Variations in Cereal Volume Affect the Amount Selected and Eaten for Breakfast

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ABSTRACT
Food volume could influence both the portions that people take and the amount that they eat, but these effects have had little investigation. The influence of food volume was tested by systematically reducing the flake size of a breakfast cereal so that the cereal was more compact and the same weight filled a smaller volume. In a crossover design, 41 adults ate cereal for breakfast once a week for 4 weeks during 2011 and 2012. The cereal was either standard wheat flakes or the same cereal crushed to reduce the volume to 80%, 60%, or 40% of the standard. A constant weight of cereal was provided in an opaque container and participants poured the amount they wanted into a bowl, added fat-free milk and noncalorie sweetener as desired, and consumed as much as they wanted. Results from a mixed linear model showed that as flake size was reduced, subjects poured a smaller volume of cereal, but still took a greater amount by weight and energy content (both P values <0.0001). Despite these differences, subjects estimated that they had taken a similar number of calories of all versions of the cereal. They ate most of the cereal they took, so as flake size was reduced, breakfast energy intake increased from a mean±standard error of the mean of 286±18 kcal to 358±19 kcal, an increase of a mean±standard error of the mean 34%±7% ($P<0.0001$). These findings demonstrate that variations in food volume associated with the size of a food's individual pieces affect the portion served, which in turn affects energy intake.
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NATIONAL DIETARY GUIDELINES DEFINE RECOMmended amounts of most food groups in terms of volume.[1] For some voluminous foods, such as raw leafy greens[2] and puffed cereals,[3] the recommended amount is larger than for more compact versions of these foods. For other foods, however, recommended amounts have not been adjusted for variations in physical properties that affect volume, such as aeration, cooking, and the size and shape of individual pieces. The food weight and energy required to fill a given volume can vary. Such variations in the energy content of recommended amounts could be a challenge to the maintenance of energy balance. The present study tests the hypothesis that a physical property of food affecting its volume, specifically the size of the individual pieces, will influence the amount served, which will in turn affect energy intake.

Food volume is of particular interest because of the cues it provides about portion size. Although many studies have demonstrated that portion size affects energy intake,[4-9] in most of these studies the amount of available food varied simultaneously in weight and volume. Food volume can be dissociated from food weight by varying the degree of aeration, and studies have shown that incorporating air into extruded snacks[10] or milkshakes[11] to increase the volume led to a reduction in energy intake. Food volume can also be influenced by variations in the size and shape of individual food pieces because the same weight of food in large or irregular pieces packs less closely together. In the present study, the size of food pieces was systematically varied in order to determine for the first time whether the resulting differences in volume, independent of weight, affect the amount of food taken and consumed. Breakfast cereal was chosen as the test food because it has a wide variety of forms with pieces in many sizes and shapes, which could make it difficult to select an appropriate portion.

METHODS

Study Design

This study used a crossover design, in which subjects were presented all of the experimental meals in a specified sequence over time, thus serving as their own controls. Once a week for 4 weeks, participants ate cereal for breakfast in the laboratory. Across meals, the cereal was either standard wheat flakes or the same cereal crushed to reduce the flake size and volume to 80%, 60%, or 40% of the standard. The order of presenting the four experimental meals was counterbalanced across subjects using Latin squares, so that in each study week the four versions of cereal were served with similar frequency.

Participants

Participants were recruited from the local community and university campus using newspapers, leaflets, and electronic

newsletters. Potential subjects came to the laboratory and had their height and weight measured and completed demographic and screening questionnaires. Women and men were eligible for the study if they were 19 to 45 years old, had a body mass index of 18.5 to 35.0, regularly ate breakfast, ate cereal occasionally, and were willing to eat wheat flakes with fat-free milk and without sugar. Individuals were not eligible if they were dieting, athletes in training, pregnant or breastfeeding, smokers, or using medications that affect appetite or food intake. The Institutional Review Board of The Pennsylvania State University approved the protocol. Subjects were told that the study purpose was to investigate the effects of a breakfast meal; they provided written informed consent and were financially compensated for their participation. The study was conducted between July 2011 and April 2012.

Forty-five participants were enrolled, but 4 did not complete the study; 2 withdrew for personal reasons and 2 failed to attend scheduled meals. The final sample consisted of 41 subjects (24 women; 17 men) with a mean age±standard error of mean (SEM) of 27.2±1.2 years and body mass index of 24.2±0.6. Seven participants (17%) were overweight and 6 (15%) were obese. Mean±SEM scores on the Eating Inventory[12] were 9.2±0.7 for dietary restraint (potential range=0 to 21), 4.3±0.4 for disinhibition (potential range=0 to 16), and 3.6±0.4 for tendency toward hunger (potential range=0 to 14).

Test Foods and Meal Procedures

In order to maintain consistent taste and nutrient composition, the same type of cereal was served at all meals (Wheaties; General Mills, Inc; energy density 3.5 kcal/g). For the cereal with standard (100%) flake size, the commercially available product was used; measurements showed that 140 g of this cereal filled a 1,000-mL beaker. For the remaining meals, the cereal was crushed, following a uniform procedure: 140 g standard cereal was spread within a sealed plastic bag and crushed with a rolling pin a specified number of times. The crushed cereal was measured in a 1,000-mL beaker to ensure that the volume was reduced to 80%, 60%, or 40% (Figure 1A). At each meal, the weight of cereal provided was 280 g and the volume differed according to the flake size (2,000, 1,600, 1,200, or 800 mL).

Subjects were instructed not to eat any food after 10 PM the night before and during the morning before each breakfast, and to drink nothing but water during this time. Upon arrival for breakfast, subjects were seated in individual cubicles and were not allowed reading material or other distractions. Participants rated their hunger and fullness using 100-mm visual analog scales,[13] which were anchored on the left with "Not at all hungry" and on the right with "Extremely hungry," with similar anchors for fullness. Subjects were then brought the cereal in a 3.8-L opaque container typically used for dispensing cereal. The opening at the top of the container did not allow the contents to be easily viewed, but was large enough for the cereal to flow freely. Participants were instructed to pour the amount of cereal they would like for their breakfast into a 900-mL bowl and were informed that they could not request additional cereal; the cereal container was then removed. Next, participants were brought a nonopaque container of 475 g fat-free milk and instructed to add milk to the cereal as desired; the milk container was then removed. Subjects estimated the number of calories of cereal they had poured in the bowl and rated cereal characteristics (pleasantness of appearance, taste, and texture) using visual analog scales after taking one bite of the cereal. Noncalorie sweetener was provided with the meal and a preselected noncalorie hot beverage was served, to which creamer and noncalorie sweetener could be added as desired. Participants were instructed to consume as much of the meal as they wanted and to take as much time as they wanted.

Outcome Assessments

Containers of cereal and milk were weighed before and after serving to determine the weight that subjects had poured. The volume of poured cereal was calculated from the weight using the ratio for each cereal flake size (2,000, 1,600, 1,200, or 800 mL per 280 g cereal). Although subjects ate most of the cereal they poured, any uneaten cereal was strained of milk so that the weights of the remaining cereal and milk could be determined separately. Energy intakes of each breakfast item were calculated from the difference between pre- and post-meal weights and using data from a standard nutrient database.[14]

Data Analysis

Outcomes were analyzed using a mixed linear model with repeated measures. The fixed effects in the model were cereal volume (100%, 80%, 60%, or 40%), study week, and subject sex; subjects were treated as a random effect. The Tukey-Kramer method was used to adjust significance levels for multiple pairwise comparisons. Study outcomes were the volume and weight of cereal poured and consumed; cereal and meal energy intakes; and subject ratings of hunger, fullness, and cereal taste, texture, and appearance. Accuracy of calorie estimation was defined as the difference between the number of calories in the cereal poured at each meal and the subject's estimate of this number. Analysis of covariance was used to determine whether the relationship between cereal volume and intake was affected by subject characteristics of age, sex, body mass index, dietary restraint, disinhibition, tendency toward hunger, and calorie estimation accuracy. Results are reported as mean±SEM and were considered significant at $P<0.05$. Statistical analyses were conducted using SAS software (version 9.3, 2011, SAS Institute Inc).

RESULTS AND DISCUSSION

As cereal flake size was reduced, participants decreased the volume of cereal they poured from an average of 441 mL to 262 mL (1.9 cups to 1.1 cups) ($P<0.0001$; Table). Despite this reduction in volume selected, there was a significant increase in the weight and energy of cereal taken as flake size was reduced ($P<0.0001$; Table). In contrast, the amount of milk poured was relatively consistent, differing only for the smallest flake size (Table). Figure 1B shows that, although subjects took more cereal energy as flake size was reduced, their estimates of the number of calories taken did not change ($P=0.21$). For the two cereals with the largest flakes, calorie estimates were fairly accurate, but for the two cereals