, Bell, & Thorwart, 1999a). Previous studies of reductions in ED, however, have not determined whether these methods differ in their effects on intake. The purpose of the current study was to compare three methods commonly used to reduce ED (decreasing fat, increasing fruit and vegetables, and adding water) in order to determine whether they have different effects on daily energy intake and at individual eating occasions over a day.

The impact that ED has on energy intake can be influenced by a variety of factors. On the one hand, numerous studies show that people tend to eat a consistent weight or volume of food when ED is varied (Bell, Castellanos, Pelkman, Thorwart, & Rolls, 1998; Blatt et al., 2011a; Stubbs, Johnstone, O'Reilly, Barton, & Reid, 1998). On the other hand, since food intake results from a complex interplay of a number of factors, this tendency to eat a consistent amount can be affected by food characteristics such as portion size (Rolls, Morris, & Roe, 2002), palatability (de Graaf, de Jong, & Lambers, 1999; Drewnowski, 1998), and differences in sensory properties like moistness (Viskaal-van Dongen, Kok, & de Graaf, 2011). The various methods of ED reduction could also influence energy intake over the day by engaging different biological mechanisms. Changes in macronutrients, fiber, and moistness associated with reductions in ED could affect gastric emptying and release of satiety hormones and thereby influence both the magnitude and the time course of effects on intake (Burton-Freeman, 2000; Chaudhri, Small, & Bloom, 2006; Lejeune, Westerterp, Adam, Luscombe-Marsh, & Westerterp-Plantenga, 2006; Marciani et al., 2012). Engagement of these various biological mechanisms has led some researchers to propose that the different methods to reduce ED could lead to differences in the persistence of the effect on energy intake beyond a meal (Stubbs, Ferres, & Horgan, 2000; Westerterp-Plantenga, 2004). Because of the numerous processes involved, it is possible that energy consumption over the day will be differentially influenced by the method of ED reduction.

The present study therefore investigated whether energy intake at individual eating occasions and over the day differed when the entrées at main meals were reduced in ED by 20% using different methods. Since variations in palatability can mask other attributes of food that affect *ad libitum* consumption or satiation (de Graaf et al., 1999; Drewnowski, 1998), we sought to match palatability across conditions. Because a number of previous studies have shown that people tend to eat a consistent weight of food when palatability is matched and ED is reduced, we hypothesized that all three methods of reducing entrée ED would decrease energy intake at all meals and over the day compared to serving entrées of a higher ED. However, because these three methods can have different effects on sensory and physiological processes, we also tested the hypothesis that they would vary in their effects on energy intake at individual eating occasions and over the day.

METHODS

Subjects

Men and women aged 20 to 45 y were recruited for the study through advertisements in campus electronic newsletters and newspapers from September 2010 to March 2011. Telephone interviews were conducted with potential participants to determine whether they met the initial study criteria, including that they had a body mass index (BMI; kg/m²) between 18–40, regularly ate three meals per day, did not have any food allergies or restrictions, were not dieting, were not athletes in training, were not taking medications that would affect appetite, did not smoke, and were willing to consume the foods served in the

test meals. Potential subjects who met the initial study criteria came to the laboratory to rate the taste of food samples, including the standard versions of lunch and dinner entrées that were served in the study, and to have their height and weight measured (model 707; Seca Corp., Hanover, MD, USA). The following questionnaires were completed: a demographic and health questionnaire; the Eating Attitudes Test (Garner, Olmsted, Bohr, & Garfinkel, 1982), which assesses indicators of disordered eating; the Zung Self-Rating Scale (Zung, 1986), which evaluates symptoms of depression; and the Eating Inventory (Stunkard & Messick, 1985), which measures disinhibition, dietary restraint, and tendency toward hunger. Potential subjects were excluded if they had a taste rating for any entrée sample 30 mm on a 100-mm scale; a score 20 on the Eating Attitudes Test; or a score 40 on the Zung scale.

The sample size for the experiment was estimated using data from previous one-day studies in the laboratory. The minimum difference in daily energy intake assumed to be clinically significant was 200 kcal (837 kJ). A power analysis estimated that a sample size of 40 was needed to detect this difference in daily energy intake with > 80% power using a two-sided test with a significance level of 0.05.

Subjects were told the purpose of the study was to investigate eating behaviors at different meals. All subjects provided signed consent and were financially compensated \$75 for their participation. The Pennsylvania State University Office for Research Protections approved all aspects of the study. A total of 32 men and 30 women were enrolled in the study. One man and one woman were excluded from the study for noncompliance with the study protocol. The data of one additional man was excluded for having undue influence on the outcomes according to the procedure of Littell, Milliken, Stroup, Wolfinger, and Schabenberger (2006); this individual had extremely low intakes on one test day. Thus, a total of 30 men and 29 women completed the study. The characteristics of these subjects are given in Table 1.

Study design

This experiment used a crossover design with repeated measures within subjects. The order of experimental conditions was counterbalanced across subjects using Latin squares and the orders were randomly assigned to subjects. Once a week for four weeks, participants were provided with all of their foods and beverages for breakfast, lunch, dinner, and evening snack. Across test days, the entrées served at the three meals were varied in ED between a standard level (100%) and a reduced level (80% of the standard). There were three reduced-ED versions of the entrées: decreased fat, increased fruit and vegetables (F&V), and added water.

Manipulated entrées

The composition of the entrées is shown in Table 2. The ED of the standard entrées was 1.8 kcal/g (7.54 kJ/g), which is similar to that of typical main dishes. The ED of the reduced entrées was 1.44 kcal/g (6.03 kJ/g). The use of separate methods to reduce ED limited the choice of entrées and imposed constraints on the degree to which ED could be reduced. The 20% reduction in ED allowed the use of single methods without changing the form of the food (i.e. adding an amount of water that would make a soup). Although the reduced entrées had the same ED, they differed in their proportion of macronutrients, fiber content, and moisture. On all test days, participants were served 700 g of the breakfast entrée and 900 g of both the lunch and dinner entrées. These entrée amounts were chosen so subjects' food intake would not be limited by the amount of food provided.

The entrées were covertly manipulated in ED in order to minimize differences in appearance and taste across the conditions. The versions of the entrées for each meal had the same ingredients, but the proportions of the ingredients were varied based on the experimental condition. The entrées decreased in fat were prepared by removing butter or oil from the recipes. For the entrées increased in F&V, the amount of fruit was increased in the breakfast entrée and the amount of vegetables was increased in the lunch and dinner entrées. The F&V were either chopped in small pieces or puréed so that the increase in amount was less noticeable. The entrées with added water contained a greater amount of tap water. To create the reduced-ED entrées from the standard version, the weights of the manipulated ingredients and all other recipe ingredients were exchanged proportionally; this maintained the total amount of food served to avoid the introduction of confounding effects due to differences in portion size (Rolls et al., 2002). Water losses due to cooking were accounted for in the calculation of ED. A bomb calorimeter (model 1261; Parr Instrument Co, Moline, IL, USA) was used to verify that the planned reduction in ED of the entrées was achieved.

Meals and evening snack

On each test day, participants were served breakfast, lunch, and dinner meals that included a manipulated entrée and unmanipulated side dishes; all foods served were consumed *ad libitum*, but subjects could not ask for additional servings. The entrée was the main source of energy at the meal and the side dishes were served to provide variety. Side dishes consisted of small amounts of food that differed in ED and were appropriate for the meal (Table 3). A variety of evening snacks that differed in ED were provided in order to determine whether the method used to reduce ED would result in differences in energy intake at the subsequent unmanipulated eating occasion.

One liter of water was served with each meal in addition to the choice of coffee or tea with breakfast. To allow measurement of water intake, bottled water was provided for consumption outside of the laboratory between meals and could be consumed as desired up to one hour before each meal. Bottled water was also provided with the evening snack. All foods and beverages were weighed before and after meals and the amount consumed was recorded to the nearest 0.1g. Energy and macronutrient intakes were calculated using information from a standard nutrient database (U.S. Department of Agriculture, Agricultural Research Service, 2008) and food manufacturers.

Procedures

On the day prior to each test day, participants were instructed to keep their food intake and activity level consistent, to refrain from consuming alcohol, and to refrain from eating after 10 PM. They were asked to record this information to encourage compliance. On test days, they were instructed to consume only those foods and beverages provided by the researchers until midnight. Subjects came to the laboratory at scheduled meal times and were seated in individual cubicles. Lunch was served 3 h after breakfast, and dinner was served 4 h after lunch. Evening snack was consumed outside of the laboratory prior to midnight.

Before each meal, participants completed a brief questionnaire asking whether they had felt ill, taken any medications, or consumed any foods or beverages not provided by the researchers since the last meal. After completing the questionnaire, they were provided with their meal and were instructed to consume as much or as little as desired. Subjects were also given as much time as desired to eat their meals and the length of time taken to eat was recorded. Following the dinner meal, they were provided with bottled water and a variety of evening snacks for consumption at home. After the final meal of the study, subjects completed a discharge questionnaire to describe their ideas about the purpose of the study and any differences they noticed between test days. A validated fat preference questionnaire

was also completed, which listed common foods available in different versions that varied in fat content; participants were asked to indicate which version of each food they thought tasted better and which version they ate most often. (Ledikwe et al., 2007)

Ratings of hunger, satiety, and food characteristics

Subjects used 100-mm visual analog scales (Flint, Raben, Blundell, & Astrup, 2000) to rate their hunger, fullness, prospective consumption, thirst, and nausea immediately before each test meal, after the meal, and immediately before consuming the evening snack. Participants also used visual analog scales to rate the overall liking, pleasantness of taste, calorie content, and fat content of the entrées at the beginning of the meal and immediately after the meal. Subjects were instructed to first serve themselves some of the entrée from the large serving bowl and then to take a bite of the entrée and answer the questions about the entrée characteristics. For example, participants were asked, “Based on what you are eating right now, how pleasant is the taste of this entrée?” The visual analog scale included anchors of “not at all pleasant” on the left and “extremely pleasant” on the right. In comparison, the anchors for the calorie content question were “very low in calories” on the left and “very high in calories” on the right. In addition, the moistness of the entrées was measured with a modified visual analogue scale that asked participants, “Based on what you are eating right now, how appropriate is the moistness of this entrée?” This modified scale had a “just right” indicator at the midpoint and included anchors of “much too dry” on the left and “much too moist” on the right. Immediately after the meal subjects were provided with a sample of the manipulated entrée and were instructed to eat the entire sample and then to answer all of the questions.

Data analysis

Data were analyzed using a mixed linear model with repeated measures (SAS System for Windows, version 9.3, SAS Institute, Inc., Cary, NC, USA). The fixed effects in the model were experimental condition (entrée version), subject sex, and study week. The primary outcomes for the study were energy intakes at each meal and for the entire day. To test the first hypothesis that all three methods of reducing entrée ED would decrease energy intake, the reduced-ED conditions were compared to the standard-ED condition and a Dunnett-Hsu adjustment was used to correct for multiple comparisons.

To test the second hypothesis that the methods of ED reduction had different effects on energy consumption over the day, three outcomes were investigated. Firstly, the magnitude of meal and daily energy intakes were compared across the reduced-ED conditions and a Tukey-Kramer adjustment was used to correct for multiple comparisons. As a second test of whether the methods of ED reduction differed in their effects, the curvature of cumulative energy intake over the day was examined across the reduced-ED conditions using a random coefficients analysis (Brown & Prescott, 1999). It was expected that if the effects of one method were less persistent, the curve of cumulative energy intake would increase more steeply as the day progressed. In the random coefficients model, time was treated as a continuous covariate and lower-order polynomial factors of time were fitted if they were significantly related to the outcome. This model accounts for the correlation of the repeated measures within subjects by allowing the cumulative intake curve over the day to vary randomly for each participant. Finally, energy intake at the evening snack was compared across the reduced-ED conditions to determine whether any differences in satiety were indicated by differences at the unmanipulated eating occasion at the end of the day.

Secondary study outcomes were the weight of food consumed at meals and for the entire day; dietary ED over the day; macronutrient intakes at meals and over the day; participant ratings of hunger, satiety, and food characteristics; and eating rate. The calculation of dietary

ED was determined using foods only; beverages were excluded (Ledikwe et al., 2005). Visual analog scales for hunger, satiety, and the food characteristics of overall liking, taste, calories, and fat ranged from 0 to 100. Ratings for moistness were assessed as the distance from the midpoint and ranged from -50 to 50. Summary measures of hunger and fullness for the day (including the ratings all time points at meals and evening snack) were calculated from the area under the curve of the ratings across time using the trapezoid formula (Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003). Analysis of covariance was used to determine whether any of the subject characteristics or participant ratings of entrée characteristics individually influenced the relation between the experimental condition and intakes of the manipulated entrées. Eating rate was calculated by dividing the weight of food consumed in grams by the time taken to eat the meal in minutes. Results are reported as mean $\pm$ standard error and were considered significant at $P < 0.05$.

RESULTS

Energy intake

Comparing standard- and reduced-ED conditions—Reducing the ED of entrées by each of the methods (decreasing fat, increasing F&V, or adding water) significantly decreased daily energy intake compared with the standard-ED entrées [$F(3,162) = 37.08$; $p < 0.0001$; Figure 1A]. The reduced-ED conditions decreased daily energy intake by a mean of 396 ± 44 kcal (1658 ± 184 kJ) when fat was decreased, by 308 ± 41 kcal (1290 ± 172 kJ) when F&V were increased, and by 230 ± 35 kcal (963 ± 147 kJ) when water was added. These differences were equivalent to a reduction over the day of 15, 11, and 9% of mean energy intake, respectively. For both men and women, energy intake from the entrées accounted for about two-thirds of daily energy intake. Energy intakes in all three reduced-ED conditions were significantly decreased at breakfast, lunch, and dinner compared to the standard-ED condition (Table 5).

Comparing the methods used to reduce ED—A comparison of the methods used to reduce ED showed that daily energy intake differed significantly [$F(2, 107) = 8.90$; $p < 0.001$; Figure 1A]. Daily energy intake was lowest when entrées were decreased in fat and was a mean of 89 ± 39 kcal (373 ± 163 kJ) higher when F&V were increased and 166 ± 37 kcal (695 ± 155 kJ) higher when water was added. When assessing individual meals, energy intake at breakfast and lunch, but not dinner, varied significantly according to the method of ED reduction (Table 5). Compared to when entrées were decreased in fat, energy intake was a mean of 46 ± 13 kcal (193 ± 54 kJ) higher at breakfast when F&V were increased [$F(2,113) = 6.82$; $p < 0.01$] and 66 ± 21 kcal (276 ± 88 kJ) higher at lunch when water was added [$F(2,107) = 5.66$; $p < 0.01$]. There were no significant differences in energy intake at meals when comparing the conditions in which F&V or water was increased. In contrast to the findings for daily and meal energy intakes, the curve for cumulative daily energy intake did not differ significantly across the methods used to reduce ED [$F(2,595) = 2.44$; $p = 0.09$; data not shown]. The pattern of energy consumption over the day was characterized by a similar second-order polynomial for all the reduced-ED conditions. Lastly, energy intake at the unmanipulated evening snack did not differ across the reduced-ED conditions (mean 368 ± 12 kcal [1541 ± 50 kJ]).

Weight of foods and beverages consumed

Comparing standard- and reduced-ED conditions—Compared to the standard-ED condition, the total weight of food consumed over the day did not differ significantly when ED was reduced by decreasing fat or increasing F&V. Reducing ED by adding water, however, increased the daily weight of food consumed by 83 ± 23 g compared to the standard-ED condition [$F(3,170) = 8.06$; $p < 0.0001$; Figure 1B]. In contrast to these

findings, the total weight of food consumed at individual meals (breakfast, lunch, and dinner) did not differ significantly between the conditions that were standard in ED or reduced in ED by adding water or decreasing fat. On the other hand, when F&V were increased, a significantly greater weight of food was consumed at breakfast but not at lunch or dinner compared to the standard-ED condition [$F(3,171) = 5.58$; $p < 0.01$; Table 5]. The weight of unmanipulated foods (side dishes and evening snack) consumed was not significantly different between the standard- and reduced-ED conditions.

Comparing the methods used to reduce ED—The method used to reduce ED had a significant impact on the weight of food consumed over the day [$F(2,111) = 10.37$; $p < 0.0001$; Figure 1B]. Participants consumed a mean of 109 ± 24 g more when water was added and 70 ± 23 g more when F&V were increased compared to when fat was decreased. When individual meals were examined, the method of ED reduction significantly influenced the weight of food consumed at breakfast and lunch but not dinner (Table 5). Compared to when fat was decreased, the weight of food consumed at breakfast was a mean of 32 ± 9 g more when F&V were increased [$F(2,113) = 6.51$; $p < 0.01$] and at lunch was 43 ± 15 g more when water was added [$F(2,108) = 4.81$; $p < 0.02$]. Across the methods, there were no significant differences in the weight of unmanipulated side dishes and evening snack consumed. The daily amount of water consumed as a beverage also did not differ significantly across the methods.

Macronutrient and fiber intakes

Daily intakes of fat, carbohydrate, protein, and fiber are shown in Table 4. Macronutrient and fiber intakes for the day varied significantly across the methods, as expected from the differences in entrée composition. For example, a reduction in ED by decreasing fat resulted in a daily intake of protein that was 15 ± 2 g more than increasing F&V and 12 ± 1 g more than adding water [$F(2,106) = 59.57$; $p < 0.0001$]. In addition, both decreasing fat and increasing F&V led to a small but significant increase in daily fiber intake of 2 ± 3 g compared to when water was added [$F(2,113) = 16.93$; $p < 0.0001$].

Macronutrient and fiber intakes at each meal also differed significantly across the methods (Table 5). For instance, protein intake at dinner was 5 ± 1 g higher when fat was decreased compared to the other two methods [$F(2,95) = 31.02$; $p < 0.0001$]. Fiber intake at dinner also differed significantly for all three methods in that fiber intakes were greatest when F&V were increased, intermediate when fat was decreased, and lowest when water was added [$F(2,113) = 135$; $p < 0.0001$]. However, fiber intakes differed by less than 2 g between any of the methods. At the evening snack there were no significant differences in intakes of fat, carbohydrate, protein, or fiber across the reduced-ED conditions.

Energy density

Reducing the ED of entrées led to a significant decrease in ED over the day compared to the standard-ED entrées [$F(3,171) = 254.61$; $p < 0.0001$; Table 4]. Comparing the reduced-ED conditions, dietary ED over the day did not differ significantly by the method used to reduce ED. The overall ED of the foods consumed was 1.72 ± 0.01 kcal/g (7.20 ± 0.04 kJ/g) when ED was standard and 1.49 ± 0.01 kcal/g (6.24 ± 0.04 kJ/g) when ED was reduced. There was no difference in the ED of foods consumed at the evening snack across conditions. Thus, the 20% reduction in ED of the three entrées, which accounted for approximately two-thirds of daily energy intake, led to a 13% reduction in dietary ED over the day.

Ratings of hunger, satiety, and food characteristics

Participant ratings of hunger, fullness, thirst, prospective consumption, and nausea did not vary significantly based on ED or the method used to reduce ED either before or after meals

or at the evening snack. Summary measures of hunger and fullness (area under the curve) also did not differ significantly across conditions (data not shown). Thus, ratings of hunger and fullness did not differ according to the method used to reduce ED.

Ratings of food characteristics for each of the entrées are shown in Table 6. All entrées were well liked by subjects as evidenced by mean ratings for pleasantness of taste from 60 to 80 mm. None of the reduced-ED entrées were rated significantly different in overall liking than the standard-ED versions. Participant ratings of entrée fat and calorie content did not differ significantly even though there were large differences in fat and calorie content across conditions. In contrast, moistness ratings differed significantly across conditions at each meal. The breakfast entrée with increased fruit as well as the lunch and dinner entrées with added water were rated significantly moister than the other versions of the same entrées. Analysis of covariance showed that the differences in entrée characteristic ratings did not influence the effect of the method of ED reduction on intake of the manipulated entrées.

Eating rate (g/min) also varied significantly across the methods at breakfast and lunch. At breakfast, eating rate was faster when fruit was increased (43.0 ± 2.2 g/min) than when either fat was decreased (38.2 ± 2.0 g/min) or water was added (37.6 ± 2.0 g/min) [$F(2,109) = 6.68$; $p < 0.01$]. At lunch, eating rate was faster when water was added (48.2 ± 1.7 g/min) than when either fat was decreased (43.4 ± 1.7 g/min) or vegetables were increased (45.6 ± 1.7 g/min) [$F(2,111) = 10.51$; $p < 0.0001$].

Subject characteristics

Analysis of covariance showed that the relationships between experimental condition and the outcomes of daily energy and food intakes were not significantly influenced by participant age, weight, height, BMI, scores for disinhibition, dietary restraint, or tendency toward hunger, or scores on the fat preference questionnaire. Subjects who indicated a preference for high-fat foods did not differ in their energy intake or ratings of entrée fat content compared to subjects who did not prefer high-fat foods (data not shown). Additionally, the effect of condition on daily energy intake did not differ significantly between men and women [$F(2,108) = 2.07$; $P = 0.13$]. Comments from the discharge questionnaire showed that no participants accurately discerned the purpose of the study.

DISCUSSION

This study demonstrated that three different methods of reducing entrée energy density (decreasing fat, increasing fruit and vegetables, and adding water) all resulted in a substantial decrease in energy intake over one day. While all three methods were effective, decreasing fat led to the greatest reduction in energy intake for the entire day, although not at individual meals. Daily summary ratings of hunger and fullness were similar despite the differences in energy intake across the conditions. The curves for cumulative energy consumption over the day were also similar across the methods. These findings confirm the efficacy of reducing ED by a variety of methods in order to moderate energy intake, but indicate that the magnitude of the effect may depend upon factors such as the method of ED reduction and the foods or meals being compared.

A possible explanation for the differences in food and energy intakes across the reduced-ED conditions is variations in the palatability and sensory characteristics of the entrées. Changes in these properties could influence the tendency for people to eat a similar amount of food when ED varies (Bell et al., 1998; Blatt et al., 2011; Stubbs et al., 1998) and therefore might explain why food intakes were lower when entrées were reduced in fat. Although we sought to limit the influence of palatability (de Graaf et al., 1999; Drewnowski, 1998), the use of single methods of ED reduction made it difficult to eliminate all of the differences in

sensory characteristics. We found that ratings of the pleasantness of the taste of the entrées were similar at breakfast and lunch but differed at dinner. Palatability ratings at dinner did not relate to meal intake, however, suggesting that other factors contributed to intake differences. The use of single methods of ED reduction also influenced the moistness of entrées, which could affect ease of consumption, eating rate, and food and energy intakes (Andrade, Greene, & Melanson, 2008; Viskaal-van Dongen et al., 2011). We found that an increase in either water or F&V generally resulted in entrées that were rated moister and were associated with faster eating rates compared to the reduced-fat entrées. Although energy intakes tended to be higher for the entrées that were rated moister, these ratings were not significantly related to intake in our study; it is possible that there may have been insufficient statistical power to detect such effects. Whether or not participants perceived differences in fat content could be another factor that influenced intake; yet, entrée fat content was rated similarly across the methods, suggesting that intake was not a result of participants noticing differences (Drewnowski, 1998). Although we did not find associations between intakes and the palatability or sensory characteristics of the reduced-ED entrées, it is still possible that variations in these properties influenced the tendency to consume similar amounts of food and thus affected energy intakes.

Another reason for the differences in energy intake across the methods could relate to variations in macronutrient composition of the entrées. We found that consumption of the reduced-fat entrées resulted in lower intakes of fat and higher intakes of protein compared to the other two methods. Previous research showed that changes in fat content did not significantly affect intake when ED was held constant (Rolls et al, 1999b; Raben, Agerholm-Larsen, Flint, Holst, & Astrup, 2003). When protein was increased and ED was held constant, however, energy intake was decreased in some studies (Gosby et al, 2011; Martens, Lemmens, & Westerterp-Plantenga, 2013) but not others (Blatt, Roe, & Rolls, 2011b; Raben et al., 2003). It remains possible that the decrease in daily energy intake from the consumption of reduced-fat entrées resulted from the small increases in protein intake at meals. Differences in macronutrient composition could affect intake through various mechanisms such as alterations in gastric emptying rates and post-ingestive hormones (Burton-Freeman, 2000; Chaudhri et al., 2006; Lejuene et al., 2006). Changes in these biological processes could affect not only the magnitude, but also the persistence of the effects on energy intake (Stubbs et al., 2000; Westerterp-Plantenga, 2004). In our study, however, we did not find differences in intake at the unmanipulated evening snack, the curvature of cumulative energy consumption, or ratings of hunger and fullness over the day. These findings suggest that the influence of ED on energy intake is not solely dependent on variations in the proportions of macronutrients. Additional research over longer periods will help to determine how biological processes and other factors associated with ED reduction combine and persist to influence energy intake.

Evaluating the results of adding either plain water or F&V to entrées made it possible to investigate whether F&V affected energy intake as a result of their fiber content. In comparison to the water condition, the addition of F&V led to a small (2 gram/d) increase in fiber intake, which was associated with no significant difference in daily energy intake. Previous investigations have shown that differences in fiber intakes as low as 14 grams over the day influence energy intake (Howarth, Saltzman, & Roberts, 2001), suggesting that the variations in fiber intake in this study were too small to exert different effects on energy intake over the day. Increasing the proportion of F&V in foods has the potential to decrease energy intake to a greater extent than adding water, because of the various effects that fiber can have on satiety (Burton-Freeman, 2000). Fruits and vegetables can also add bulk to foods and can increase the amount of chewing required (Burton-Freeman, 2000; Moorhead et al., 2006); however, these differences were lessened in our study since some of the F&V in the entrées were canned or puréed. The similarity in energy intake between the F&V and

water conditions indicates that the effects on intake when F&V were increased were not attributable to their fiber content.

The impact that reductions in dietary ED can have on energy intake in studies of satiation depends upon the foods available to participants. For instance, in studies where all of the foods provided were reduced in ED, the decrease in energy intake paralleled the reduction in ED (Lissner et al., 1987; Rolls, Roe, & Meengs, 2006). In such situations, energy intake could be constrained, since the only way people can compensate for consuming less energy is to eat more of the manipulated foods (Westerterp-Plantenga, 2004). However, a number of studies have found that reductions in ED were associated with decreased energy intake when only a portion of the diet was manipulated (Blatt et al., 2011a; Rolls et al., 1999b). In this study, participants consumed similar amounts of unmanipulated side dishes and evening snack when given these opportunities to adjust for energy deficits associated with the reduction in ED of the entrées. The 20% reduction in ED was associated with a 9 to 15% decrease in daily energy intake, depending on the method, and these reductions are comparable to previous research in which only part of the diet was reduced in ED (Blatt et al., 2011a; Rolls et al., 1999b). It is possible that in an abundant environment where there are almost unlimited opportunities to eat, greater compensation for ED reductions than was found in our study would be seen. Nevertheless, this study showed that reducing ED by a variety of methods had robust effects on energy intake even when individuals were given the opportunity to compensate by eating other foods.

In conclusion, reducing the ED of entrées by decreasing fat, increasing fruit and vegetables, or adding water decreased daily energy intake compared to serving standard-ED entrées. Although in this study the reduced-fat entrées led to the lowest daily intake, it is important to recognize that the entrées were chosen in order to manipulate the composition in distinct ways while minimizing differences in sensory properties. In practice, not all foods are suitable for reduction in ED by each method. Because of the different effects on sensory properties associated with the different methods, individuals may prefer one over another; for example, people who like moister foods might choose to add water to reduce ED. Individuals may also favor one method for reasons related to health, such as incorporating F&V to help consume recommended amounts of these foods. The finding that all three methods reduced energy intake at meals and over the day suggests that individuals can modify the ED of foods using their preferred methods or a combination of methods, such as replacing oil with applesauce when baking (fat reduction along with increased fruit). The practical implication is that a variety of diet compositions can be recommended to reduce overall dietary ED in order to moderate energy intake.

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Highlights

- Energy density was reduced by three methods and daily energy intakes were compared
- The methods were reducing fat, increasing fruit and vegetables, and adding water
- All three methods of reducing energy density decreased daily energy intake
- Decreasing the fat content led to the greatest decrease in daily energy intake
- Ratings of hunger and fullness over the day were not different across the methods

FIGURE 1.

Mean ($\pm$ SEM) energy (A) and food (B) intakes by condition at meals and evening snack consumed by 59 men and women who were served manipulated entrées at each meal that were either standard in energy density (ED) or reduced in ED by decreasing fat, increasing fruit and vegetables (F&V), or adding water.

Means with different letters were significantly different across the reduced-ED conditions ($P < 0.02$) as assessed by a mixed linear model with repeated measures and with a Tukey-Kramer adjustment for multiple comparisons. Means marked with an asterisk were significantly different than the standard-ED condition ($P < 0.0001$) as assessed by a mixed linear model with repeated measures and with a Dunnett-Hsu adjustment.

TABLE 1

Characteristics of subjects in a study in which the energy density of entrées was reduced by decreasing fat, increasing fruit and vegetables, or adding water¹

Characteristic	Men (n= 30)		Women (n= 29)	
	Mean ± SEM	Range	Mean ± SEM	Range
Age (y)	26.1 ± 1.0	20.3–43.1	25.6 ± 1.1	20.3–44.9
Height (m)	1.79 ± 0.01	1.69–1.91	1.66 ± 0.01 ^a	1.56–1.83
Weight (kg)	78.1 ± 1.7	62.7–100.0	61.5 ± 1.8 ^a	48.4–90.0
Body mass index (kg/m ²)	24.5 ± 0.5	20.3–29.8	22.4 ± 0.7 ^a	18.6–36.9
Dietary restraint score ³	6.3 ± 0.7	0–14	8.7 ± 0.8 ^a	0–15
Disinhibition score ³	4.4 ± 0.4	0–9	5.2 ± 0.6 ^a	1–15
Hunger score ³	4.2 ± 0.6	0–12	3.9 ± 0.6	0–13

¹ All values are means ± SEMs

² Daily energy expenditure was estimated from sex, age, height, weight, and activity level (33).

³ Scores from the Eating Inventory (31).

^a Mean for women is significantly different from men ($P < 0.04$).

TABLE 2

Composition of the manipulated entrées served at breakfast, lunch, and dinner in a study in which the energy density was reduced by decreasing fat, increasing fruit and vegetables, or adding water

	100% energy density	80% energy density		
	Standard	Decreased fat	Increased fruit and vegetables	Added water
Breakfast (700 g)				
Oatmeal				
Energy (kcal)	1256	999	1002	1002
Energy (kJ)	5259	4183	4195	4195
Carbohydrate (% energy)	53.7	72.5	59.2	53.7
Protein (% energy)	11.5	15.6	10.4	11.5
Fat (% energy)	34.8	11.9	30.4	34.8
Fiber (g)	18.6	19.2	14.4	14.9
Energy density (kcal/g)	1.79	1.43	1.43	1.43
Energy density (kJ/g)	7.49	5.99	5.99	5.99
Fruit & vegetables (g)	17.0	18.2	226.6	13.6
Added water (g)	0.0	0.0	0.0	141.6
Lunch (900 g)				
Tex-Mex pasta casserole				
Energy (kcal)	1594	1276	1276	1277
Energy (kJ)	6674	5342	5342	5347
Carbohydrate (% energy)	45.7	59.7	47.2	45.7
Protein (% energy)	15.0	19.6	15.0	15.0
Fat (% energy)	39.3	20.7	37.8	39.3
Fiber (g)	15.1	15.8	14.6	12.2
Energy density (kcal/g)	1.77	1.42	1.42	1.42
Energy density (kJ/g)	7.41	5.95	5.95	5.95
Fruit & vegetables (g)	15.4	16.1	222.6	12.3
Added water (g)	0.0	0.0	0.0	183.0
Dinner (900 g)				
Chicken rice casserole				
Energy (kcal)	1586	1273	1273	1273
Energy (kJ)	6640	5330	5330	5330
Carbohydrate (% energy)	45.1	59.0	46.3	45.1
Protein (% energy)	14.9	19.5	15.4	14.9
Fat (% energy)	40.0	21.5	38.3	40.0
Fiber (g)	6.5	6.8	9.6	5.2
Energy density (kcal/g)	1.76	1.41	1.41	1.41
Energy density (kJ/g)	7.37	5.90	5.90	5.90
Fruit & vegetables (g)	58.2	60.9	268.2	46.8
Added water (g)	255.0	266.6	195.4	393.4

¹Recipes available upon request to the corresponding author.

TABLE 3

Composition of foods served as side dishes at meals and for evening snack in a study that reduced the energy density of entrées by decreasing fat, increasing fruit and vegetables, or adding water

Meal	Food	Amount (g)
Breakfast	Strawberry yogurt ¹	114
	Creamer ²	15
Lunch	Unsweetened applesauce ³	113
	White roll ⁴	43
	Butter ⁵	5
Dinner	Red grapes	76
	Wheat roll ⁶	43
	Butter ⁵	5
Evening snack	Fig newton cookie ⁷	62
	Cheese popcorn ⁸	56
	Baby carrots	150

¹Yoplait USA Inc, Minneapolis, MN, USA

²Morningstar Foods LLC, Dallas, TX, USA

³Knouse Foods Co-Op Inc, Peach Glen, PA, USA

⁴Flowers Bakeries Food Service, Tucker, GA, USA

⁵Land O'Lakes Inc, Arden Hills, MN, USA

⁶Bakery de France, Rockville, MD, USA

⁷Kraft Foods Global Inc, Northfield, IL, USA

⁸Frito-Lay Inc, Plano, TX, USA

TABLE 4

Daily intakes for 59 participants in a study in which the energy density of entrées was reduced by decreasing fat, increasing fruit and vegetables, or adding water^I

	100% energy density	80% energy density		
	Standard	Decreased fat	Increased fruit and vegetables	Added water
Energy (kcal)	2668 ± 77	2272 ± 66 ^{a#}	2360 ± 66 ^{b#}	2438 ± 72 ^{b#}
Energy (kJ)	11,170 ± 322	9512 ± 276 ^{a#}	9881 ± 276 ^{b#}	10,207 ± 301 ^{b#}
Weight (g)	1554 ± 46	1529 ± 49 ^a	1598 ± 48 ^b	1637 ± 52 ^{b#}
Carbohydrate (g)	358 ± 10	365 ± 11 ^a	332 ± 9.0 ^{b#}	328 ± 10 ^{b#}
Protein (g)	85 ± 3	87 ± 3 ^a	73 ± 2 ^{b#}	76 ± 3 ^{b#}
Fat (g)	105 ± 3	55 ± 2 ^{a#}	88 ± 3 [#]	96 ± 3 ^{c#}
Fiber (g)	26 ± 0.8	27 ± 0.8 ^a	27 ± 0.8 ^a	25 ± 0.7 ^{b#}
Energy density (kcal/g)	1.72 ± 0.01	1.49 ± 0.01 ^{a#}	1.48 ± 0.01 ^{a#}	1.49 ± 0.01 ^{a#}
Energy density (kJ/g)	7.20 ± 0.04	6.24 ± 0.04 ^{a#}	6.24 ± 0.04 ^{a#}	6.24 ± 0.04 ^{a#}

^I All values are means ± SEMs.

^{a,b,c} Values in the same row with different superscript letters were significantly different ($P < 0.04$) as assessed by a mixed linear model with repeated measures and with a Tukey-Kramer adjustment for multiple comparisons.

[#] Values in the same row that are marked with a superscript # were significantly different from the standard ED condition ($P < 0.01$) as assessed by a mixed linear model with repeated measures and with a Dunnett-Hsu adjustment for multiple comparisons.

Table 5

Intakes by meal for 59 participants in a study in which the energy density of entrées was reduced by decreasing fat, increasing fruit and vegetables, or adding water ^{1,2}

	100% energy density	80% energy density		
	Standard	Decreased fat	Added fruit & vegetables	Added water
Breakfast				
Energy (kcal)	553 ± 25	451 ± 19 ^{a#}	497 ± 21 ^{b#}	475 ± 20 ^{a#}
Energy (kJ)	2315 ± 105	1888 ± 80	2080 ± 88	1989 ± 84
Weight (g)	350 ± 14	346 ± 14 ^a	378 ± 15 ^{b#}	364 ± 14 ^{ab}
Fat (g)	20 ± 1.0	6 ± 0.3 ^{a#}	16 ± 0.7 ^{b#}	17 ± 0.8 ^{b#}
Carbohydrate (g)	82 ± 4	85 ± 4 ^a	80 ± 3 ^b	71 ± 3 ^{c#}
Protein (g)	17 ± 0.7	18 ± 0.8 ^a	14 ± 0.6 ^{b#}	15 ± 0.6 ^{b#}
Fiber (g)	7 ± 0.3	7 ± 0.4 ^a	6 ± 0.3 [#]	6 ± 0.3 ^{b#}
Lunch				
Energy (kcal)	896 ± 33	736 ± 26 ^{a#}	771 ± 29 ^{a#}	802 ± 28 ^{b#}
Energy (kJ)	3751 ± 138	3081 ± 109	3228 ± 121	3358 ± 117
Weight (g)	556 ± 19	545 ± 19 ^a	570 ± 21 ^{ab}	588 ± 21 ^b
Fat (g)	36 ± 1.5	17 ± 0.6 ^{a#}	29 ± 1.3 ^{b#}	32 ± 1.3 ^{b#}
Carbohydrate (g)	116 ± 4	118 ± 4 ^a	104 ± 7 ^{b#}	105 ± 3 ^{b#}
Protein (g)	32 ± 1	33 ± 1 ^a	27 ± 1 ^{b#}	29 ± 1 ^{b#}
Fiber (g)	10 ± 0.3	10 ± 0.3 ^a	10 ± 0.3 ^a	9 ± 0.3 ^{b#}
Dinner				
Energy (kcal)	878 ± 32	728 ± 29 ^{a#}	735 ± 27 ^{a#}	771 ± 33 ^{a#}
Energy (kJ)	3676 ± 134	3048 ± 121	3077 ± 113	3228 ± 138
Weight (g)	525 ± 18	517 ± 21 ^a	522 ± 19 ^a	547 ± 23 ^a
Fat (g)	35 ± 1.4	16 ± 0.7 ^{a#}	27 ± 1.2 ^{b#}	30 ± 1.4 ^{b#}
Carbohydrate (g)	112 ± 4	114 ± 4 ^a	98 ± 3 ^{b#}	100 ± 4 ^{b#}
Protein (g)	30 ± 1	31 ± 1 ^a	26 ± 1 ^{b#}	26 ± 1 ^{b#}
Fiber (g)	5 ± 0.1	5 ± 0.2 ^a	6 ± 0.2 ^{b#}	4 ± 0.1 ^{c#}
Evening snack				
Energy (kcal)	340 ± 25	357 ± 20 ^a	358 ± 23 ^a	389 ± 19 ^{a#}
Energy (kJ)	1424 ± 105	1495 ± 84	1499 ± 96	1629 ± 80
Weight (g)	123 ± 11	121 ± 10 ^a	128 ± 11 ^a	138 ± 10 ^a
Fat (g)	14 ± 1.2	16 ± 1.0 ^a	15 ± 1.1 ^a	17 ± 0.9 ^{a#}
Carbohydrate (g)	48 ± 4	48 ± 3 ^a	49 ± 3 ^a	52 ± 3 ^a
Protein (g)	5 ± 0.4	6 ± 0.3 ^a	5 ± 0.4 ^a	6 ± 0.3 ^{a#}
Fiber (g)	5 ± 0.4	5 ± 0.4 ^a	5 ± 0.4 ^a	6 ± 0.4 ^{a#}

¹All values are means $\pm$ SEMs.

²Breakfast, lunch, and dinner meals include the entrée plus side dishes and the evening snack includes all foods that were provided.

^{a,b,c}Values in the same row with different superscript letters were significantly different ($P < 0.04$) as assessed by a mixed linear model with repeated measures and with a Tukey-Kramer adjustment for multiple comparisons.

[#]Values in the same row that are marked with a superscript symbol (#) were significantly different from the standard ED condition ($P < 0.04$) as assessed by a mixed linear model with repeated measures and with a Dunnett-Hsu adjustment.

TABLE 6

Ratings of food characteristics for each of the manipulated entrées for 59 participants in a study in which the energy density of entrées was reduced by decreasing fat, increasing fruit and vegetables, or adding water^{*l*}

	100% energy density	80% energy density		
	Standard	Decreased fat	Increased fruit and vegetables	Added water
Oatmeal				
Overall liking	70 ± 2	64 ± 2 ^{<i>a</i>}	70 ± 2 ^{<i>b</i>}	67 ± 2 ^{<i>ab</i>}
Taste	70 ± 2	66 ± 2 ^{<i>a</i>}	71 ± 2 ^{<i>a</i>}	67 ± 2 ^{<i>a</i>}
Fat	30 ± 2	28 ± 2 ^{<i>a</i>}	29 ± 2 ^{<i>a</i>}	29 ± 2 ^{<i>a</i>}
Calories	44 ± 3	42 ± 3 ^{<i>a</i>}	43 ± 2 ^{<i>a</i>}	43 ± 3 ^{<i>a</i>}
Moistness	-1 ± 2	-4 ± 2 ^{<i>a</i>}	8 ± 2 ^{<i>b#</i>}	-1 ± 2 ^{<i>a</i>}
Tex-Mex pasta casserole				
Overall liking	78 ± 2	77 ± 2	78 ± 2 ^{<i>a</i>}	74 ± 2 ^{<i>a</i>}
Taste	78 ± 2	78 ± 2 ^{<i>a</i>}	78 ± 2 ^{<i>a</i>}	75 ± 2 ^{<i>a</i>}
Fat	54 ± 3	54 ± 3 ^{<i>a</i>}	53 ± 3 ^{<i>a</i>}	52 ± 3 ^{<i>a</i>}
Calories	64 ± 2	61 ± 2 ^{<i>a</i>}	61 ± 2 ^{<i>a</i>}	60 ± 2 ^{<i>a</i>}
Moistness	1 ± 1	-1 ± 1 ^{<i>a</i>}	1 ± 1 ^{<i>a</i>}	5 ± 1 ^{<i>b#</i>}
Chicken rice casserole				
Overall liking	67 ± 2	68 ± 2 ^{<i>a</i>}	63 ± 2 ^{<i>a</i>}	66 ± 2 ^{<i>a</i>}
Taste	67 ± 2	67 ± 3 ^{<i>a</i>}	61 ± 3 ^{<i>b#</i>}	62 ± 3 ^{<i>b#</i>}
Fat	54 ± 3	49 ± 3 ^{<i>a</i>}	52 ± 3 ^{<i>a</i>}	52 ± 3 ^{<i>a</i>}
Calories	61 ± 3	58 ± 2 ^{<i>a</i>}	58 ± 3 ^{<i>a</i>}	59 ± 3 ^{<i>a</i>}
Moistness	4 ± 1	-1 ± 2 ^{<i>a#</i>}	5 ± 2 ^{<i>b</i>}	11 ± 2 ^{<i>c#</i>}

^{*l*} All values are means ± SEMs. Ratings for overall liking, taste, fat, and calories are from 100-mm visual analog scales. Ratings for moistness are from 100-mm visual analog scales but were assessed as the distance from the midpoint (50 mm) and are expressed as values ± 50 mm. A rating of zero represents “just right”, negative ratings are toward the “too dry” anchor, and positive ratings are toward the “too moist” anchor.

^{*a,b,c*} Values in the same row with different superscript letters were significantly different ($P < 0.04$) as assessed by a mixed linear model with repeated measures and with a Tukey-Kramer adjustment for multiple comparisons.

^{*#*} Values in the same row that are marked with a superscript symbol (#) were significantly different from the standard ED condition ($P < 0.02$) as assessed by a mixed linear model with repeated measures and with a Dunnett-Hsu adjustment