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What is eaten when all of the foods at a meal are served in large portions?

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ABSTRACT

Portion size affects intake, but when all foods are served in large portions, it is unclear whether every food will be consumed in greater amounts. We varied the portion size (PS) of all foods at a meal to investigate the influence of food energy density (ED) on the PS effect as well as that of palatability and subject characteristics. In a crossover design, 48 women ate lunch in the laboratory on four occasions. The meal had three medium-ED foods (pasta, bread, cake) and three low-ED foods (broccoli, tomatoes, grapes), which were simultaneously varied in PS across meals (100%, 133%, 167%, or 200% of baseline amounts). The results showed that the effect of PS on the weight of food consumed did not differ between medium-ED and low-ED foods ($p < 0.0001$). Energy intake, however, was substantially affected by food ED across all portions served, with medium-ED foods contributing 86% of energy. Doubling the portions of all foods increased meal energy intake by a mean (±SEM) of 900 ± 117 kJ (215 ± 28 kcal; 34%). As portions were increased, subjects consumed a smaller proportion of the amount served; this response was characterized by a quadratic curve. The strongest predictor of the weight of food consumed was the weight of food served, both for the entire meal ($p < 0.0001$) and for individual foods ($p = 0.014$); subject characteristics explained less variability. Intake in response to larger portions was greater for foods that subjects ranked higher in taste ($p < 0.0001$); rankings were not related to food ED. This study demonstrates the complexity of the PS effect. While the response to PS can vary between individuals, the effect depends primarily on the amounts of foods offered and their palatability compared to other available foods.

1. Introduction

Increases in portion size (PS) have a substantial effect on energy intake and have been implicated as an environmental factor contributing to obesity rates (Kral & Rolls, 2011; Livingstone & Pourshahidi, 2014; Rolls, 2014). In controlled experiments, serving a larger portion of a single food increases its consumption. Although it is common in the current eating environment for all available foods to be oversized, few studies have tested the effects of simultaneously increasing the PS of multiple foods. Such investigations are needed because the portion size effect may vary for different foods at a meal. For example, intake in response to large portions may be affected by the energy density (ED) or the liking of the various foods offered; additionally, intake of one food may influence consumption of the others. Such differential changes could moderate or enhance the effect of portion size on energy intake of the entire meal. The purpose of this experiment was to investigate the effects of portion size on intake when all foods in a meal were varied simultaneously, and to explore whether the response to PS was influenced by food-related properties including ED and palatability, or by subject characteristics such as body size, age, and measures of eating behavior.

Controlled experiments in adults have shown that serving a larger portion of a single food or beverage, without changing the accompanying foods, leads to increased intake of the varied item (Diliberti, Bordi, Conklin, Roe, & Rolls, 2004; Flood, Roe, & Rolls, 2006; Kral, Roe, & Rolls, 2004; Rolls, Morris, & Roe, 2002; Rolls, Roe, & Meengs, 2010; Rolls, Roe, Kral, Meengs, & Wall, 2004; Rolls, Roe, Meengs, & Wall, 2004). The few experiments that simultaneously increased the PS of all foods at meals found that this led to increases in total intake, but effects on individual foods were

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not systematically reported (Kelly et al., 2009; Levitsky & Youn, 2004; Rolls, Roe, & Meengs, 2006a, 2006b; Rolls, Roe, & Meengs, 2007). In two experiments that varied all foods, some data suggested that the PS effect was related to the ED of the foods. In the first study, it was observed that serving larger portions over two days led to increased intake of high-ED snacks and beverages but not the accompanying low-ED options (Rolls et al., 2006a). In an 11-day study, the magnitude of the portion size effect across 161 foods was related to the ED of the foods (Rolls et al., 2007). It is possible that this relationship between PS and ED occurred because the higher-ED foods were more palatable than those lower in ED (Drewnowski, 1998); however, the influence of palatability on the relationship was not reported. In the present study, we tested the hypotheses that serving larger portions of all foods at a meal would lead to a greater increase in consumption of higher-ED foods than lower-ED foods and that this effect would be related to the palatability of the individual foods.

Another aim was to assess the influence of subject characteristics on the PS effect. Several recent reviews have focused on identifying individual differences in response to PS, and have come to different conclusions about variability across individuals (Benton, 2015; English, Lasschuijt, & Keller, 2015; Steenhuis & Vermeer, 2009; Zlatevska, Dubelaar, & Holden, 2014). The ability to identify influential subject characteristics could be improved by better statistical modeling of the portion size effect. In our early experimental studies of portion size, we observed that the mean trajectory of intake across four or more portion sizes was curvilinear: when two smaller portions were served, intake increased steeply as subjects consumed most of the available food, but when two larger portions were served, intake increased less steeply (Rolls et al., 2002; Rolls, Roe, Kral et al., 2004; Rolls, Roe, Meengs et al., 2004). Neither we nor others, however, have previously accounted for this non-linearity in analyzing the food intake of individuals. Modeling the curvilinear relationships could help to characterize the portion size effect when all foods are available in large amounts, and thus help to determine whether it is more effective to focus interventions on all foods, foods with certain properties, or particular types of consumers.

2. Methods

2.1. Experimental design

This experiment used a crossover design with repeated measures within subjects, so that subjects served as their own controls. Once a week for four weeks, participants came to the laboratory and were served a lunch consisting of six foods: three medium in energy density and three low in energy density. Across the four meals, participants were served either baseline (100%) portions of all foods or 133%, 167%, or 200% of the baseline amounts. The order of the portion size conditions was counterbalanced across subjects using Latin squares, and subjects were randomly assigned one of the condition sequences.

2.2. Subject recruitment and characteristics

Women aged 20–45 years were recruited using notices in local newspapers, in the community, and on university websites. Respondents were interviewed by telephone to determine whether they met the following initial criteria: had a reported body mass index between 18 and 40 kg/m^2, regularly ate three meals per day, and were willing to eat the foods served in the experimental meal. Potential subjects were excluded if they were dieting to gain or lose weight, had food allergies or restrictions, were taking medications known to affect appetite, were smokers or athletes in training, or were pregnant or breastfeeding.

Potential subjects who met the initial criteria came to the laboratory to complete the following questionnaires: the Zung Self-Rating Scale (Zung, 1986), which assesses symptoms of depression; the Eating Attitudes Test (Garner, Olsted, Bohr, & Garfinkel, 1982), which evaluates disordered attitudes toward food; and the Eating Inventory (Stunkard & Messick, 1985), which assesses dietary restraint, disinhibition, and tendency toward hunger. The height and weight of potential participants (without shoes and coats) was measured using a stadiometer and an electronic scale (Seca North America, Chino, CA, USA). Individuals were only eligible for study if they scored ≤40 on the Zung Self-Rating Scale, scored ≤20 on the Eating Attitudes Test, and had a measured body mass index between 18 and 40 kg/m^2. Individuals gave signed informed consent and were financially compensated for their participation in the study. The study protocol was approved by the Office for Research Protections of The Pennsylvania State University.

The sample size for the experiment was based on data from previous studies conducted in the laboratory (Kral et al., 2004; Rolls et al., 2002; Rolls, Roe, Meengs et al., 2004). Only women were included as subjects in this experiment in order to reduce the variability in intake and increase the statistical power. The minimum clinically significant difference in meal energy intake was taken to be 167 kJ (40 kcal), or about 5–10% of women's meal intakes in previous studies. A power analysis showed that a sample of 43 subjects would allow the detection of this difference with >80% power at a significance level of 0.05. Fifty-one women were enrolled in the study, but two subjects failed to attend scheduled meals and did not complete the study. The data of one additional subject was excluded for having undue influence on the results according to the procedure of Littell, Milliken, Stroup, Wolfinger, and Schabenberger (2006); at one meal this subject ate only broccoli and grapes (623 kJ; 149 kcal). Thus, the analysis included data from 48 women; 34 (71%) were normal weight, 8 (17%) were overweight, and 6 (13%) were obese. Additional subject characteristics are shown in Table 1.

2.3. Experimental meals

The experimental meal consisted of the six foods shown in Table 2, which were selected to vary in energy density (ED) and to include the components of a typical meal. The portion sizes in the baseline (100%) meal were chosen to provide generous amounts of each of the six foods, allowing for variability in preference for the different foods across subjects. The portion sizes of all foods in the other experimental conditions were simultaneously increased to 133%, 167%, and 200% of the baseline amounts. Since the amounts of the low-ED and medium-ED foods were increased proportionally,

Table 1
Characteristics of the 48 women who participated in the study.

Characteristic	Mean ± SEM	Range
Age (y)	28.6 ± 1.2	20.0–45.5
Weight (kg)	66.3 ± 2.2	49.9–117.1
Height (m)	1.65 ± 0.01	1.50–1.78
Body mass index (kg/m^2)	24.4 ± 0.7	18.6–39.3
Estimated energy expenditure (kJ/d)[a]	9321 ± 138	8050–12155
Estimated energy expenditure (kcal/d)[a]	2228 ± 33	1924–2905
Eating Attitudes Test score	4.0 ± 0.5	0–13
Restraint score[b]	8.1 ± 0.6	0–18
Disinhibition score[b]	5.4 ± 0.5	0–15
Hunger tendency score[b]	4.6 ± 0.4	0–12

[a] Energy expenditure was estimated from sex, age, height, weight, and activity level (Institute of Medicine, 2002).
[b] Scores from the Eating Inventory (Stunkard & Messick, 1985).