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Comparing the portion size effect in women with and without extended training in portion control: a follow-up to the Portion-Control Strategies Trial

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Abstract

Following a 1-year randomized controlled trial that tested how weight loss was influenced by different targeted strategies for managing food portions, we evaluated whether the effect of portion size on intake in a controlled setting was attenuated in trained participants compared to untrained controls. Subjects were 3 groups of women: 39 participants with overweight and obesity from the Portion-Control Strategies Trial, 34 controls with overweight and obesity, and 29 controls with normal weight. In a crossover design, on 4 different occasions subjects were served a meal consisting of 7 foods that differed in energy density (ED). Across the meals, all foods were varied in portion size (100%, 125%, 150%, or 175% of baseline). The results showed that serving larger portions increased the weight and energy of food consumed at the meal ($P<0.0001$), and this effect did not differ across groups. Increasing portions by 75% increased food intake by a mean (±SEM) of 111±10 g (27%) and increased energy intake by 126±14 kcal (25%). Across all meals, however, trained participants had lower energy intake (506±15 vs. 601±12 kcal, $P=0.006$) and lower meal ED (1.09±0.02 vs. 1.27±0.02 kcal/g; $P=0.003$) than controls, whose intake did not differ by weight status. The lower energy intake of trained participants was attributable to consuming meals with a greater proportion of lower-ED foods than controls. These results further demonstrate the robust nature of the portion size effect and reinforce that reducing meal ED is an effective way to moderate energy intake in the presence of large portions.

Keywords

Portion size; energy density; portion control; food intake; energy intake; adults

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INTRODUCTION

Serving larger portions leads individuals to consume more food, and this response results in substantial increases in energy intake across different types of people, foods, and settings (1–4). Given the prevalence of large portions of energy-dense foods (5–7), which contribute to overconsumption of energy (8), strategies are needed to moderate the effect of portion size on intake. One method that is recommended is training in portion control, for example through use of portion-control tools or instruction on appropriate food portions (9–14). Although educational interventions can increase the accuracy of portion size estimation (15), such training in the short-term has not been shown to influence intake (16). Furthermore, the effect of prolonged portion-control training on intake from large portions has not been systematically evaluated. To address this, we compared the response to portion size in trained individuals (who had been taught to manage food portions as part of a weight loss trial) to the response in individuals without such training.

The portion size effect was assessed by measuring food intake from a meal in which all foods were systematically varied in portion size. Thus, the purpose of this study was to determine whether individuals with extended training in portion-control strategies were less responsive to the portion size effect than those without training. The Portion-Control Strategies Trial provided a unique population in which to test the influence of training on the portion size effect. In this 1-year randomized controlled trial, women with overweight and obesity received instruction in one of three different targeted strategies for managing food portions. Although the various interventions differed in the content and intensity of instruction in portion control, the total duration of training was equivalent and all strategies were successful in promoting weight loss (17). After the trial, we aimed to determine whether the response to portion size under controlled conditions differed between trained subjects and untrained controls of differing weight status. We were also interested in the strategies that trained individuals might adopt in order to moderate energy intake when offered large portions, in comparison to control subjects. At a meal comprised of multiple foods, individuals trained in portion control might limit the amounts of all foods consumed, or instead, make differential adjustments in intake of individual foods according to their perceived healthfulness or energy density (ED) (1).

The current study used a crossover design to test differences between subject groups in the amounts and types of food consumed in response to increasing portions, with the goal of assessing whether energy intake differed by training or weight status. Previous research showed that the effect of portion size on intake can be comprehensively evaluated by serving a meal of multiple foods that are simultaneously varied across four or more portion sizes. This paradigm allows choices among foods that differ in ED and facilitates assessment of the influence of subject characteristics (e.g. body size, eating behaviors) and food properties (e.g. healthfulness, palatability) on the response to portion size (18). We hypothesized that the effect of portion size on the weight and energy content of food consumed would be attenuated in participants who were trained in portion control, compared to untrained controls. Additionally, portion size has been implicated as contributing to the obesity epidemic (5, 7), but there is limited experimental evidence demonstrating a relationship between the portion size effect and weight status. Thus, we also tested the hypothesis that the effect of portion size on intake differed between the untrained controls with overweight and obesity and the controls with normal weight.

SUBJECTS AND METHODS

Study design

In a crossover design, women from different subject groups came to the laboratory to eat lunch once a week for 4 weeks. Across the 4 meals the same menu was served, but the portions of all foods were simultaneously varied (100%, 125%, 150%, or 175% of baseline amounts). At all meals, weighed intake of each food was determined. The order of presenting the portion size conditions was counterbalanced across subjects using Latin squares, and subjects were randomly assigned a sequence. The study was conducted at the Laboratory for the Study of Human Ingestive Behavior at the University Park campus of The Pennsylvania State University, and all procedures were approved by the Office for Research Protections. Subjects were told that the purpose of the study was to investigate eating behavior. Subjects provided signed informed consent and were financially compensated for their participation.

Subjects

One group of subjects was recruited from among women who had completed the Portion-Control Strategies Trial. In that 1-year trial, 186 women with overweight and obesity were randomly assigned to receive training in three different strategies to promote weight loss: using pre-portioned foods to structure meals, using measuring tools to select food portions based on ED, or following standard advice to eat less while selecting nutritious foods. Participants in all interventions had frequent individual contact with trained interventionists, received instruction on meal planning and healthful choices within food groups, and were advised to increase physical activity (17). For enrollment in the trial, women were required to be aged 20–65 y with a body mass index (BMI) of 28–45 kg/m^2 and were excluded if they showed evidence of disordered eating (scored >19 on the Eating Attitudes Test (19)) or depression (scored >25 on the Beck Depression Inventory (20)). Recruitment for the current study took place after the trial was completed; it was presented as a separate study unrelated to the trial and was conducted in a different location with different staff. A subset of trial completers from all three intervention groups who were willing to participate in this study were enrolled. The trial participants, hereafter referred to as trained participants, who enrolled in the current study had lost a mean of 5.3±0.9% of their body weight during the trial, comparable to the 6% weight loss in all trial participants (17), but all of them still had overweight or obesity (Table 1).

The control population for the current study consisted of women who had not participated in the weight-loss trial and were recruited through advertisements posted on campus, in the local community, and online. Controls were eligible for the study if they were aged 20–65 y, had a BMI of 19–45 kg/m^2, and did not show evidence of disordered eating (scored >19 on the Eating Attitudes Test (19)) or depression (scored >40 on the Self-rating Depression Scale (23)). We included control subjects with normal weight as well as those with overweight and obesity in order to assess the effect of weight status on intake in response to increasing food portions. Potential participants were excluded if they had food allergies, restrictions, or dislike for the study foods; did not regularly eat 3 meals per day; were dieting to gain or lose weight; or were smokers, athletes in training, pregnant, or breastfeeding.

The sample size for the experiment was based on data from a related study conducted in the laboratory (18). A power analysis was conducted to determine the sample size needed to detect a 40% reduction in the slope of the portion size trajectory in trained participants compared to controls with >80% power at a significance level of 0.05. The analysis showed that it would require 40 trained participants and 60 controls (with normal weight and with overweight and obesity) to detect this difference. A total of 105 subjects were enrolled in the study, but 3 subjects failed to attend all scheduled meals. Thus, 102 subjects completed the study: 39 trained participants and 63 controls. Among the trained participants, 12 were from the pre-portioned foods intervention, 16 from the portion selection intervention, and 11 from the standard advice intervention. Among the controls, 34 had overweight or obesity and 29 had normal weight.

Prior to the first meal, subjects completed the Eating Inventory (22), which consists of 51 items about eating behavior that assess dietary restraint, disinhibition, and tendency towards hunger. Subject energy requirements were estimated from age, sex, height, weight, and activity level (21).

Test meal

The test meal consisted of 7 commercially available foods that were chosen to represent typical meal components and that differed in ED (Table 2). In the baseline (100%) condition, the portion sizes were based on intake of women in previous studies in the laboratory (18, 24); in the other conditions, the portions of all foods were simultaneously increased to 125%, 150%, or 175% of baseline amounts (Table 2). Four portion sizes were used in order to characterize the trajectory of the weight of food consumed across the range of weight served (18). One liter of water was served as a beverage at all meals. To determine the amount of food consumed, all items were weighed to within 0.1 g before and after meals. Energy intake was calculated using information from food manufacturers and a standard food composition database (25).

Study procedures and assessments

Subjects came to the laboratory to eat a test meal once a week for 4 weeks on a scheduled day and time. They were told that the purpose of the study was to assess eating behavior in a laboratory. Since the study was conducted on a different site and with different personnel than the weight loss trial, the environment was novel both to subjects who had participated in the weight-loss trial and to untrained controls. Subjects were instructed to maintain a consistent level of exercise and refrain from drinking alcoholic beverages on the day before their test meal and to refrain from eating after 10 pm the previous evening. They were told to eat a consistent breakfast the day of the test meal and not to consume any food or energy-containing beverages between breakfast and lunch.

Upon arrival for their meal, subjects were seated in private cubicles and rated their hunger, fullness, thirst, prospective consumption, and nausea using 100-mm visual analog scales

(VAS; 26). Subjects were then served the meal and told that they could eat and drink as much or as little as they liked. After consuming the meal, subjects again rated their hunger, fullness, and prospective consumption, as well as how pleasant the meal tasted overall, how healthy the meal they consumed was, and how many calories they thought they consumed from the meal. At a discharge session in the fifth week, subjects were given small samples of the 7 test foods, which they tasted and rated for liking and healthfulness on 100-mm visual analog scales. Thus, subjects rated healthfulness and liking of each of the four full meals they had consumed as well as liking and healthfulness of each of the individual foods that made up the meals. Additionally, after the first cohort, a subset of 88 subjects (86%) ranked the test foods for pleasantness of taste from 1 (highest) to 7 (lowest).

Statistical analysis

The main outcome of the effect of portion size on meal intake was defined as the trajectory of the weight of food consumed across the weight of food served. Previous research demonstrated a curvilinear trajectory of mean intake as portions were increased (18). The portion size response was characterized by a polynomial equation and analyzed by random coefficients models (27). The fixed factors in the model were meal portion size (g), subject group (trained participants, controls with overweight and obesity, and controls with normal weight), and study week. Subjects were treated as random factors; thus the intake trajectory of each individual was modeled separately. The trajectories were centered at the smallest condition of portion size, so that the linear coefficient (slope) represented the increase in intake as portions were increased above baseline amounts, and the quadratic coefficient described the deceleration of intake as portions were further increased. In addition to meal weight, the trajectories of meal ED and energy were analyzed as main outcomes using random coefficients models. Subject characteristics and questionnaire scores were tested as covariates in the models to determine whether any of these factors influenced the trajectory of intake in response to increased portion size.

Intake of the individual foods in the meal was analyzed as a secondary outcome. All the foods were included in a univariate manner in a single random coefficients model, so that intake trajectories were adjusted for the other foods in the meal. Subject characteristics and questionnaire scores were tested as covariates as in the main models. In addition, subject ratings and rankings of food-specific factors (such as liking) were also tested for their influence on food intake trajectories.

Other secondary outcomes were subject ratings of hunger, satiety, and characteristics of the meal and foods. Differences in these outcomes were analyzed by a mixed linear model with repeated measures; the fixed effects in the model were portion size condition (100%, 125%, 150%, and 175%), subject group, and study week. Post-meal ratings of hunger and satiety were adjusted by including the pre-meal rating as a covariate in the model. For all mixed linear models, the F-statistic and its denominator degrees of freedom were adjusted using the Kenward-Roger approximation, and adjustment for multiple comparisons between means was made using the Tukey-Kramer method (27). Differences in the distribution of food taste rankings across groups were tested using ordinal repeated-measures logistic regression. The repeated-measures correlation between subject ratings of healthfulness of the meal consumed and the overall ED of the foods consumed at the meal was determined from the covariance parameters of a mixed linear model in which the two variables were treated as repeated measures (28). The correlation between mean ratings of healthfulness of the individual foods and the ED of the food were calculated using the Pearson correlation coefficient according to the method of Bland and Altman (29). Standardized effect sizes were calculated using Cohen's *d* statistic, ignoring the correlations between outcomes. Differences in subject characteristics across groups were tested by fixed effects models for continuous variables and by Fisher's exact test for categorical variables. All analyses were performed using SAS software (version 9.4, SAS Institute, Cary, NC). Outcomes are reported as mean ± SEM and results were considered significant at P<0.05.

RESULTS

Subject characteristics

Subject characteristics are shown in Table 1. Trained participants were older and had higher BMI than participants in both control groups. Estimated daily energy expenditure, however, did not differ significantly between trained participants and controls with overweight and obesity. Energy requirements of the controls with normal weight were significantly lower than those of the other two groups. The study population was 97% white, 2% black, and 1% Asian; 4% were Hispanic or Latino. There was no significant difference across participant groups in the distribution of race (table probability=0.051; P=0.33) or ethnicity (table probability=0.029; P=0.07).

Meal intake by weight

Serving larger portions of all foods significantly increased the weight of food consumed at the meal (Figure 1A; F(1,101)=138.61, P<0.0001). The trajectory of meal intake (weight of food consumed across weight served) was linear and did not differ significantly across participant groups (F(2,99)=0.45, P=0.64) nor across the type of portion-control intervention in trained participants (F(2,36)=2.29, P=0.12). Thus, the hypothesis that trained individuals would show an attenuated response to large portions was not supported, since trained participants, controls with overweight and obesity, and controls with normal weight all responded similarly to increases in meal portion size by consuming a greater weight of food. The slope of the relationship showed an increase of 26±2 g consumed per additional 100 g served, indicating that participants consumed a mean of 26% of the food added to the baseline meal in each of the three larger portion conditions. Increasing all portions by 75% increased food intake by 111±10 g (27%; *d*=1.02).

Meal energy density (ED)

The effect of increasing portion size on the ED consumed at the meal differed across participant groups (Figure 1B; linear coefficient interaction F(2,243)=3.43, P=0.034; quadratic coefficient interaction F(2,202)=3.66, P=0.028). For trained participants, there was a curvilinear trajectory of meal ED across portion sizes: an initial decrease (negative linear coefficient; t(243)= −3.44, P=0.0007) as portions were increased from baseline, followed by an increase (positive quadratic coefficient; t(201)= 3.28, P=0.001) as portions were increased further. In contrast, meal ED for control participants with overweight or normal weight did not change significantly as portions were increased (linear coefficients t(243)= 0.28, P=0.78 and t(243)= −0.77, P=0.44, respectively; quadratic coefficients t(203)= −0.63, P=0.53 and t(201)= 0.93, P=0.35, respectively). Across all the portions served, the overall ED of the meal also differed by participant group (F(2,111)= 4.85; P=0.010). The meals eaten by trained participants were lower in ED (1.09±0.02 kcal/g) than those eaten by controls with overweight and obesity (1.22±0.02 kcal/g; *d*=0.53) or controls with normal weight (1.31±0.02 kcal/g; *d*=0.82), which did not differ significantly. In trained participants, the effects on meal ED in response to increased portion size did not differ significantly across the different portion-control interventions (linear coefficient interaction F(2,94.4)=0.32, P=0.72; quadratic coefficient interaction F(2,75)=0.47, P=0.63).

Meal energy intake

For both trained participants and controls, serving larger portions significantly increased energy intake at the meal (F(1,101)=2.36, P<0.0001; Figure 1C). Across all groups, the trajectory of energy intake was linear and the slope of the relationship showed an increase of 29±3 kcal per additional 100 g served. Increasing all portions by 75% increased energy intake by 25% (126±14 kcal; *d*=0.68). Independent of the effect of portion size, the magnitude of meal energy intake differed significantly across participant groups (F(2,99)=3.78, P=0.026). Across all meals, trained participants consumed less energy (506±15 kcal) than controls with overweight and obesity (592±16 kcal; *d*=0.45) or controls with normal weight (611±17 kcal; *d*=0.55), whose intakes did not differ significantly. Thus, although food intake by weight increased similarly across portion sizes for all groups, the differences in meal energy density across groups led to significant differences in meal energy intake. Among trained participants, the effect on energy intake did not differ according to the type of portion-control intervention (F(2,36)=0.97, P=0.39).

Intake of individual foods

Analyzing intake of the 7 foods in a single model showed that the effects of portion size on the weight of individual foods consumed were linear and the slopes did not differ across participant groups (F(2,119) = 0.61; P=0.54), similar to the findings for the entire meal. The portion size effects, however, did differ across food items (Table 3; F(6,2621)=3.55, P=0.0017). Additionally, although the participant groups had similar slopes for the portion size effects, the groups had significant differences in overall consumption of 3 foods: garlic bread (F(2,1025)=5.50, P=0.004), pasta (F(2,1169)=14.03, P<0.0001), and salad (F(2,1220)=12.05, P<0.0001). Across all meals, trained participants consumed significantly less garlic bread than did controls with overweight and obesity; they also consumed less garlic bread and pasta, but more salad, than did controls with normal weight. Thus, the lower energy density of the meals consumed by trained participants compared to controls was attributable to eating less of the higher-ED garlic bread and pasta, and more of the very-low-ED salad.

Influence of subject characteristics

The effect of portion size on the trajectory of meal intake by weight was not influenced by the subject characteristics of age (F1,102)=0.22, P=0.64), estimated energy expenditure (F1,102)=0.05, P=0.83), or scores for restraint (F1,101)=0.01, P=0.94), disinhibition

(F1,102)=0.41, P=0.52), or tendency towards hunger (F1,102)=0.35, P=0.56). Similarly, these subject characteristics did not influence the effect of portion size on overall meal energy density or energy intake (data not shown).

Ratings of hunger and satiety, and meal characteristics

As food portions were increased and meal intake correspondingly increased in all groups, participant ratings of post-meal fullness on 100-mm visual analog scales increased from 80.0±1.7 mm in the 100% portion size condition to 84.7±1.4 mm in the 175% condition (F(3,199)=3.44, P=0.018; *d*=2.82). Likewise, ratings of hunger decreased from 6.6±1.1 mm in the 100% condition to 4.0±0.5 mm in the 175% condition (F(3,195)=2.69, P=0.048; *d*= −1.85). Participant post-meal estimates of energy intake also increased as portions were increased (F(3,216)=4.33, P=0.005); this outcome did not differ across subject groups (F(2,100)=0.16, P=0.85). Estimated energy intake in the baseline portion size condition (598±22 kcal) was significantly less than in the 3 larger conditions (mean 640±14 kcal), which did not differ from each other. Thus, although measured energy intake increased 25% between the meals with the smallest and largest portions, participant estimates of their energy intake only increased by 7%.

Post-meal ratings of pleasantness of taste (mean 76±1.0 mm) and healthfulness (mean 64±1.0 mm) of the meals consumed did not differ across experimental conditions (F(3,219)=1.16, P=0.33 and F(3,216)=.034, P=0.79, respectively). This was expected since the types and proportions of foods were not varied as portions were increased. There were differences, however, across participant groups in ratings of healthfulness of the meals consumed (F(2,100)=4.45, P=0.014); trained participants rated the meals they ate as more healthful (mean 68.4±1.2 mm) than did controls with normal-weight (58.0±1.7 mm; *d*= −0.64). Post-meal ratings of meal healthfulness were inversely related to the ED of the meal that subjects had consumed (repeated measures correlation=−0.30; P<0.0001).

Subject ratings of liking and healthfulness of the individual foods (completed at discharge) showed significant differences across items (Table 4; F(6,697)=19.03, P<0.0001 and F(6,698)=372.02, P<0.0001, respectively); there were no differences, however, between trained participants and controls for these ratings (F(12,685)=1.36, P=0.18 and F(12,686)=1.02, P=0.43, respectively). Mean subject ratings of healthfulness of the individual foods were strongly and negatively correlated with the ED of the item (r=−0.94; P=0.0018). In the subgroup of subjects who completed rankings of food taste at discharge, the distribution of the rankings did not differ across subject groups (F(2,602)= 0.02, P=0.98).

The analysis of the portion size effect on individual foods (the trajectories of the weight of food consumed in response to increasing weight served) showed a positive effect of food liking on the slopes, and that this effect differed by subject group (F(2,2327)=12.48, P<0.0001). Across all items, the positive effect of food liking on the slopes of the intake trajectories was smaller for trained participants than for controls. Thus, although there were similar ratings of liking across subject groups, the effects of liking on the portion size response differed across groups. The ranking of the relative taste of the individual foods also influenced the portion size effect in the subset of subjects who completed this task (Figure 2;

$F(6,2238)=15.96$, $P<0.0001$). Across all subject groups, items ranked higher in taste had a greater increase in intake (more positive slope) as portions were increased.

DISCUSSION

Serving larger portions of all foods at a meal led to an increase in the weight of food consumed by both individuals with extended training in different portion-control strategies and those without such training. Thus, the results did not support the hypothesis that the portion size effect would be attenuated in trained participants compared to controls. Furthermore, the response to portion size did not differ between the two control groups that varied by weight status. Compared to the control groups, however, trained participants moderated their energy intake at all meals. This was achieved not by limiting the overall amount eaten at the meals, but by consuming a greater proportion of lower-ED foods. Thus, contrary to expectation, individuals trained in portion control did not resist the portion size effect; they did, however, reduce their energy intake compared to untrained controls through their food choices at meals.

Our findings emphasize the strength of the portion size effect; despite their training, participants from the Portion-Control Strategies Trial consumed more food and more energy when they were served larger portions. This is consistent with previous unsuccessful efforts to attenuate the response to large portions, including offering portion options (30), providing short-term training in portion size awareness (16), and presenting explicit information about the portion size served (31, 32). We also found that across meals, trained participants ate a similar weight of food to untrained controls, despite differences in training and weight status. Unlike previous studies (13), post-meal ratings of hunger and fullness for all groups were affected by portion size; subjects ate to a greater level of fullness as portions were increased. The contrast between this study and others could be due to the increased power associated with large number of observations in this study. These findings provide further evidence that the portion served is a primary determinant of the amount consumed (18, 33–35), and indicate that even prolonged training in standard portion-control strategies, such as using scales and measuring tools, using pre-portioned foods, or instruction to eat less, may not be powerful enough to counteract the influence of cues from the amount of food available (36, 37). More innovative strategies are needed that provide immediate awareness of the energy content of the portions of food served, along with ways to sustain the salience of this knowledge.

Although participants with portion-control training did not resist the effect of portion size on the amount eaten, they did consume less energy at meals than controls. This difference was attributable to the lower ED of the meals that trained participants chose to consume; compared to controls, they ate more of the very-low-ED foods and less of the higher-ED foods, particularly the items they rated lowest in healthfulness. This finding shows the substantial effect of ED on energy intake and supports previous work demonstrating that decreasing meal ED reduces energy intake independent of changes in portion size (34). Trained participants also rated the meals they consumed as more healthful than did controls, and these ratings were related to the lower ED of the meals they consumed. Additionally, despite similar ratings of liking and healthfulness of the foods across groups, trained participants' response to portion size for individual foods was less influenced by ratings of liking than it was for controls. The combination of these findings suggests that trained participants placed greater importance on healthfulness in determining food choice than did controls. Indeed, although the emphasis of the training was on targeted portion-control strategies, another component for all intervention groups was on making healthful food choices. The intake patterns of the trained subjects in this study reflected the self-reported behaviors of all participants in the weight loss trial. By the end of the trial, use of portion-control methods was no higher than at baseline; however, use of several strategies for selecting healthy foods had increased from baseline and been maintained (17). These results correspondingly suggest that it may be easier or more sustainable to moderate energy intake by consuming healthy, low-ED foods than to try to resist eating large portions. Future interventions should encourage individuals to evaluate the types of foods available, rather than focusing only on the amount of food that is served.

Another aim of the current study was to assess whether individual characteristics, such as weight status, influence the portion size effect. Although large portions have been linked to the increased energy intake driving the rise in obesity rates (7, 38), this study and those conducted previously have not shown a differential response to portion size according to weight status in adults under controlled conditions (summarized in 3, 39). Not only did we fail to find differences according to weight status, but also the magnitude of the portion size effect did not vary across age, estimated energy expenditure, or scores for restraint, disinhibition, or tendency towards hunger. These findings support previous work, which has consistently found that the portion size effect in adults persists across a range of individual characteristics (3, 4). Nevertheless, future studies should attempt to characterize individuals who are more responsive to variations in portion size and determine whether these responses are sustained, since even small increases in intake could accumulate over time. Identifying such characteristics will assist in the development of personalized interventions to attenuate the effect of large portions on intake.

One measure that did influence responsiveness to portion size was subject taste rankings of the foods. For all groups, the magnitude of the effect of portion size on intake of individual foods was related to the rankings of taste, as was observed in a previous study (18). Moreover, we extended this finding by demonstrating that not only the relative taste but also the absolute liking of individual foods affected intake in response to increasing portion size; the portion size effect on individual foods was greater for better-liked foods. Thus, methods to increase the liking of low-ED foods, in particular fruits and vegetables, have the potential to encourage preferential intake of these foods in the presence of large portions. Such methods include increasing the palatability of low-ED options (40–42) as well as repeated exposure to these foods (43, 44). Furthermore, this study and previous work have shown that serving larger portions can be used strategically to increase intake of healthful low-ED foods if they are well-liked (45) and relatively more palatable than the other foods available (18).

Because this study was designed to compare the portion size effect in individuals with and without extended training in portion-control strategies, there were some important differences between the subject groups. For instance, trained participants had a history of dieting and recent weight loss due to their participation in the trial. In addition, trained participants were significantly older and heavier than controls, although their estimated energy expenditure did not differ from that of controls with overweight and obesity. Only women were enrolled in this study, and although previous studies demonstrate similar portion size effects in men and women (24, 30, 33, 46), future research should evaluate the effect in men trained in portion control given the possibility of sex differences in compliance to the training or success in weight loss (47, 48). A potential confounding factor in this study is the demand characteristic associated with eating meals in controlled conditions. The trained participants may have responded differently to being under observation, since unlike the control subjects, they had previously participated in a weight-loss trial that was administered on the same campus. However, this potential influence was lessened by using different locations and different research staff for the two studies. Furthermore, despite the possibility of such a demand characteristic, the effect of portion size on the total amount consumed at the meal was similar between trained participants and controls.

In this study, the effect of portion size on the weight of food consumed and energy intake was found even in women with extended training in portion control. One explanation could be the difficulty of using visual cues to assess food amounts and energy content in order to adjust intake (37, 49). Despite the instruction that trained participants received in the trial, their estimates of energy intake from the three meals with the largest portions did not differ. Although differences in portion size can be difficult to detect, differences in food healthfulness and energy density are often more obvious. We found that ratings of the healthfulness of individual food items were closely correlated with the ED of the food, and these ratings did not differ across groups. Trained participants, however, applied their knowledge of healthfulness to reduce meal ED and moderate energy intake from larger portions, compared to controls. Thus, strategies to counteract the effect of portion size on energy intake should encourage preferential selection of healthful, lower ED foods as well as awareness of portion sizes.

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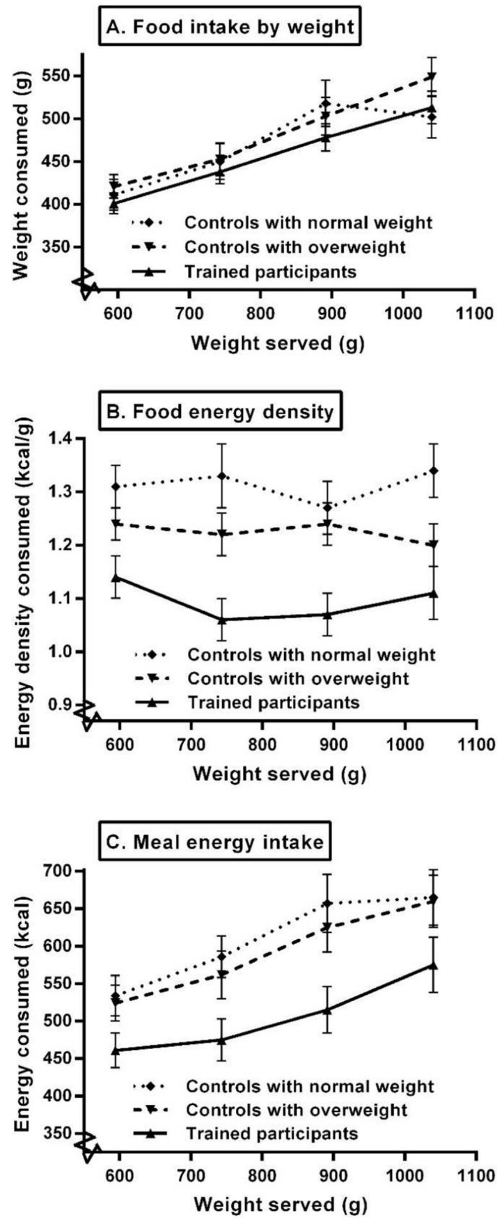

Figure 1.

Mean (±SEM) intakes of meals that were varied across 4 portion sizes, for trained participants (n=39), controls with overweight and obesity (n=34), and controls with normal weight: (n=29), as assessed by random coefficients models. Figure 1A: The weight of food consumed significantly increased as portions were increased ($P<0.0001$), and this effect did not differ across groups. Figure 1B: In trained participants, meal energy density (ED) initially decreased as portions were increased ($P=0.0006$), followed by an increase ($P=0.001$); in controls, meal ED was not affected by portion size (both $P>0.35$). Additionally, across all 4 portions, meal ED was significantly lower for trained participants than controls ($P<0.015$). Figure 1C: Meal energy intake increased as portions were increased ($P<0.0001$), and this effect did not differ across groups. However, across all 4 portions, trained participants had a lower energy intake than both control groups (P=0.023), whose intake did not differ.

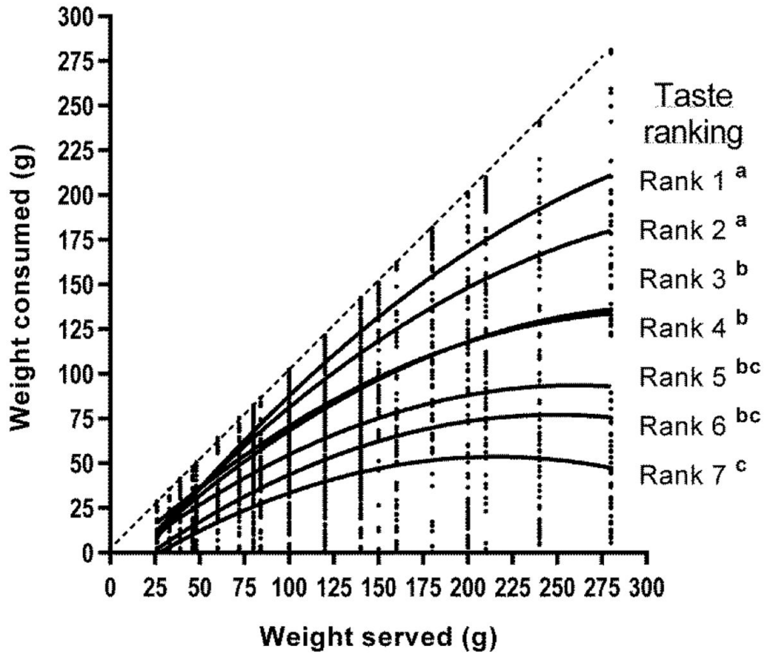

Figure 2.

Mean intake curves for the seven foods in the meal according to their taste ranking by the 88 women who completed this assessment. The curve for Rank 1 shows the mean portion size response for the food ranked as best-tasting; the highest-ranked food was different for different subjects. Subject rankings of food taste significantly influenced the trajectory of intake, according to a random coefficients analysis ($P<0.0001$). Foods ranked higher in taste showed a greater effect of portion size on intake. Taste rankings with different superscripts had significantly different linear coefficients for the intake curve. The scatterplots show individual food intakes and the dotted line represents consumption of the entire amount of food served (line of equality).

Table 1

Subject characteristics of 102 women[1]

Variable	Trained participants (n=39)	Controls with overweight and obesity (n=34)	Controls with normal weight (n=29)	Difference between groups (P-value)
Weight (kg)	86.4 ± 15.2 [a]	78.7 ± 13.3 [b]	60.3 ± 5.8 [c]	<0.0001
Body mass index (kg/m^2)	32.3 ± 4.8 [a]	29.5 ± 4.0 [b]	22.3 ± 1.6 [c]	<0.0001
Number with obesity (%)[2]	25 (64%)	14 (41%)	0 (0%)	
Number with overweight (%)[2]	14 (36%)	20 (59%)	0 (0%)	<0.0001
Number with normal weight (%)[2]	0 (0%)	0 (0%)	29 (100%)	
Age (years)	51.3 ± 11.6 [a]	42.9 ± 14.5 [b]	35.5 ± 14.6 [b]	<0.0001
Energy requirement (kcal/d)[3]	2354 ± 264 [a]	2318 ± 208 [a]	2079 ± 118 [b]	<0.0001
Dietary restraint score [4] (range 0–21)	14.4 ± 3.3 [a]	7.5 ± 4.0 [b]	8.0 ± 4.4 [b]	<0.0001
Disinhibition score [4] (range 0–16)	8.9 ± 3.9 [a]	7.3 ± 4.1 [ab]	5.4 ± 3.5 [b]	0.002
Hunger tendency score [4] (range 0–14)	5.6 ± 3.35	5.5 ± 2.9	5.1 ± 3.3	0.81

[1]Values are mean ± SD unless otherwise indicated.

[2]Obesity is defined as body mass index ≥ 30 kg/m^2; overweight as body mass index 25–29.9 kg/m^2; and normal weight as < 25 kg/m^2

[3]Energy requirements were estimated from sex, age, height, weight, and activity level (21).

[4]Scores from the Eating Inventory (22).

[a,b,c]Means with different superscript letters are significantly different according to a fixed effects model (P<0.05).

Table 2

Composition of test meals served to 102 women

Food served	Energy density (kcal/g)	100% portion sizes		125% portion sizes		150% portion sizes		175% portion sizes	
		Weight (g)	Energy (kcal)	Weight (g)	Energy (kcal)	Weight (g)	Energy (kcal)	Weight (g)	Energy (kcal)
Chicken, breaded pieces[a]	1.86	80	149	100	186	120	223	140	260
Pasta[b] with tomato sauce[c] and cheese[d]	1.38	160	221	200	277	240	332	280	387
Broccoli	0.45	80	36	100	45	120	54	140	62
Salad with light dressing	0.40	120	48	150	60	180	73	210	85
Garlic bread[e]	3.60	48	173	60	216	72	259	84	302
Grapes	0.69	80	55	100	69	120	83	140	97
Chocolate chip cookies[f]	4.84	26	126	33	157	39	189	46	220
Entire meal	1.36	594	808	743	1010	891	1212	1040	1414

[a] Bell & Evans, Fredericksburg, PA, USA.

[b] Barilla USA, Northbrook, IL, USA.

[c] Campbell's, Camden, NJ, USA.

[d] The Kraft Heinz Co., Glenview, IL, USA.

[e] Pepperidge Farm Inc, Norwalk, CT, USA.

[f] Nabisco, East Hanover, NJ, USA.

Table 3

Weight (g) of individual foods consumed at test meals by 102 women[1]

Food item	Trained participants (n = 39)				Controls with overweight and obesity (n=34)				Controls with normal weight (n=29)				Portion size effect[2] (P-value)	Group effect[3] (P-value)
	Portion size served				Portion size served				Portion size served					
	100%	125%	150%	175%	100%	125%	150%	175%	100%	125%	150%	175%		
Chicken, breaded pieces	63.9±3.6	67.0±4.6	72.7±5.1	74.4±5.6	67.0±3.3	72.8±4.6	81.4±6.2	87.5±6.5	65.6±3.3	79.4±4.8	93.8±5.8	80.9±7.8	0.002	0.07
Pasta with tomato sauce and cheese	82.1±8.5	76.4±10.4	77.4±11.6	95.4±11.7	94.8±9.3	96.5±10.8	96.5±12.1	118.1±14.1	97.1±10.2	112.8±12.4	116.7±15.8	118.3±15.1	0.005	<0.0001[4]
Broccoli	73.0±2.7	83.7±4.0	98.2±5.0	99.8±6.3	69.2±3.8	77.5±4.9	90.0±5.9	94.8±7.5	65.8±4.1	74.9±6.2	86.9±6.7	84.0±8.9	<0.0001	0.09
Salad with light dressing	91.7±5.3	114.8±5.6	122.7±9.3	134.9±9.9	92.5±4.4	108.0±6.2	118.2±8.3	132.9±10.1	77.8±7.1	81.9±9.5	107.4±10.4	96.7±12.4	<0.0001	<0.0001[5]
Garlic bread	20.3±2.6	21.3±3.2	24.2±3.5	31.4±4.1	32.8±2.7	34.8±3.4	42.6±3.2	38.1±4.0	31.9±2.9	34.1±3.6	39.8±4.6	44.4±4.5	0.043	0.004[6]
Grapes	61.1±4.2	67.4±4.6	74.5±5.5	67.5±7.0	55.8±4.7	52.7±6.0	62.3±7.4	66.5±8.3	60.0±4.8	55.1±7.0	63.1±8.5	63.1±9.2	0.11	0.12
Chocolate chip cookies	8.9±1.6	7.8±1.7	8.4±1.9	9.5±2.3	9.1±1.7	11.0±2.1	11.5±2.4	11.4±2.4	12.6±1.8	11.5±2.2	10.8±2.3	14.6±2.7	0.78	0.69

[1] Values are mean ± SEM

[2] Portion size effect: non-zero slope of food intake across the portions served, as assessed by a random coefficients model

[3] Group effect: difference in food intake across subject groups, as assessed by a random coefficients model

[4] For pasta, intake of trained participants < intake of controls with normal weight

[5] For salad, intake of trained participants and controls with overweight and obesity > intake of controls with normal weight

[6] For bread, intake of trained participants < both groups of controls

Table 4

Mean (± SEM) ratings of food characteristics at discharge by 102 women[1]

Food item	Liking rating	Healthfulness rating
Chicken, breaded pieces	76.2 ± 2.4 [b]	52.8 ± 1.8 [c]
Pasta with tomato sauce and cheese	64.2 ± 2.4 [c]	47.3 ± 1.8 [c]
Broccoli	80.5 ± 2.4 [ab]	89.5 ± 1.1 [a]
Salad with light dressing	83.1 ± 1.8 [ab]	81.2 ± 1.7 [b]
Garlic bread	77.8 ± 2.3 [b]	27.4 ± 2.1 [d]
Grapes	85.9 ± 1.7 [a]	92.1 ± 0.9 [a]
Chocolate chip cookies	58.2 ± 3.1 [c]	14.3 ± 1.5 [e]

[1] Ratings were assessed by visual analog scales and ranged from 0 to 100 mm. Both ratings differed significantly across food items according to a mixed model with repeated measures ($P<0.0001$). Means for the same rating with different superscripts were significantly different ($P<0.05$, adjusted for multiple comparisons by Tukey-Kramer method). There were no significant differences between trained participants and controls for these ratings.