Effects of repeated exposure on liking for a reduced-energy-dense food\textsuperscript{1–3}

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ABSTRACT

Background: Reduced-energy-dense diet foods are often formulated to match the sensory characteristics of their regular-energy-dense counterparts. However, the extent to which attitudes toward a reduced-energy-dense food remain constant, even after repeated ingestion, remains to be explored systematically.

Objective: The objective was to determine whether liking, “expected satiety,” and “expected satiation” change after repeated exposure to a familiar food that has been reduced in energy density. Expected satiety and expected satiation refer to the extent to which foods are expected to stave off hunger and to deliver “fullness,” respectively, when compared on a calorie-for-calorie basis.

Design: Participants (n = 36) consumed either reduced-energy-dense (374 kcal) or standard-energy-dense (567 kcal) spaghetti Bolognese for lunch over 5 test sessions. During each test session, liking for the spaghetti Bolognese was assessed, together with measures of expected satiety and expected satiation.

Results: Participants in the reduced-energy-dense condition reported a decrease in liking for the spaghetti Bolognese over the test sessions (~30%), whereas liking in the standard condition remained constant [condition (reduced/standard) x session (1–5) interaction, P < 0.008]. By contrast, both expected satiation and expected satiety remained similar across conditions and test sessions.

Conclusions: Over time, the pleasantness of a reformulated low-energy-dense food can decrease, and this may undermine its efficacy as a weight-loss product. It remains to be determined whether a longer period of “flavor-nutrient learning” is needed for shifts in expected satiety and expected satiation to be observed. Am J Clin Nutr 2010;91:1584–9.

INTRODUCTION

The World Health Organization recommends that overweight and obesity should be addressed by reducing the consumption of low-energy-dense foods (1). Commercially, many foods are now available in reduced-energy-dense (eg, “diet”) varieties. This is relevant, because food-intake studies suggest that humans are insensitive to differences in energy density and that feelings of fullness (satiation) tend to be determined by the volume of food that is consumed and not by its energy content (2, 3). Critically, this insensitivity persists even over several days (4). Notwithstanding these findings, 2 important questions about the use of diet foods remain.

First, reduced-energy-dense foods are often formulated to match the sensory characteristics of their regular-energy-dense counterparts. However, the extent to which liking for a reduced-energy-dense food remains constant, even after repeated ingestion, is yet to be explored systematically. Several studies (eg, references 5, 6) show that liking for a novel flavor increases after it has been incorporated into a high-energy-dense food and consumed several times. However, it remains to be determined whether this “flavor-nutrient learning” decreases the palatability of a reduced-energy-dense food over time.

Second, in addition to affective characteristics, learning might also modify other beliefs about the consequences of consuming reduced-energy-dense foods. Recently, researchers in our laboratory have carried out calorie-for-calorie comparisons of expectations associated with the consequences of consuming different foods. Expected satiety and expected satiation refer to the extent to which foods are expected to stave off hunger and to deliver “fullness,” respectively, when compared on a calorie-for-calorie basis (7, 8). Importantly, familiarity changes these expectations (7). Indeed, expected satiety differentially shifts (via flavor-nutrient learning) even after a single exposure to an otherwise identical high- or low-energy-dense novel food (9). The prospect that expectations change after exposure to a reduced-energy-dense food warrants investigation because expected satiety and expected satiation are excellent predictors of portion-size selection (in kcal) (8, 10).

To explore these questions, we took an already familiar food (spaghetti Bolognese) and presented it to participants over 5 days in either a reduced- or a “standard”-energy-dense form. Over this period, we measured changes in liking for spaghetti Bolognese (question 1) and explored shifts in expected satiety and expected satiation (question 2).

SUBJECTS AND METHODS

Subjects

Thirty-six participants (27 women and 9 men) were recruited from the staff and student populations at the University of Bristol

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(United Kingdom). Vegetarians and vegans were excluded, together with participants who declared either a food allergy or food intolerance. Our sample had a mean body mass index (BMI; in kg/m²) of 24.1 (SD = 3.4). All participants received £50 for their assistance. Ethical approval was granted (22 May 2008) by the University of Bristol’s Faculty of Science Human Research Ethics Committee. Initial recruitment began on 9 June 2008.

Empyreal Foods spaghetti Bolognese

In the reduced-energy-dense condition, the participants consumed a 374-kcal portion of a reduced-energy-dense (84 kcal/100 g) spaghetti Bolognese (Be Good to Yourself; supplied by Sainsbury’s Supermarkets Ltd, Holborn, London, United Kingdom). In the standard-energy-dense condition, participants received a 567-kcal portion of a regular-energy-dense version (141 kcal/100 g) spaghetti Bolognese (Empyreal Foods). In the standard-energy-dense condition, participants received a 567-kcal portion of a regular-energy-dense version (141 kcal/100 g) (Italian Range; Sainsbury’s Supermarkets Ltd). (See Table 1 for the macronutrient composition of these foods.) Both versions weighed ~400 g and were served on a dinner plate, together with packaging that depicted a fictitious brand logo (Empyreal Foods).

Measures

All measures were elicited by using custom written software (available from the authors on request) written in Visual Basic (version 6.0 distributed by Microsoft; Microsoft Corp, Redmond, WA).

Expected satiety

Expected satiety (the extent to which foods are expected to stave off hunger when compared on a calorie-for-calorie basis) was assessed in the Empyreal Foods spaghetti Bolognese (the consumed food) and also in 4 comparison foods: pasta and sauce [egg penne pasta (supplied by Sainsbury’s Supermarkets Ltd) and sundried stir-in tomato sauce (supplied by Dolmio, Masterfoods, Melton Mowbray, Leicestershire, United Kingdom)], oven fries (supplied by McCain Foods Ltd, Scarborough, North Yorkshire, United Kingdom), chicken tikka massala (supplied by Sainsbury’s Supermarkets Ltd), and pizza [supplied by Goodfella’s UK (Green Isle Foods Ltd, Salford Quays, Manchester, United Kingdom)]. (See Table 1 for the macronutrient composition of these foods.) In this measure we included comparison foods to assess the extent to which differential effects of exposure to the standard- or reduced-energy-dense spaghetti Bolognese generalize to other types of food. Each participant evaluated these foods separately and in a different randomly assigned order.

During each evaluation, participants were shown a picture (182 × 160 mm: actual displayed size) of a test food on a visual display unit. Participants were instructed to “Select the amount of food that would be needed to stave off hunger until you eat again at dinnertime. (Press left arrow for less and right arrow for more).” The left and right arrow key caused a smaller and a larger portion, respectively, to be displayed. Continuous depression of either key gave the impression that the change in portion size was “animated.” Fifty-one images were taken of each type of Empyreal Food spaghetti Bolognese (a different set for the reduced- and the standard-energy-dense version) and of each comparison food. Picture number 25 showed a 250-kcal portion. Pictures 0 and 50 displayed 0.2 and 5 times this amount, respectively. Across this range, the portion size increased in equally spaced logarithmic steps. This method of adjustment has been developed and used in other studies carried out in our laboratory (8, 11).

For each food, a set of 51 images was obtained by using a high-quality digital camera that was mounted directly overhead. In each case, the foods were arranged on a 255-mm-diameter white plate. Particular care was taken to ensure identical lighting and arrangement of the plate across foods and portion sizes. The name of the food and (where appropriate) brand information (ie, logos, etc) were included in the lower left corner of each image. Images of both the reduced and the standard spaghetti Bolognese were labeled “spaghetti Bolognese” and included the same Empyreal Foods logo.

The 2 versions of spaghetti Bolognese had a similar appearance but differed in their energy density. Rather than obtaining the expected satiety estimates by using images of only the reduced- or only the standard-energy-dense version, in each condition, half of the participants were shown pictures of the reduced-energy-dense version and half were shown pictures of the standard-energy-dense version. This allocation remained in other measures (described below). Therefore, we used the average energy density [(1.41 kcal/g [standard] + 0.83 kcal/g [reduced])/2 = 1.12 kcal/g] of the standard and the reduced version to equate responses derived from each set of images. Specifically, results were standardized by multiplying the weight of the selected portion (in g) by this intermediate energy density. For each participant, this produced an “expected-satiety score” (in kcal) for the Empyreal Foods spaghetti Bolognese.

<table>
<thead>
<tr>
<th>Food type</th>
<th>Carbohydrate</th>
<th>Protein</th>
<th>Fat</th>
<th>Energy density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasta and sauce</td>
<td>14</td>
<td>3.5</td>
<td>3.5</td>
<td>1.69</td>
</tr>
<tr>
<td>Fries (oven)</td>
<td>32.4</td>
<td>3.4</td>
<td>4.9</td>
<td>1.72</td>
</tr>
<tr>
<td>Chicken tikka massala</td>
<td>11</td>
<td>5.5</td>
<td>4</td>
<td>1.56</td>
</tr>
<tr>
<td>Pizza</td>
<td>40.2</td>
<td>16.5</td>
<td>13.2</td>
<td>3.46</td>
</tr>
<tr>
<td>Empyreal Foods–labeled spaghetti Bolognese</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard-energy-dense condition</td>
<td>16.2</td>
<td>7.2</td>
<td>5.3</td>
<td>1.41</td>
</tr>
<tr>
<td>Reduced-energy-dense condition</td>
<td>12.9</td>
<td>4.8</td>
<td>1.4</td>
<td>0.83</td>
</tr>
</tbody>
</table>

1 Values are given per 100 g food.
All participants saw the same comparison foods. Therefore, their associated expected-satiety scores were based simply on the energy value of the selected portion (in kcal).

**Expected satiation**

We quantified the expected satiation (the extent to which foods are expected to be filling when compared on a calorie-for-calorie basis) associated with the Empyreal Foods spaghetti Bolognese by using a technique previously introduced by Brunstrom and Shakeshaft (8). Measures were obtained by using images and food logos from the expected-satiety task. Participants were shown a picture of a 250-kcal portion (picture number 25) of spaghetti Bolognese. During each trial, the participant changed the amount of this comparison food. As in the expected-satiety task, this was achieved by depressing the arrow keys on a keyboard. For each pairing, the participant was asked the following: “Imagine you are having the plate of Empyreal Foods spaghetti Bolognese for lunch TODAY (look at the picture on the left). Now look at the food picture on the right. Match the picture on the right so that both foods will leave you feeling EQUALLY FULL (immediately after they have been eaten).” This method of adjustment provides a point of subjective equality (PSE). The PSE represents the amount (in kcal) of the comparison food that is expected to be as filling as the Empyreal Foods spaghetti Bolognese. As in previous studies (7–10), our choice of comparison foods was motivated by a concern to present stimuli that are highly familiar. Here, selection was based on familiarity data obtained from a similar population (10). By choosing highly familiar comparison foods, we sought to minimize variance generated by uncertainty about the satiating properties of the foods. Accuracy was further improved by obtaining several estimates with the use of different comparison foods.

Each participant completed a single block of 4 trials during which each comparison food was presented. The order of these foods was randomly assigned across participants. All images were 182 × 160 mm (actual displayed size). As in the expected-satiety task, half of the participants responded to images of the reduced-energy-density spaghetti Bolognese and half responded to images of the standard-energy-density spaghetti Bolognese (counterbalanced across conditions). The reduced- and standard-energy-density 250-kcal portions weighed 301 and 177 g, respectively. As with expected-satiety scores, PSE scores were standardized to accommodate this difference. In this case, expected-satiation scores were calculated by dividing each PSE by one of these weights, as appropriate. Each participant generated 4 expected-satiation scores, one for each comparison food.

**Liking**

Participants rated their liking for the Empyreal Foods spaghetti Bolognese and for each of the comparison foods. Measures of liking were obtained from the comparison foods to establish the extent to which any shifts in the valance of the spaghetti Bolognese generalize to other uneaten foods.

In each trial, a picture of a 250-kcal portion was presented in the center of the computer screen (127 × 184 mm: actual displayed size). As in other tasks, images were presented in combination with brand information and associated food name. Below each image, a 154-mm visual analog rating scale was displayed. This rating was headed, “How much do you like the taste of this food?” with end anchor points “not at all” and “extremely like.” Participants provided ratings by marking the scale using a computer mouse. The order of the foods was randomly assigned within and across participants. Responses were coded on a 0–100 scale.

**Familiarity**

Participants were shown a picture of each food in turn. In each case, they were encouraged to reflect on their general familiarity with the food (ie, irrespective of the food’s brand or origin) and to indicate how often they consume the food by selecting one of the following: “never,” “less than once per year,” “once a year,” “monthly,” and “every week.” These responses were coded 1–5, respectively.

**Procedure**

During recruitment, participants were informed (via e-mail and poster advertisements) that the study had been commissioned by a “leading food manufacturer” to investigate beliefs about a new food (Empyreal Foods spaghetti Bolognese) that they planned to launch in the United Kingdom. This cover story was included to detract attention away from the aims of the study. We reasoned that this approach might also limit the extent to which expectations might be guided by experience with other commonly consumed varieties.

Participants attended 5 lunchtime sessions, which were held between 1200 and 1400. Each participant arrived at the same time on consecutive days (Monday–Friday). During each session, participants reported the number of hours since their last meal and then rated their hunger and fullness by using a computerized 154-mm visual analog rating scale. This rating scale was headed, “How (hungry/full as appropriate) do you feel right now?” with anchor points “not at all” and “extremely” (hungry/full as appropriate). These measures were taken to explore potential baseline differences in appetite across conditions. The participants were shown a portion of Empyreal Foods spaghetti Bolognese and were asked to consume a mouthful. They then provided measures of liking, expected satiation, and expected satiety (in this order). One possibility is that shifts in expectations are associated with the hunger and fullness that is experienced after consuming the spaghetti Bolognese. To explore this idea, after consuming the remaining food, we asked participants to rate their hunger and fullness for a second time. Throughout the experiment condiments (eg, salt and pepper) were unavailable.

At the beginning of the first session the participants provided signed consent and completed the measure of food familiarity. Before each session the participants were instructed to consume their normal breakfast and to abstain from eating between meals (ie, between breakfast and the test session and between the test session and dinner). To increase compliance with this request, participants completed a food diary over the 5 test days.

At the end of the final test session the participants completed the restraint section of the Dutch Eating Behavior Questionnaire (DEBQ) (12). Measures of height and weight were then taken, and all participants were debriefed and thanked for their assistance. These additional measures were included to assess the match in participant characteristics across conditions.
Statistics

Independent-sample t tests were used to explore differences in baseline measures of appetite and participant characteristics across conditions. For each participant and each test session, we calculated a mean score on the basis of the expected satiety associated with the 4 comparison foods. Hereafter, we refer to these means as “expected-satiety comparison scores.” By using a $5 \times 2 \times 2$ mixed-model analysis of variance (ANOVA), we explored the effects of the test session (day 1 to day 5), condition (reduced-/standard-energy-dense), and food type (spaghetti Bolognese/expected-satiety comparison score) on expected satiety. For each participant and each test session, separate hunger and fullness “change scores” were calculated on the basis of the difference between ratings taken before and after consuming the spaghetti Bolognese. Similar $5 \times 2 \times 2$ mixed-model ANOVAs were used to explore both sets of change scores (hunger and fullness) and ratings of liking.

In the expected-satiety task, the Empyreal Foods spaghetti Bolognese was paired with each comparison food. This yielded 4 expected-satiety scores. For each participant, a mean expected-satiety score was calculated, and this was submitted to a $5 \times 2 \times 2$ (test day) $\times$ 2 (condition) mixed-model ANOVA.

All statistical analyses were performed by using SPSS version 12.0.1 (SPSS Inc, Chicago, IL).

RESULTS

Participant characteristics

Eighteen participants were tested in each condition. In the reduced condition, 14 were women and 4 were men. In the standard condition, 13 were women and 5 were men. For each condition, the average age, DEBQ restraint score, and BMI of the participants, together with the average familiarity scores for the spaghetti Bolognese and each comparison food, are reported in Table 2. For each of these variables, an independent t test revealed no significant difference between conditions (all $P > 0.05$).

Expected satiety

Our ANOVA revealed a main effect of food type. The comparison foods had lower expected satiety scores [$F(1, 136) = 18.0, P < 0.01$]. However, this main effect was not moderated by condition, which indicates that learning failed to occur. Consistent with this interpretation, expected-satiety scores for the spaghetti Bolognese remained very similar across conditions and across test sessions (see Figure 1). All other main effects and interactions failed to reach significance (all $P > 0.05$).

Expected satiation

Mean expected-satiety scores across the 5 test sessions are shown in Figure 2. Separate values are provided for the reduced and the standard condition. As with expected satiety, our ANOVA revealed little evidence that the spaghetti Bolognese differed in expected satiation across conditions or across test sessions. All main effects and interactions failed to reach significance (all $P > 0.05$).

Liking

Our ANOVA revealed a significant 3-way interaction between food type, test session, and condition [$F(4, 136) = 3.3, P = 0.012$]. This interaction is plotted in Figure 3. Liking for the spaghetti Bolognese decreased over the test sessions but only in the reduced-energy-dense condition (see Figure 3A). By
All tests failed to reach significance (interaction failed to predict liking for the comparison foods the reduced condition \(n = 3.6, P = 0.012\)). For the Empyreal Foods–labeled spaghetti Bolognese (A), the \(\text{spaghetti/comparison foods} \times \text{test session} = 0.008\), whereas for the comparison foods (B), the same interaction was not significant \((P > 0.05)\).

Contrast, liking scores for the comparison foods were similar across conditions and remained constant across test days (see Figure 3B).

Liking scores for the spaghetti Bolognese and the comparison foods were then analyzed with separate ANOVAs. This process confirmed that liking for the spaghetti Bolognese was moderated by an interaction between test session and condition \((F(4, 136) = 3.3, P = 0.008)\); whereas for the comparison foods (B), the same interaction was not significant \((P > 0.05)\).

Measures of appetite

We compared the initial ratings of hunger and fullness and the self-reported number of hours since last eating across conditions. All tests failed to reach significance \((P < 0.05)\). Similarly, our analysis of hunger and fullness change scores revealed no significant interactions or main effects.

DISCUSSION

Dieters are encouraged to select weight-loss products that have a reduced energy density. The underlying logic is that a reduction in energy density promotes a negative energy balance, which leads to a lower BMI. However, if relearning occurs, then the efficacy of weight-loss products may become compromised. In this study, we considered 2 plausible yet previously unexplored ways in which this might occur. Specifically, we focused on learned changes in liking (question 1) and expected satiation/satiety (question 2). In relation to expected satiation and satiety, we observed little evidence that they change after exposure to a reduced-energy-dense formulation of a familiar food. By contrast, this exposure caused a reduction in the food’s palatability but had no effect on liking for a set of control (comparison) foods.

Several studies report an increase in the palatability of a novel flavor after it has been incorporated into a high-energy-dense meal and consumed on several occasions. This flavor-nutrient learning is attributed to an association that forms between the sensory characteristics of the flavor and the postingestive effects of the meal \((5, 6, 13)\). To our knowledge, this finding is the first demonstration of a learned reduction in palatability after repeated exposure to a familiar yet reduced-energy-dense food.

The capacity to learn or relearn associations of this kind is important because it promotes a correspondence between foods that are palatable and those that confer a biological advantage (ie, those that are energy dense). Our data indicate that this learning might also decrease the affective quality of a food. We show that the rated palatability of the reduced-energy-dense spaghetti Bolognese decreased by 21 points (of 100), and by the end of the study the reduced version was rated in the middle of the scale, which perhaps indicates “learned neutrality.” However, the prospect that this might have an effect on consumer behavior remains to be established. We note that commercially produced low-energy-dense foods are often widely available, which indicates that they are successful products. At face value, this would seem at odds with our findings. However, in relation to this observation, it may be relevant that palatability is not the only determinant of food reward (and presumably food acceptance) \((10)\). We also note that long-term food restriction is unusual and that the majority of dieters engage in bouts of restriction that lead to little or no weight loss in the longer term \((14)\). In this context, it would be interesting to explore the meaning of these valance shifts and whether they can account for the common tendency to revert back to regular energy-dense counterparts and to sample and explore different types of weight-loss products while dieting.

Related to this question, it would also be instructive to explore valance shifts across a range of different foods. In many cultures, low-energy-dense varieties are now commonplace, and foods such as yogurt, low-fat spreads, and ice cream are widely accepted. In these foods, choice (preference) might be governed by the prospect of consuming a healthy alternative, and this might compensate for shifts in palatability over time. Alternatively, palatability might be preserved, especially in foods that are consumed in smaller portions. We reason that reducing the energy density of a small food portion (eg, a snack food) is likely to have a modest effect on its postigestive response. By contrast, the same change to a large portion (eg, a main meal) will have a marked absolute effect, which may explain why learning was observed in the present study and why certain reformulated low-
energy-dense products maintain their acceptability, even after repeated exposure (for related points, see references 15 and 16).

As noted above, we observed little evidence that lowering the energy density of spaghetti Bolognese brought about changes in its expected satiety and expected satiation over the 5 test sessions. Generally, these findings are encouraging because they suggest that weight-loss foods maintain the same expected satiety as their regular-energy-dense counterparts. One explanation is that people are extremely familiar with regular-energy-dense varieties. This experience may inhibit extinction or relearning of previously acquired flavor-nutrient associations (17). Consistent with this hypothesis, researchers in our laboratory have recently reported learned shifts in expected satiety in a highly novel food. Specifically, we show differential shifts in expected satiety even after a single exposure to an otherwise identical high- and reduced-energy-dense dessert (9). In the present study, we considered shifts in expected satiety and satiation in a food that was already familiar to our participants. Because commercial diet foods also tend to be highly familiar, the results from this study inform our understanding of the learning that might be expected after early encounters with foods of this kind. Of course, prior familiarity does not obviate the possibility that learning will occur but instead suggests that relearning might take place over a longer period of time. Our study involved limited exposure to an already familiar food over several days. Therefore, we cannot rule out the possibility that shifts in expectations (satiety/satiation) will occur after a longer exposure period.

Notwithstanding this point, from a foraging perspective it would seem prudent for an animal to assume that novel foods are low energy dense and then to learn otherwise. This strategy limits foraging for foods that turn out to be of little (nutritive) value (7). Consistent with this idea, previously published studies (in our laboratory) show that expectations are positively correlated with food familiarity. Therefore, a further possibility is that shifts in expected satiation are more likely to occur in one direction (ie, expected satiation will tend to increase). This “expected satiation drift” hypothesis is specific to fullness expectations, and it remains to be tested formally. [Note that other learned responses to low-energy-dense foods have been observed previously (eg, references 16 and 18).] Nevertheless, this idea holds the promise that expectations around weight-loss varieties might be highly resistant to relearning.

To minimize demand and expectancy effects, we labeled our spaghetti Bolognese with a novel Empyreal Foods logo. Future studies might also consider the role that logos and product labeling play in determining expected satiety and satiation. One possibility is that the labeling associated with regular and diet branded foods draws attention to the mismatch between the energy density of these varieties. In this context, greater learning might be promoted and shifts in expectations might be observed.

Overall, we observed little evidence that expected satiety and expected satiation change after repeated exposure to a reduced-energy-dense version of a familiar food. These expectations are an excellent predictor of ideal portion size (10). Therefore, we have little evidence that dieters will desire larger portions of reduced-energy-dense varieties, at least in the short term. By contrast, a reduction in palatability was observed. In the future, researchers might consider the extent to which this affects the acceptability of reduced-energy-dense weight loss foods.

The authors’ responsibilities were as follows—JMB (principal investigator), DF, and HLO: were responsible for the design of the study; HLO and DF: collected the data; EA: provided advice and consultation throughout; and HLO: performed the statistical analysis and prepared an initial draft of the manuscript. Final editing was carried out by all authors. At the time the research was carried out, EA was employed by the funder. The other authors declared no conflicts of interest.

REFERENCES