Sensory Stimulation and Energy Density in the Development of Satiety

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ROLLS, B. J., M. HETHERINGTON AND V. J. BURLEY. Sensory stimulation and energy density in the development of satiety. PHYSIOL BEHAV 44(6) 727-733, 1988.—To determine the contribution of sensory stimulation to the changing hedonic response to foods, the effects of consuming very low-calorie and higher calorie versions of soup and jello on the subjective pleasantness of foods were compared. Subjects were 24 normal weight females with low dietary restraint. Half the subjects were given test meals of low- and high-calorie tomato soup and half were given low- and high-calorie orange jello. They rated the pleasantness of the appearance, smell, texture and taste of nine sample foods as well as hunger and stomach fullness before and 2, 20, 40 and 60 min after consumption of the test meal. After the 60 min rating subjects were offered as much as they wanted to eat of a second course of cheese on crackers. Despite differences in the energy density of the test meals, there were no significant differences in the weights of food eaten in either the first or second course and no significant compensation in the second course for the energy differences of the first course. No differential effects of the caloric manipulation were observed in terms of hunger or fullness or in the development, time course and magnitude of sensory-specific satiety. That very low-calorie foods can produce sensory-specific satiety indicates that the sensory properties of foods are important for the changing hedonic response to foods as they are consumed.

Energy density  Sensory-specific satiety  Caloric compensation  Food intake

CABANAC (5) has argued that the pleasantness of a taste or smell depends on the physiological usefulness of the substance as determined by internal signals. He found that the subjective ratings of the pleasantness of the sweet taste changed as sweet solutions were consumed. The sensory stimulation accompanying ingestion was thought to have relatively little to do with this changing hedonic response since rinsing the mouth with sweet solutions had little effect, whereas intragastric loads of sugar did decrease the pleasantness of the sweet taste (6). However, several other studies suggest that the sensory stimulation may be important. Wooley et al. (23) found that ingestion of a noncaloric sweet solution of cyclamate was just as effective in decreasing the pleasantness of a sucrose solution as was glucose. We (14) and Drewnowski et al. (7) have also found that the pleasantness of solutions declines when they are tasted but not ingested.

The hypothesis to be tested in the present experiment is that the sensory stimulation which accompanies ingestion is an important influence on the changing hedonic response to foods and on the termination of eating. This was done by formulating foods with practically no energy value similar in sensory quality to higher calorie versions. In this way we were able to determine the effects of the sensory stimulation accompanying ingestion when there was little change in the nutritive state of the subjects.

The present study was the first to investigate the effects of foods with almost no calories on the changing hedonic response to foods or "sensory-specific satiety" (18). Previous studies have almost always used sweet solutions which may not be relevant to the controls of food intake. In a recent study in which foods were used Birch and Deysher (2) found that low-calorie pudding (which still contained significant calories) was as effective as higher calorie pudding in reducing the preference for the pudding in children and adults. The decrease in preference, therefore, did not depend on energy density.

Sensory-specific satiety is assessed by having subjects rate the pleasantness of the sensory properties of a variety of food samples on visual analog scales. Subjects then consume

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as much as they want of one of the foods, in this case either the high or low calorie version of soup or jello. Periodically over the hour after they finish eating, the subjects again taste and rate the food samples. The typical response (12, 16–18) is that the food consumed decreases in pleasantness more than the other tasted foods. However, we have found that eating a particular food can sometimes decrease the pleasantness of other foods (11,15). One of the aims of the present experiment was to investigate what properties of foods influence the generalization of sensory-specific satiety to foods that have not been consumed. For example, subjects were asked to rate the pleasantness of sample foods which were similar in flavor, texture and food type before and after the test meals.

Also of interest was to determine how foods of different energy densities, and particularly foods with almost no energy can affect assessments of general hunger and satiety. Thus subjects were asked to rate the pleasantness of the sensory properties of foods as well as their feelings of hunger and stomach fullness. To assess whether changes in these subjective ratings related to actual food intake, subjects were offered a second course test meal one hour after the first course. Thus differential effects of energy density on subjective measures of hunger and fullness as well as subsequent food intake were investigated.

In this study we assessed the extent to which sensory-specific satiety, more general ratings of hunger and satiety, and food intake within a meal depend upon the sensory stimulation accompanying ingestion and the energy content of foods.

This work has been presented at a meeting on the Chemical Senses and Nutrition (18) and at a NAAOS Workshop on the Effect of Sweeteners on Food Intake (19).

**METHOD**

**Procedure**

Subjects were requested to report for lunch between 12:00 and 12:30 p.m. on two test days. They were asked to refrain from eating and drinking between breakfast and lunch, and to eat similar breakfasts on both test days. This instruction ensured that the subjects reached the laboratory in a similar state of hunger on each test day (there were no significant differences in initial hunger ratings between test days). On arrival, subjects were shown to individual cubicles, where they read instructions and were given a demonstration on the use of visual analog scales (100 mm lines). Subjects were told that they were participating in an experiment of the type of experiment (e.g., Psychology students) were excluded from the study. In addition, all subjects scored less than 20 (mean=7.5, S.D.=4.1) on the Eating Attitudes Test (8) indicating that none of the subjects had an eating disorder or preoccupation with food or body weight. All subjects were tested under two caloric conditions (high-calorie and low-calorie) on two separate days at least one week apart to minimize the effects of learning. Each subject was offered either the soup test food (n=12) if they preferred soup or the jello test food if they preferred jello (n=12). Six of the subjects receiving soup and six of the subjects receiving jello were assigned to the low-calorie condition first. The remaining subjects in both groups were assigned to the high-calorie condition on the first test day.

**Foods**

The sample foods were presented as small aliquots (of no more than 5 g) in 20 ml plastic containers on a tray. The order of the nine sample foods was: diluted orange drink, fresh tomato, cheese on Ritz cracker, orange jello (0.32 kcal/g), tomato soup (0.28 kcal/g), chocolate confectionery, beef consomme, fresh orange, and raspberry jello. The samples of the two test meals were presented as intermediate energy density rather than samples from either the high- or low-calorie versions of the test foods. Overall, the calories consumed during pleasantness ratings were extremely small and of similar amounts in the different test conditions and therefore were not included as significant caloric intake.

The test meals consisted of 550 g of low-calorie (0.07 kcal/g) or high-calorie (0.49 kcal/g) tomato soup and 550 g of low-calorie (0.09 kcal/g) or high-calorie (0.54 kcal/g) orange jello. These were prepared in collaboration with Unilever, U.K. Soup test meals were prepared using the same soup base. The caloric value of the "high-calorie" version of the soup was increased by using maltodextrin (12.5 g per 100 ml of water) and this was substituted with guar gum (a low energy density thickener; 0.37 g per 100 ml of water). The samples of the test meals were prepared as intermediate energy density rather than samples from either the high- or low-calorie versions of the test foods. Overall, the calories consumed during pleasantness ratings were extremely small and of similar amounts in the different test conditions and therefore were not included as significant caloric intake.

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second course offered one hour after completion of the test meals consisted of 60 g of mild English cheddar cheese (4.06 kcal/g) served on 15 Ritz crackers (4.95 kcal/g).

### Statistics

The changes in hunger, fullness and the pleasantness of the four sensory variables were calculated by subtracting the initial ratings from those taken at 2, 20, 40, 60 min after the first course. The changes in hunger were analyzed using a two factor analysis of variance with caloric value and time as factors. The changes in the pleasantness ratings were analyzed by a three-factor analysis of variance, with caloric value (high vs. low), food (eaten vs. uneaten or the nine foods separately) and time as factors. Following significant main effects or interactions in the analysis of variance, individual means were compared using the Newman-Keuls test. Mean food intakes were compared using the paired t-test.

### RESULTS

#### Effects of Energy Density on Intake of the Test Meals

Subjects ate approximately the same weight of low-calorie and high-calorie tomato soup (237 g; 297 g, respectively; see Table 1a) so that the calories consumed were significantly different (low: 16.8 kcal; high: 146.4 kcal, t=7.05, p<0.001). Also, approximately the same weight of orange jello was consumed by subjects in both the low- and high-calorie conditions (227.5 g; 259.8 g, respectively; see Table 1b) so that there was a significant difference in energy intake (low: 20.2 kcal; high: 140 kcal, t=9.315, p<0.001). Time taken to consume the first course was less than 20 min in each case, for all subjects.

#### Effects of Energy Density on Hunger and Fullness Ratings

Immediately following both the low- and high-calorie soups and jellies hunger declined significantly (p<0.05) (Fig. 1) and fullness increased significantly (p<0.05) as determined by an analysis of variance of the absolute ratings of hunger and fullness. There were no significant differences between the changes in hunger and fullness ratings for the low- versus the high-calorie test meals, nor any significant differences over the time course tracked between the two conditions. Therefore, the test meals were equally effective in reducing hunger regardless of energy density and no differential effect of energy density was observed in the time course of the changes in hunger, F(1,11)=0.81, p=ns. Similarly, both versions of the test meals increased fullness immediately after consumption of the first course and no differences were recorded between the changes in fullness following the high-calorie versions of the test foods relative to the low-calorie test foods. Differences in energy density did not influence the time course or magnitude of the changes in fullness following the test meals.

#### Changes in Pleasantness Following Low- and High-Calorie Test Meals

No significant differences were observed between the low- and high-calorie conditions in the changing pleasantness of the appearance, smell, texture and taste of the foods over time. Thus, changes in the pleasantness of the appearance, smell, texture and taste of the foods did not differ as a function of the energy density of the test meals. The changes in the pleasantness of the taste of the low- and high-calorie test meals are shown in Fig. 2. Changes in the pleasantness of the appearance, smell, texture and taste of the foods were similar and did not differ significantly across sensory variables.

These results indicate that there was no significant difference in the time course, magnitude and development of sensory-specific satiety between the low- and high-energy density meals for any of the sensory variables examined.

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### Table 1

<table>
<thead>
<tr>
<th>Weight (g)</th>
<th>First</th>
<th>Second</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-Calorie</td>
<td>237.5 ± 34.5</td>
<td>101.2 ± 9.9</td>
<td>340.7 ± 37.9</td>
</tr>
<tr>
<td>High-Calorie</td>
<td>297.4 ± 36.6</td>
<td>95.7 ± 8.4</td>
<td>393.1 ± 40.0</td>
</tr>
<tr>
<td>Energy (kcal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-Calorie</td>
<td>16.8 ± 2.4*</td>
<td>452.8 ± 45.2</td>
<td>466.3 ± 45.0†</td>
</tr>
<tr>
<td>High-Calorie</td>
<td>146.4 ± 18.0*</td>
<td>427.7 ± 36.0</td>
<td>575.7 ± 44.0†</td>
</tr>
</tbody>
</table>

*Mean weight and energy intake (±SEM) of the first course of tomato soup, second course of cheese on crackers and total intake in the soup condition.

†Indicates a significant difference between means at p<0.001.

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Interactions Between Changes in the Pleasantness of the Taste of the Eaten Food and the Uneaten Foods

A Newman-Keuls test performed on the mean changes in pleasantness revealed the effect of consuming the test food on the pleasantness of the taste of the individual foods. Since there were no significant differences between the low- and high-calorie conditions in terms of the magnitude or time course of the changes in pleasantness of the taste of the foods consumed, the data for both conditions have been combined.

For all sensory variables and for both the soup and jello test meals, there was a significant difference between the
FIG. 3. Mean changes in the pleasantness of the taste of the eaten food (broken line) and uneaten foods (solid lines) following consumption of low- and high-calorie tomato soup (data from both caloric conditions combined).

FIG. 4. Mean changes in the pleasantness of the taste of the eaten food (broken line) and uneaten foods (solid lines) following consumption of low- and high-calorie orange jello (data from both caloric conditions combined).
eaten and uneaten foods, such that the pleasantness of the eaten food declined significantly more than that of the uneaten foods ($p<0.05$, in all cases). For both the soup and jello test meals, and for all the variables examined, the greatest effect observed was the decrease in the pleasantness of the taste of the eaten food relative to the mean decrease of all the uneaten foods immediately following consumption of the test meal. The eaten food was still significantly less pleasant than the uneaten foods at 60 min ($p<0.05$), again for all of the sensory variables studied.

Following consumption of the tomato soup, the pleasantness of the taste of the tomato soup declined to a greater extent than the pleasantness of all the uneaten foods ($p<0.01$, except consomme $p<0.05$; Fig. 3). The pleasantness of the taste of the consomme and the orange drink appeared to follow a similar trend to the taste of the tomato soup in that they too declined relative to the other uneaten foods. This indicates that there may have been an interaction between consumption of the soup test meals and the pleasantness of the taste of another soup (beef consomme) and another liquid (orange drink).

Changes in the pleasantness of the taste of orange jello following a test meal of that food were significantly different from all the sample foods (Fig. 4) except the raspberry jello and orange drink which decreased similarly in pleasantness, perhaps indicating an interaction between foods of the same type (jello) and the same flavor (orange).

**Effects of Energy Density on Intake of the Second Course**

Subjects did not eat significantly more of the second course following the low-calorie soup relative to the high-calorie soup (see Table 1a). Thus there was no significant compensation for the difference in energy intake from consumption of the two soup conditions. Having consumed similar volumes of soup in the first course regardless of energy density, the subjects then consumed similar amounts of cheese on cracker in the second course.

The results recorded for the jello condition are shown in Table 1b. Subjects ate approximately the same weight of orange jello in the first course resulting in a substantial difference in energy intake. In the second course the subjects ate more cheese on crackers following the low-calorie orange jello than after the high-calorie jello. However, this difference in intake of the second course did not reach statistical significance.

**Total Food Intake**

Overall energy intake in the soup condition demonstrated a significant difference between the total energy intake in the low-calorie condition relative to the high-calorie condition ($r=2.13$, $p<0.05$) (Table 1a). This result suggested that the subjects did not compensate for the energy discrepancy between the two caloric versions of the soup. However, in the jello condition the total energy intake between the two conditions did not differ (Table 1b).

**DISCUSSION**

These results indicate that the changes in the pleasantness of the sensory properties of foods that occur during ingestion are influenced by the sensory stimulation accompanying ingestion. This conclusion follows from the finding that sensory-specific satiety follows the ingestion of foods with practically no calories. Thus the changes in the pleasantness of the taste, texture, smell, and appearance of soup or jello were similar following caloric and virtually noncaloric versions of the foods. We have referred to the changing pleasantness of the sensory properties of foods as "sensory-specific satiety." This terminology had been introduced by LeMagnen (9) and seemed appropriate since our previous studies had also indicated that the sensory properties of foods rather than just the nutritional consequences of ingestion were important. Thus we found that the reduction in pleasantness of the taste of a food occurred rapidly, i.e., within 2 min of finishing eating and the present data indicate that these changes appear to be maximal at that time. Also, we have found that changing just the sensory properties of foods, i.e., flavor or shape, can enhance food intake when presented in successive courses compared to intake of just one flavor or shape (11,13). This implies that satiety can be relatively specific to the sensory properties of foods. However, by stressing the importance of the sensory properties of foods for the changing hedonic response we do not wish to imply that the physiological and nutritive consequences of ingestion play no role.

Although the greatest changes in palatability that occur after eating are for the food consumed, some uneaten foods also decrease in pleasantness. Such interactions might occur because the foods have similar sensory properties, or because cognitively the foods are considered to be of the same type, or perhaps because the foods have the same macronutrient content. We have not found evidence for interactions due to macronutrient content (17,18), but it appears that if uneaten foods are similar in taste to the eaten food, they may also decrease in pleasantness. For example, after consumption of one sweet food, other sweet foods declined in pleasantness, but savory foods showed no decrease, whereas the consumption of savory foods decreased the pleasantness of other savory foods but not sweet foods (12,15). Although such interactions may occur on the basis of taste for flavor, they may not be seen if other sensory properties of the foods are very different. Foods of the same type also interact. For example, in the present experiment following the meal of orange jello, raspberry jello also declined in pleasantness. Similarly, following consumption of tomato soup, consomme also decreased in pleasantness. This type of interaction may be due to beliefs about the similarities between foods, i.e., the way in which foods are cognitively grouped together, as well as to similarities in their sensory qualities.

A clear finding in the present study was that the high- and low-calorie versions of the soup and jello have similar effects on subjective ratings of hunger and stomach fullness. Following the low-calorie foods there was a very marked reduction in hunger and increase in stomach fullness which lasted over the hour after eating terminated despite consumption of only 17 to 20 kcal. It was apparent in the debriefing following the experiment that the subjects were not aware of the manipulation of energy density. It seems likely that when subjects were presented with familiar foods such as soup or jello that they relied on their previous experience with the foods and consumed volumes that they had previously learned were appropriate to satisfy hunger (1,4). Subjects ate similar weights of the foods regardless of the energy density. The beliefs about the foods appeared to be so strong that foods with little energy content reduced hunger for the hour after consumption. It is also possible that low-calorie foods evoke physiological changes such as stomach distension and the release of hormones associated with satiety. In a recent study on the differential effects of preloads of different en-
ergy density on hunger and food intake Wardle (22) found that subjective ratings but not intake were sensitive to the caloric content of the preload. Therefore, in her study (22) subjects discriminated between preloads on the basis of hunger, fullness and foods selected from a menu but not in terms of actual food consumption measured two hours after the preloads. Wardle concluded that food intake is influenced strongly by the environmental conditions under which food is presented. This may account for the lack of compensation found in the present study.

Blundell and Hill (3) have suggested that the foods used in the present study have some special anorectic property. This seems unlikely since all of the ingredients are commonly used in foods and furthermore we have seen similar reductions in hunger with other commercially available jello and pudding products (19). Although there was a trend towards some compensation for the reduction in calories in the jello condition when the cheese and crackers were offered after an hour, this did not reach statistical significance. This further reinforces the suggestion that the subjects did not detect the very low energy intake associated with the low-calorie foods. The difference in intake which was associated with consumption of the high- and low-calorie versions of the foods was approximately 120 kcal. It is possible that this is too small a difference to be detected. Nevertheless, it seems surprising that the subjects did not detect that they had eaten only 17 to 20 kcal with the low-calorie foods. This suggests that at least in the short-term reduced energy foods may be of some benefit in reducing hunger and can be satisfying in subjects who are unaware of the energy manipulation.

In conclusion, these studies show that the sensory properties of foods are important for the changing hedonic response to foods as they are consumed. Thus referring to the behavior as "sensory-specific satiety" is appropriate.

**REFERENCES**