Sensory-specific satiety in obese and normal-weight women[1–3]

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ABSTRACT

Background: Sensory-specific satiety has been found to play an important role in food choice and meal termination, and it might be a factor contributing to obesity.

Objective: We hypothesized that obese and normal-weight people have different sensitivities to sensory-specific satiety for high-fat foods.

Design: Sensory-specific satiety was measured in 21 obese [$\bar{x}$ body mass index (BMI; in kg/m^2): 33.1] and 23 normal-weight (BMI: 22.8) women who were matched for restrained eating behavior, physical activity, age, and smoking behavior. Food intake, appetite ratings, and liking scores before and after an ad libitum lunch were measured. Products differed in fat content and taste (ie, low-fat sweet, low-fat savory, high-fat sweet, and high-fat savory), and the subjects tested all 4 products. In the first study, sandwiches were tested; in the second study, snacks were tested.

Results: Sensory-specific satiety for all products was observed in both subject groups. No significant differences were observed between the obese and normal-weight subjects in either sensory-specific satiety or food intake for any of the products or product categories tested. Taste (sweet or savory) had a significantly ($P < 0.05$) stronger effect on sensory-specific satiety than did fat content. Appetite ratings strongly decreased after lunch, and appetite for a meal or snack after lunch was significantly higher in obese than in normal-weight subjects, whereas scores before lunch did not differ significantly.

Conclusions: Obese and normal-weight people do not differ in their sensitivity to sensory-specific satiety, and factors other than fat content have the greatest effect on sensory-specific satiety. *Am J Clin Nutr* 2004;80:823–31.

KEY WORDS Sensory-specific satiety, obesity, overweight, fat-specific satiety, appetite, taste

INTRODUCTION

Obesity results from a long-term positive energy balance—ie, the energy intake is greater than the energy expenditure. Energy or food intake is regulated by, among other factors, subject factors (eg, appetite, satiation or satiety, and self-inhibition) and product factors (eg, hedonic value and variety) (1–3). Under experimental conditions, the intake of a single food relative to the intake of other foods is strongly affected by sensory-specific satiety. This phenomenon was first observed in monkeys and was found to be reflected in the change in the response of hypothalamic neurons: the response stops when the monkey is exposed to the sight and taste of foods on which the monkey has fed to satiety, whereas the neurons continue to respond to other foods (4). Sensory-specific satiety has been defined as the decrease in pleasantness of a product after it is eaten compared with the decrease in the pleasantness of products that were tasted but not eaten to satiety. For example, after eating sausages, the liking of the sausages strongly declined at the same time that liking of other savory products declined less, and the liking of sweet foods such as cookies even increased (2). The decrease in liking is also associated with a lower intake of that particular food in a second course. Sensory-specific satiety occurs within 2 min after consumption, when there has been little opportunity for digestion and absorption, and it is specific for the sensory aspects of products (2, 5, 6).

Knowledge of the required amount of food eaten to reach sensory-specific satiety is limited. Texture, flavor, and color have been described as important factors affecting the degree of sensory-specific satiety (3, 6). There is also evidence of the influence of macronutrients on sensory-specific satiety (7–11). A clear effect of higher sensory-specific satiety was observed only for foods that are high in protein (7, 10, 12), and a trend for higher sensory-specific satiety was found for products high in sweet carbohydrates (13, 14) and fatty acids (15).

A high intake of energy from overeating of high-fat products is the result of the high energy density, high palatability, and weak satiation of high-fat foods (16–21). The results of various studies have suggested that obese subjects show a greater preference for high-fat foods than do normal-weight subjects (22–24). In addition, interindividual differences in sensory-specific satiety could very well contribute to differences in food intake. Differences in sensory-specific satiety have been found in subjects with eating disorders (25) and between different age groups (26). The results of a study by Epstein et al (27) suggest that obese women may be less sensitive to sensory-specific satiety than are normal-weight women. In that study, obese women showed a smaller decline in salivary flow than did normal-weight women after repeated exposure to palatable food cues. In a cross-sectional study by McCrory et al (28), obese subjects consumed a greater variety of energy-dense foods than did normal-weight

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TABLE 1
Characteristics of subjects in the 2 experiments[1]

Group	Age	Height	Weight	BMI	Restrained eating questionnaire score[2]
	y	*m*	*kg*	*kg/m²*	
Sandwich experiment					
Normal-weight subjects, $n = 23$	46 ± 10	1.68 ± 0.07	64 ± 6.3	22.8 ± 1.42	2.72 ± 0.68
Obese subjects, $n = 21$	47 ± 11	1.68 ± 0.06	93 ± 8.7[3]	33.1 ± 1.79[3]	2.76 ± 0.73
Snack experiment					
Normal-weight subjects, $n = 21$	47 ± 9	1.69 ± 0.07	65 ± 6.5	22.8 ± 1.39	2.70 ± 0.71
Obese subjects, $n = 22$	47 ± 10	1.68 ± 0.06	93 ± 8.4[3]	32.9 ± 1.93[3]	2.69 ± 0.74

[1] All values are $\bar{x}$ ± SD. The number of smokers per group was $n = 5$ (normal-weight) and 6 (obese) in the sandwich experiment and $n = 4$ (normal-weight and 5 (obese) in the snack experiment.
[2] Dutch Eating Behavior Questionnaire, which uses a 5-point scale from 1 (low) to 5 (high) (29).
[3] Significantly different from normal-weight subjects, $P < 0.001$ (*t* test).

subjects, whereas normal-weight subjects consumed a greater variety of low-energy-dense foods than did obese subjects. If sensory-specific satiety for high-fat foods is less in obese subjects than in normal-weight subjects, that could be an important factor in the development of overweight (1).

In this study, obese and normal-weight women were exposed to either low-fat sweet, low-fat savory, high-fat sweet, or high-fat savory products, according to a repeated within-subject design. Thus, it could be ascertained whether sensory-specific satiety for high-fat foods differed between obese and normal-weight subjects.

SUBJECTS AND METHODS

Two experiments are reported here, one in which sandwiches were eaten, and one in which snacks were eaten. The experiments were identical in design and procedure; only the products were different.

Subjects

The number of subjects in the sandwich and snack experiments was 44 and 43, respectively; all were healthy women living in or near Zeist, Netherlands. They were selected from a pool of 1500 volunteers. Exclusion criteria for the study were age < 18 or > 65 y, dieting, consumption of >21 servings of alcohol/wk, diabetes, an unwillingness to eat or an allergy to the test foods, and the use of medication with a possible effect on taste, appetite, or both (eg, antidepressives). Allowed medications were contraceptives, cholesterol- and hypertension-reducing medication, diuretics, painkillers, and medication for asthma and disorders of the bronchial tubes. Because an insufficient number of obese men were available, only women were selected. Obese women (BMI ≥ 30) were matched with normal-weight women (BMI 20–25) for age, smoking behavior, physical activity level, and score on the restrained-eating questionnaire (29). Two subjects were unable to complete the study. Basic anthropometric data on the participating subjects are shown in **Table 1**. Subjects were told that the study was about the relation between (over)weight and taste. Each subject gave written informed consent. The procedures followed were in accordance with the ethical standards on human experimentation of the Netherlands Organization for Applied Scientific Research TNO. Forty-three of the 46 subjects in the sandwich experiment also participated in the snack experiment. Two additional subjects were recruited for the snack experiment by using the same selection and matching criteria.

Design

The design of this study was similar to that of other sensory-specific satiety studies. Subjects came to the laboratory, rated their appetite on 6 different scales, tasted and rated foods with respect to pleasantness of the taste, ate one particular food ad libitum, tasted and rated the same foods again, and rated their appetite again (**Table 2**). Each subject came 4 times and tested all 4 products once. Both the order of serving lunches and the order of rating were randomized across and within subjects. The products varied in taste (sweet or savory) and fat content (low-fat or high-fat).

Foods

In both experiments, 4 products were served according to a 2 × 2 factorial design. The first factor was taste (sweet or savory), and the second factor was fat content (low-fat or high-fat) (**Table 3**). Products were prepared the morning of consumption and served at room temperature. Table 3 shows the weight of the rating set and lunch servings and the energy and nutrient contents per 100 g test food. Nutrient composition was calculated according to the Dutch nutrient database (30).

Sandwich experiment

Sandwiches were prepared with 4 different fillings, which a pilot study found that subjects liked approximately equally. Sandwiches were prepared with 2 slices of whole-wheat bread and 35 g of either white chocolate spread (Albert Heijn, Zaandam, Netherlands), rose hip jam (Albert Heijn), pâté (Albert

TABLE 2
Time schedule of experiment[1]

Time	Action	Method
T0	Rating of appetite	Six 150-mm VAS
T0 + 5 min	Tasting and rating pleasantness of all 4 products	7-Point hedonic scale
T0 + 10 min	Ad libitum lunch, 1 of the 4 products	—
T0 + 25 min	Tasting and rerating pleasantness of the 4 products	7-Point hedonic scale
T0 + 30 min	Rerating appetite	Six 150-mm VAS
T0 + 35 min	Unexpected 2nd course[2]	—

[1] T0, time zero; VAS, visual analogue scales.
[2] Only during the last session.

TABLE 3
Weight of rating set and lunch servings and energy and nutrient contents[1]

Product	Weight of rating piece	Weight of serving	Energy	Protein	Fat	CHO	Fiber
	g	*g*	*kJ/100 g test food*	*g/100 g test food*	*g/100 g test food*	*g/100 g test food*	*g/100 g test food*
Sandwiches	36[2]	144[3]					
Bread	5.5[2]	88	1013	9.5	2.3	45.1	5.1
High-fat filling							
Chocolate spread	3.5	56	2500	2.0	41.0	56.0	0.0
Pâté	3.5	56	1569	11.0	35.5	4.0	0.0
Low-fat filling							
Rose hip jam	3.5	56	1060	2.0	0.5	60.0	1.0
Roast beef	3.5	56	704	28.3	5.7	0.8	0.0
Snacks	<30						
High-fat							
Chocolate candy bar	9	212	1871	3.6	17.3	68.9	1.0
Cheese crackers	9	150	2368	15.0	38.0	41.0	1.9
Low-fat							
Pears in light syrup	5	350	272	0.3	0.1	15.0	2.0
Fillet of chicken	5	300	667	30.9	3.8	0.0	0.0

[1] CHO: carbohydrate.
[2] Total weight of the 4 pieces (4× ⅛ sandwich).
[3] Four plastic trays of 36 g each; ad libitum amount available.

Heijn), or roast beef (Albert Heijn) (for composition, *see* Table 3). Bread crusts were removed, and sandwiches were cut in 4 pieces. The sandwiches were offered on plastic trays containing 2 pieces of sandwich each (total: ≈36 g). For the pleasantness ratings before and after the lunch, subjects were presented with a small piece (1/8 of a sandwich) of each of the 4 sandwiches.

Snack experiment

The 4 test products in the snack experiment were a chocolate candy bar (Mars Bar; Masterfoods, Veghel, Holland), pears in light syrup (Del Monte International, Staines, United Kingdom), cheese crackers (Van Kooten, Veenendaal, Netherlands), and fillet of chicken (Albert Heijn). Candy bars were cut in 6 pieces (the ends were removed); the pears and the fillet of chicken were cut in pieces weighing ≈5 g. Each product was presented on a plate in large amounts: 4 chocolate candy bars (≈212 g), 150 g cheese crackers, 350 g pear pieces (without the syrup), or 300 g fillet of chicken (Table 3). When subjects finished the food, they could ask for more, but only a few subjects did so. For the pleasantness ratings, the stimuli consisted of 1/8 of a candy bar, one piece of pear, one piece of chicken, and one cheese cracker.

Procedure

In both experiments, subjects came to the institute for lunch at 1200 or 1300 on Tuesdays, Wednesdays, or Thursdays. All subjects came 4 times during the 5 wk of the study, with at least 5 d between the sessions. Subjects were instructed to eat a normal breakfast; to eat nothing between breakfast and lunch to drink only water, tea, or coffee; and to have no unusual physical activity on the day of an experiment. The test took ≈40 min; subjects were seated in private booths and were not allowed to talk, read, or smoke during the experiment. Water was available throughout the experiment, but its intake was not measured.

Subjects first rated their appetite on six 150-mm visual analogue scales anchored with "weak" and "strong" on the left and right sides, respectively. Specifically they were asked to rate their "appetite for a meal," "appetite for something sweet," "appetite for something savory," "over-satiety (over-fullness)," "[feelings of being] feeble, weak with hunger," and "appetite for a snack." After the appetite ratings, subjects tasted and rated the pleasantness of each of the 4 products on a 7-point hedonic scale (very unpleasant to very pleasant, with neither unpleasant nor pleasant in the middle). The pieces of the foods were given one after another, and, for each serving, subjects were given a separate response form, so that they could not compare the current rating with previous ratings. The participants were instructed to take a bite of the sample and to keep the bite in their mouth while rating the food. Subjects swallowed the food when the rating was completed.

After rating, subjects were given one of the 4 products ad libitum for lunch. They were instructed to eat until they reached satiety. Subjects came at lunchtime in the snack experiment as well as in the sandwich experiment, and they were asked to eat to satiety and to consider the offered snacks as lunch, although, in the snack experiment, those were products not commonly eaten for lunch.

In the sandwich experiment, subjects were offered 4 trays at a time (containing 2 pieces of sandwich each, ≈36 g); after a few minutes, empty trays were replaced with full ones, even when there were still a few full trays left. This was repeated until the subject indicated he or she was satiated. In the snack experiment, subjects were offered large amounts of snacks on a plate. If they finished the food, they were offered a second plate.

As soon as subjects had finished lunch, they re-rated the 4 test pieces and also re-rated the appetite scales. Each subject received 1 of the 4 products for lunch in each of the 4 sessions; the order in which the 4 products were served and the order in which they were rated before and after lunch were randomized across and within subjects.

Statistical analysis

First, we calculated the mean liking ratings on the 7-point hedonic scale for each of the tasted foods, before and after lunch.

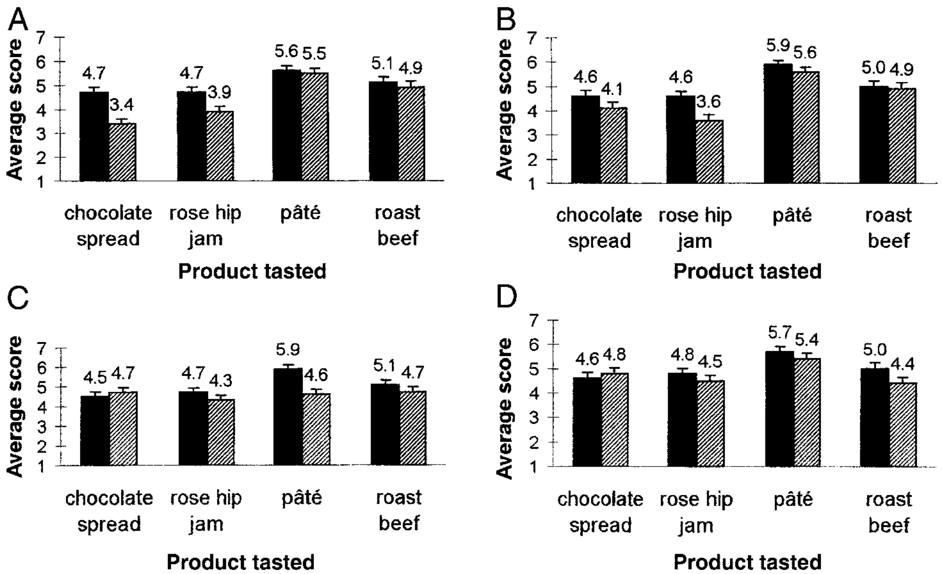

FIGURE 1. Mean (±SEM) scores of pleasantness of taste of the sandwiches on a 7-point hedonic scale (1 = very unpleasant, 7 = very pleasant) before (■) and after (▨) eating 1 of the 4 products (chocolate spread, A; rose hip jam, B; pâté, C; roast beef, D) to satiety for lunch ($n = 44$). The decline in pleasantness of the taste of eaten products was significantly larger than the decline of uneaten products for chocolate spread ($P < 0.001$), rose hip jam ($P = 0.002$), and pâté ($P < 0.001$) and was of borderline significance for roast beef ($P = 0.052$).

Sensory-specific satiety was assessed by comparing the decrease in liking (score after lunch –score before lunch) of the eaten foods with the mean decrease in liking of the uneaten foods. A paired *t* test for each of the foods was used to determine whether the sensory-specific satiety effect was significant.

Next, the decrease in liking of the eaten food was compared with the decrease in liking of the uneaten foods in the obese and normal-weight groups separately, and this process was followed for each food consumed at lunch. The effect of weight status (obesity or normal weight) on sensory-specific satiety was analyzed by analysis of variance (ANOVA), with weight status as a between-subjects factor and products as a within-subject factor. Persons were nested within groups (overweight and normal-weight). To determine whether obesity had a differential effect on taste (sweet or savory) or fat content (high- or low-fat), an ANOVA (general linear model) was conducted with sensory-specific satiety as the dependent variable and fat, taste, obesity, and obesity × fat and obesity × taste interactions as the independent variables.

The effects of taste and fat content on sensory satiety were analyzed by comparing the mean of the decrease in liking for the product that was similar to the lunch in taste or fat content and the mean of the decrease in liking for the 2 products that were dissimilar to the lunch in taste or fat content. For example, when the lunch consisted of sandwiches with chocolate spread, the decrease in liking for rose hip jam, which is similar in taste, was compared with the mean of the decreases in liking for pâté and roast beef, which are dissimilar in taste to chocolate spread. In addition, products that were similar (pâté) and dissimilar (jam and roast beef) to chocolate spread in fat content were compared. This was done for each of the products and resulted in average scores for taste and fat content in similar and dissimilar products. When liking for products similar in taste to lunch decreases more than does that for products similar in fat content to lunch (compared with dissimilar products), "taste" is probably a more important factor for sensory-specific satiety than is "fat content." Average decreases in the "similar in taste" and "similar in fat content" products were therefore compared with the use of a *t* test.

Appetite ratings were determined by measuring (in mm) the ratings on the 150-mm line scale. The ANOVA of the appetite ratings was done with the factor time (with 2 levels, ie, before and after lunch) and obesity as main factors and time × obesity as the interaction factor.

Significance in all tests was set at $P < 0.05$. All data analyses were performed with the use of EXCEL for WINDOWS software (version 7.0; Microsoft Corp, Redmond, WA) and SPSS software (version 10.1; SPSS Inc, Chicago).

RESULTS

Sandwich experiment

All lunches induced sensory-specific satiety, because the decline in pleasantness of the taste was greater for the eaten than the uneaten products. This difference in decline was significant for chocolate spread, rose hip jam, and pâté and borderline significant for roast beef ($P = 0.052$). The initial and postlunch average pleasantness ratings per product are shown in **Figure 1**.

The decline in pleasantness per product and per group of subjects in shown in **Figure 2**. Sensory-specific satiety was found in both groups, but no differences were found between obese and normal-weight subjects. Significant effects were found for the taste × fat interaction, which refers to the notion that there was little difference between chocolate spread and jam scores and greater difference between pâté and roast beef scores. No significant interactions with obesity were found. The difference in decline was significantly ($P = 0.020$) greater (and thus sensory-specific satiety was higher) for products rich in fat (chocolate spread and pâté) and lower for products low in fat (rose hip jam and roast beef).

The effect of taste and fat content on sensory-specific satiety is shown in **Figure 3**. The product eaten for lunch declined most

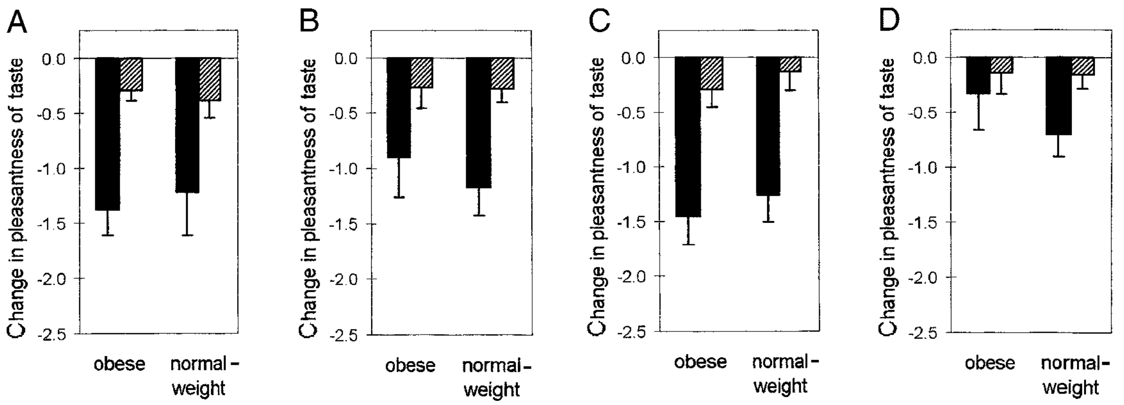

FIGURE 2. Mean (±SEM) decline in pleasantness of taste of eaten (■) and uneaten (▨) sandwiches (chocolate spread, A; rose hip jam, B; pâté, C; roast beef, D) after ad libitum lunch (score after lunch –score before lunch on 7-point hedonic scale: 1 = very unpleasant, 7 = very pleasant) per group of subjects (obese and normal-weight). No significant differences were observed between obese and normal-weight respondents. A significant interaction effect was found for taste × fat ($P = 0.044$), but no significant interactions were found for obesity (general linear model; $n = 44$: 23 normal-weight and 21 obese).

in pleasantness. Products similar to lunch in taste (sweet or savory) declined more than did products different from the lunch product, whereas products similar in fat content declined less than did the other products. Overall, taste seemed to determine sensory-specific satiety more than fat content. The decline in pleasantness was greater for products similar to lunch in taste than for products similar to lunch in fat content.

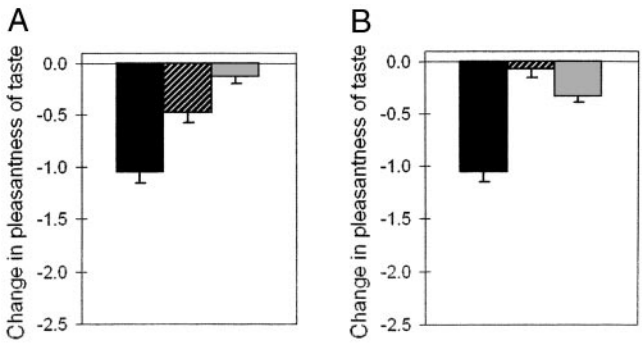

FIGURE 3. Mean (±SEM) decline in pleasantness of taste of sandwiches similar (▨) and dissimilar (▤) to lunch (■) in taste (sweet or savory; A) or fat content (low or high; B) after lunch (score after lunch –score before lunch on 7-point hedonic scale: 1 = very unpleasant, 7 = very pleasant) ($n = 44$). The decline in pleasantness was greater for products similar to lunch in taste than for products similar to lunch in fat content ($P < 0.001$).

Food intake

The average intake of the ad libitum lunch per product for obese and normal-weight subjects is shown in **Table 4**. Intakes did not differ significantly between the groups. Intake was correlated to the initial liking (score on pleasantness of the taste before lunch) of the product ($r = 0.222$, $P = 0.003$). However, there was no correlation between intake and any of the appetite ratings.

Appetite ratings

After the ad libitum lunch intake, subjects reported a strong decrease in "appetite for a meal," "appetite for something sweet," "appetite for something savory," "[feelings of being] feeble, weak with hunger," and "appetite for a snack." There was a strong increase in "over-satiety (overfull)." After a sweet meal, "appetite for something sweet" decreased more than it did after a savory meal ($P < 0.05$), and "appetite for something savory" decreased more after a savory than after a sweet meal ($P < 0.001$). Obese subjects had significantly higher after-lunch ratings for "appetite for a meal" and "appetite for a snack" than did normal-weight subjects, whereas scores before lunch did not differ significantly (**Figure 4**). All other after-lunch ratings were not significantly different between obese and normal-weight respondents (not shown in figures). In an ANOVA, we found a significant main effect for time and borderline significant effect

TABLE 4
Average intake of ad libitum lunch per group and per product by weight and energy content[1]

Intake	Chocolate spread	Rose hip jam	Pâté	Roast beef	Total
Obese subjects, $n = 21$					
(g)	118 ± 63	100 ± 51	129 ± 69	142 ± 95	123 ± 72
(kJ)	1631	1022	1586	1732	1511
Normal-weight subjects, $n = 23$					
(g)	111 ± 54	120 ± 63	132 ± 46	122 ± 41	121 ± 51
(kJ)	1534	1227	1622	1488	1468
Total subjects, $n = 44$					
(g)	114 ± 58	111 ± 58	131 ± 58	132 ± 72	122 ± 62
(kJ)	1576	1135	1610	1610	1483

[1] No significant differences were observed between obese and normal-weight subjects (*t* test).

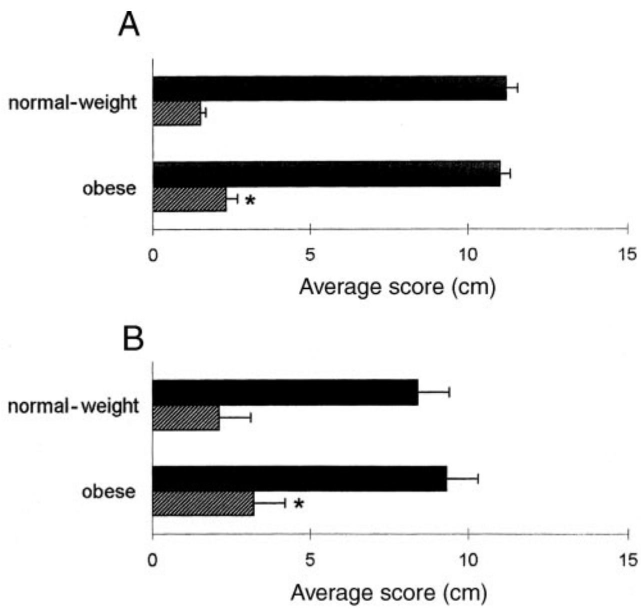

FIGURE 4. Mean (±SEM) ratings per group on two 15-cm visual analogue scales anchored by weak (0) and strong (15) scores for appetite for a meal (A) and appetite for a snack (B) before (■) and after (▨) ad libitum lunch of sandwiches ($n = 44$). There was a significant time effect ($P < 0.001$) and a borderline significant effect for obesity ($P = 0.065$) but no significant obesity effect or obesity × time interaction (ANOVA). *Significantly higher than ratings by normal-weight subjects, $P < 0.05$ (*t* test).

for obesity ($P = 0.065$), but the interaction effect was not significant ($P = 0.177$).

Snack experiment

After all snacks, sensory-specific satiety was observed. The decline in pleasantness of the taste of eaten products was significantly larger than that of uneaten products for chocolate candy bar, pears in light syrup, cheese crackers, and fillet of chicken. Initial liking scores (before lunch) differed significantly between the products ($P < 0.05$). However, there were no differences in liking between obese and normal-weight subjects. The initial and postlunch average pleasantness ratings per product are shown in **Figure 5**, and the decline in pleasantness of taste among each group of subjects is shown in **Figure 6**. Sensory-specific satiety was found in both groups, but no differences were found between obese and normal-weight subjects. No significant interactions were found between taste, fat content, and obesity.

The effect of both factors (taste and fat content) on sensory-specific satiety are shown in **Figure 7**. Products similar in taste to lunch declined more in pleasantness of taste (ie, liking) than did products different from the lunch product, whereas the opposite was true for fat content. Overall taste (sweet or savory) seemed to determine sensory-specific satiety more than did fat content; products similar to lunch in taste declined more in liking than did products similar to lunch in fat content (Figure 7).

Food intake

The average intake during the ad libitum lunch per product for obese and normal-weight subjects is shown in **Table 5**. No significant difference in intakes was found between the groups, although intake tended to be higher for obese subjects for all products except cheese crackers (Table 5). Intake was correlated to the initial liking (score on pleasantness of the taste before lunch) of the product ($r = 0.217$, $P = 0.005$) and to the appetite ratings "appetite for a meal" ($r = 0.152$, $P = 0.045$) and "appetite for a snack" ($r = 0.169$, $P = 0.029$).

Appetite ratings

After the ad libitum lunch intake, subjects reported a strong decrease in appetite for a meal, appetite for something sweet, appetite for something savory, feelings of being feeble and weak with hunger, and appetite for a snack. There was a strong increase in over-satiety (being overfull). Appetite for something sweet decreased significantly more after a sweet meal than after a savory meal, and appetite for something savory decreased significantly more after a savory meal than after a sweet meal (both: $P < 0.001$). The after-lunch scores of obese subjects were significantly lower for over-satiety ($P = 0.005$) and significantly higher for appetite for a meal, appetite for a snack, and appetite for something savory (all: $P = 0.026$) (**Figure 8**; not all data shown). Before lunch, only the average score for oversatiety was significantly higher in obese than in normal-weight subjects. In

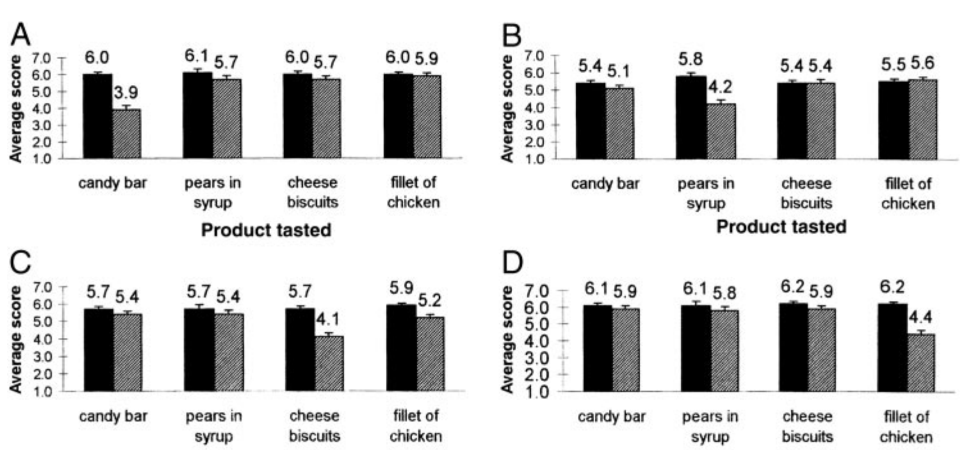

FIGURE 5. Mean (±SEM) score of pleasantness of taste of the snacks on a 7-point hedonic scale (1 = very unpleasant, 7 = very pleasant) before (■) and after (▨) eating 1 of the 4 products (chocolate candy bar, A; pears in light syrup, B; cheese crackers, C; fillet of chicken, D) to satiety for lunch ($n = 43$). The decline in the pleasantness of taste of eaten products was significantly ($P < 0.001$) greater than was the decline of pleasantness of uneaten products. Initial liking scores (before lunch) differed significantly between the products (P < 0.05). There were no significant differences between obese and normal-weight subjects.

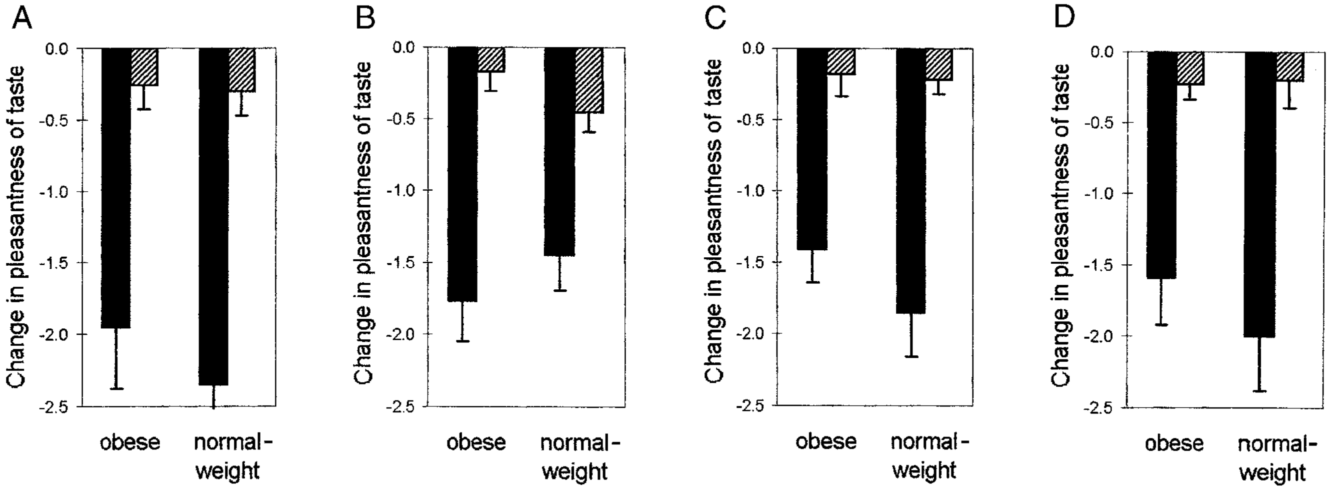

FIGURE 6. Mean (± SEM) decline in the pleasantness of taste of eaten (■) and uneaten (▨) products (chocolate bar, A; pears in syrup, B; cheese crackers, C; fillet of chicken, D) after ad libitum lunch (score after lunch –score before lunch on a 7-point hedonic scale: 1 = very unpleasant, 7 = very pleasant; $P < 0.001$) per group of subjects [obese (n = 22) and normal-weight (n = 21)]. No significant differences were observed between obese and normal-weight respondents, and no significant interactions were found for obesity, fat content, or taste (general linear model).

an ANOVA, a significant main effect for time and a significant effect for the time × obesity interaction were found, but the main effect for obesity was not significant.

DISCUSSION

The results of this study do not confirm the hypothesis that there is a difference in sensory-specific satiety between obese and normal-weight subjects for products with high fat content. In fact, this study indicates that there is no difference in the degree of sensory-specific satiety for any of the foods tested between obese and normal-weight subjects. Both groups showed strong sensory-specific satiety for all tested products, but no differences were found between the groups in either liking, sensory-specific satiety, or the amount of food eaten to satiety. In the sandwich study, a stronger sensory-specific satiety was found for products high in fat (for both groups of subjects together), but this effect was not found in the snack study.

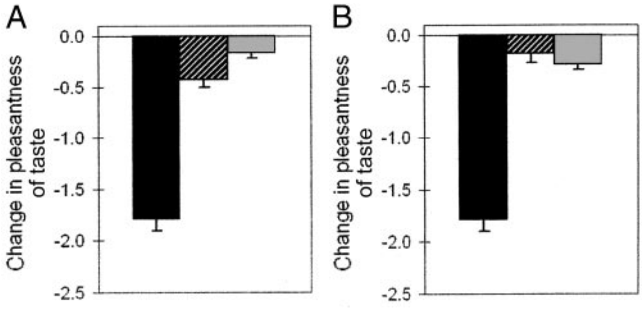

FIGURE 7. Mean (±SEM) decline in the pleasantness of taste (ie, liking) of snacks similar (▨) and dissimilar (▤) to lunch (■) in taste (sweet or savory; A) or fat content (low or high; B) after lunch (score after lunch –score before lunch on a 7-point hedonic scale: 1 = very unpleasant, 7 = very pleasant) (n = 43). Products similar to lunch in taste decreased more in liking than did products similar to lunch in fat content (P = 0.031).

Obese compared with normal-weight subjects

Although there were no differences in sensory-specific satiety, there was a difference in residual hunger between the obese and normal-weight subjects. In both studies, obese subjects had larger appetite ratings ($P < 0.05$) after the ad libitum consumption of the sandwiches and snacks, whereas the before-lunch scores did not differ. This could indicate that obese subjects, although they ate on average the same amount of food as did the normal-weight subjects and liked the products before and after the ad libitum lunch as much as did the normal-weight subjects, were expressing a greater "wanting" for more food. We speculate that the differences between the obese and normal-weight subjects refer to differences in "wanting" and not to differences in

TABLE 5
Average intake of ad libitum lunch per group and per product by weight and energy content[1]

Intake	Chocolate candy bar	Pears in light syrup	Cheese crackers	Fillet of chicken
Obese subjects, n = 21				
(g)	130 ± 52	335 ± 158	70 ± 27	164 ± 97
(kJ)	2432	911	1658	1094
Normal-weight subjects, n = 23				
(g)	122 ± 51	312 ± 119	71 ± 35	146 ± 49
(kJ)	2283	849	1681	974
Total subjects, n = 44				
(g)	126 ± 51	324 ± 140	70 ± 31	155 ± 78
(kJ)	2357	881	1658	1034

[1] No significant differences were observed between obese and normal-weight subjects (t test).

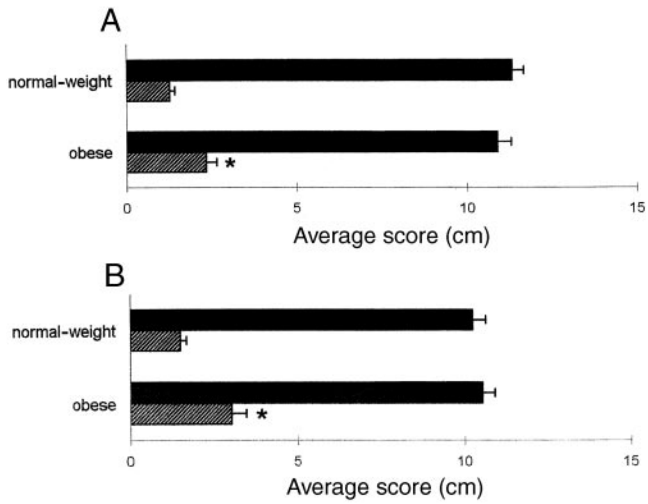

FIGURE 8. Mean (±SEM) ratings per group on two 15-cm visual analogue scales anchored by weak (0) and strong (15) scores for appetite for a meal (A) and appetite for a snack (B) before (■) and after (▨) ad libitum snack lunch ($n = 43$). There was a significant main effect for time ($P < 0.001$) and a significant time × obesity interaction effect ($P < 0.05$), but the main effect for obesity was not significant (ANOVA). *Significantly higher than ratings of normal-weight subjects, $P < 0.05$ (t test).

"liking" (31, 32). These results could also be explained on the basis of the higher energy needs of obese than of normal-weight subjects. An experiment like this does not distinguish between cause and effect. It does not answer the questions of whether greater appetite (after sensory-specific satiety) causes subjects to become overweight or whether the subjects' overweight status itself results in a higher energy need and hence a greater appetite. These questions need further investigation.

Differences between products

Sandwiches high in fat produced stronger sensory-specific satiety than did sandwiches with low fat content, but that was not the case for the snacks. Hence, the apparent effect of fat in the sandwich study is probably due to factors other than fat content.

Products with similar taste declined in liking more than did products with similar fat content. This seems logical, because fat does not seem to be a primary taste sensation, ie, one for which a specific chemoreceptor exists. This means that sensory-specific satiety due to the presence of fat results, in fact, from the effect of fat on taste, flavor, and texture. Effects from varied fat content are therefore expected to be less specific than are the sensory effects of primary taste sensations for which specific chemoreceptors exist [ie, sweet, salty, sour, bitter, and umami (the fifth basic taste: the taste of glutamate)].

In the sandwich study, consumption of sandwiches with roast beef led to the lowest sensory-specific satiety. Because roast beef was the topping with the highest protein content (Table 3), and because it has been reported that consumption of high-protein foods leads to higher sensory-specific satiety than does that of low-protein foods (12), this was unexpected. An alternative explanation for the relatively low sensory-specific satiety for the roast beef sandwiches might be that the taste intensity of roast beef is relatively weak, especially because it was served with 2 slices of bread and without salt or pepper. A product with weak taste intensity is likely to produce weaker sensory-specific satiety than are products with stronger tastes, such as pâté and chocolate spread.

Intakes in the sandwich study were comparable to the average lunch intakes of Dutch women (33). In the snack study, intake of the different products varied largely in weight and energy content. Calorie intake was especially high for the chocolate candy bars and especially low for the pears in light syrup, probably because of their different energy densities, which are high and low, respectively. However, energy density does not seem to be the only factor affecting intake. Sensory aspects may also play a role, such as the easy-to-eat texture of the pears, which may encourage intake, or the very dry texture of the cheese crackers, which may inhibit intake. The design of this study fails to distinguish between fat content and the energy density of foods as factors that may determine intake, appetite, and decrease in liking, because the higher-fat items are also higher in energy density.

Subjects were instructed to eat until they reached satiety. To check whether they really did so, an unexpected second course was offered during the last session. In this second course, subjects were offered all 4 products after all the rating had been completed, and they were invited to eat as much as they wanted. Average intakes in this second course were low (22 g in the sandwich and 16 g in the snack study) and were especially low (<3 g) for the product that they had eaten for lunch. These intakes indicate that subjects ate to satiety and confirms that their satiety was sensory specific.

The appetite ratings also confirmed that satiety was sensory specific. There were significantly stronger declines in "appetite for something sweet" after a sweet meal and in "appetite for something savory" after a savory meal in both experiments.

Ratings of "pleasantness of taste" were used to measure sensory-specific satiety. It has been suggested that initial palatability is an important factor in determining sensory-specific satiety, but a significant effect has not been reported (3, 4). Although initial liking scores were found to differ somewhat between obese and normal-weight subjects in the study described here, these differences apparently had no effect on sensory-specific satiety observed in the obese and normal-weight subjects.

It is conceivable that the level of restraint in eating affects sensory-specific satiety, and we therefore investigated this possibility. A median split in the restrained-eating score resulted in 2 groups: one with subjects with a mean restrained-eating score >2.90 and one with subjects with a mean restrained-eating score <2.90. The first group had a mean (± SD) sensory-specific satiety score of 0.94 ± 0.83, and the second group had a score of 0.66 ± 1.04), but the mean sensory-specific satiety scores of the 2 groups did not differ significantly ($t = 1.003$, $P = 0.322$). Similarly, no significant correlation was found for the relation between sensory-specific satiety and restrained-eating score (Spearman's $\rho = 0.239$, $P = 0.118$).

In this and other studies, sensory-specific satiety is measured through comparing subjective ratings before and after ad libitum consumption. Appetite was also assessed in this way. These scales have generally been shown to be reliable and valid, in the sense that they predict intake and choice (34). However, these ratings reflect conscious, rationalized liking and wanting. Berridge (32) suggested, "Subjective reports may contain false assessments of the underlying processes, or even fail to register important reward processes. The core processes of liking and wanting that constitute reward are distinct from the subjective report or conscious awareness of those processes."

The observations of Berridge (32) suggest that we must find better ways to measure liking and wanting if we are to study possible differences between obese and normal-weight humans. One way might be with the help of neuroimaging techniques to study sensory-specific satiety, as was done by O'Doherty and Rolls (35). Another way might be the design of behavioral experiments that measure "liking" and "wanting" in a more reliable (indirect) way than do subjective ratings. Epstein et al have conducted several such studies (36).

In conclusion, the results of this study show that obese and normal-weight subjects do not differ in sensitivity to sensory-specific satiety and suggest that taste is more important than is fat content in causing sensory-specific satiety. After eating a single product to satiety, obese subjects still had more appetite than did normal-weight subjects.

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The main investigator of this study was HMS, who prepared for and carried out the main body of the work, interpreted the results, and wrote a large part of this manuscript. LH and LJvG contributed to the planning and the practical work itself. Planning, processing the results, and writing the manuscript were done, under general supervision, by CdG and HW. The authors had no conflicts of interest.

REFERENCES

1. Rayner HA, Epstein LH. Dietary variety, energy regulation, and obesity. Psychol Bull 2001;127:325–41.
2. Rolls BJ, Rolls ET, Rowe EA, Sweeney K. Sensory-specific satiety in man. Physiol Behav 1981;27:137–42.
3. Rolls BJ, Rowe EA, Rolls ET, Kingstone B, Megson A. A variety in a meal enhances food intake in man. Physiol Behav 1981;26:215–21.
4. Rolls ET, Murzi E, Yaxley S, Thorpe SJ, Simpson SJ. Sensory specific satiety: food specific reduction in responsiveness of ventral forebrain neurons after feeding in the monkey. Brain Res 1986;368:79–86.
5. Hetherington M, Rolls BJ, Bruley VJ. The time course of sensory-specific satiety. Appetite 1989;12:57–68.
6. Rolls ET, Rolls JH. Olfactory sensory-specific satiety in humans. Physiol Behav 1997;3:461–73.
7. Johnson J, Vickers Z. Factors influencing sensory-specific satiety. Appetite 1992;19:15–31.
8. Hetherington MM. Sensory-specific satiety and its importance in meal termination. Neurosci Biobehav Rev 1996;20:113–7.
9. Rolls BJ, Fedoroff IC, Guthrie JF, Laster LJ. Foods with different satiating effects in humans. Appetite 1990;15:115–26.
10. Johnson J, Vickers Z. Effects of flavor and macronutrient composition of food servings on liking, hunger and subsequent intake. Appetite 1993;21:25–39.
11. Miller DL, Bell EA, Pelkman CL, Peters JC, Rolls BJ. Effects of dietary fat, nutrition labels, and repeated consumption on sensory-specific satiety. Physiol Behav 2000;71:153–8.
12. Vandewater K, Vickers Z. Higher-protein foods produce greater sensory-specific satiety. Physiol Behav 1996;59:579–83.
13. de Graaf C, Schreurs A, Blauw YH. Short-term effects of different amounts of sweet and nonsweet carbohydrates on satiety and energy intake. Physiol Behav 1993;54:833–43.
14. Vickers Z, Holton E, Wang J. Effect of yoghurt sweetness on sensory-specific satiety. J Sensory Stud 1998;13:377–88.
15. Kamphuis MMJW, Westerterp-Platenga MS, Saris WHM. Fat-specific satiety in humans for fat high in linoleic acid vs fat high in oleic acid. Eur J Clin Nutr 2001;55:499–508.
16. Lawton CL, Burley VJ, Wales JK, Blundell JE. Dietary fat and appetite control in obese subjects: weak effects on satiation and satiety. Int J Obes Relat Metab Disord 1993;17:409–16.
17. Rolls BJ, Kim-Harris S, Fischman MW, Foltin RW, Moran TH, Stoner SA. Satiety after preloads with different amounts of fat and carbohydrates: implications for obesity. Am J Clin Nutr 1994;60:476–87.
18. Golay A, Bobbioni E. The role of dietary fat in obesity. Int J Obes Relat Metab Disord 1997;21(suppl):2–11.
19. Bell EA, Castellanos VH, Pelkman CL, Thorwart ML, Rolls BJ. Energy density of foods affects energy intake in normal-weight women. Am J Clin Nutr 1998;67:412–20.
20. Green SM, Wales JK, Lawton CL, Blundell JE. Comparison of high-fat and high-carbohydrate foods in a meal or snack on short-term fat and energy intakes in obese women. Br J Nutr 2000;84:521–30.
21. Bell EA, Rolls BJ. Energy density of foods affects energy intake across multiple levels of fat content in lean and obese women. Am J Clin Nutr 2001;73:1010–8.
22. Mela DJ, Sacchetti DA. Sensory preferences for fats: relationships with diet and body composition. Am J Clin Nutr 1991;53:908–15.
23. Drewnowski A, Kurth C, Holden-Wiltse J, Saari J. Food preferences in human obesity: carbohydrates versus fats. Appetite 1992;18:207–21.
24. Lissner L, Lindroos AK, Sjostroom L. Swedish obese subjects (SOS): an obesity intervention study with a nutritional perspective. Eur J Clin Nutr 1998;52(5):316–22.
25. Rolls BJ, Andersen AE, Moran TH, McNelis AL, Baier HC, Fedoroff IC. Food intake, hunger, and satiety after preloads in women with eating disorders. Am J Clin Nutr 1992;55:1093–103.
26. Rolls BJ, McDermott TM. Effects of age on sensory-specific satiety. Am J Clin Nutr 1991;54:988–96.
27. Epstein LH, Paluch R, Coleman KJ. Differences in salivation to repeated food cues in obese and non-obese women. Psychosomat Med 1996;58:160–4.
28. McCrory MA, Fuss PJ, McCallum JE, et al. Dietary variety within foods groups: association with energy intake and body fatness in men and women. Am J Clin Nutr 1999;69:440–7.
29. van Strien T, Frijters JER, Bergers GPA, Defares PB. Nederlandse vragenlijst vooreetgedrag. (Dutch Eating Behavior Questionnaire.) Lisse, Netherlands: Swets & Zeitlingen BV, 1986 (in Dutch).
30. NEVO. Nederlandse voedingsmiddelentabel. (Dutch nutrient database table.) The Hague, Netherlands: Voorlichtingsbureau van de Voeding, 2001 (in Dutch).
31. Raynor HA, Epstein LH. Dietary variety, energy regulation, and obesity. Psychol Bull 2001;127(3):325–41.
32. Berridge K. Food reward: brain substrates of wanting and liking. Neurosci Biobehav Rev 1996;20:1–25.
33. Voedingscentrum. Zo eet Nederland, resultaten van de Voedselconsumptiepeiling 1997–1998. (Results of the Dutch national food consumption survey 1998.) Den Haag, Netherlands: Voedingscentrum, 1998:70–1.
34. De Graaf C. The validity of appetite ratings. Appetite 1993;21:156–60.
35. O'Doherty J, Rolls ET, Francis S, et al. Sensory specific satiety-related activation of the human orbitofrontal cortex. Neuroreport 2000;11:893–7.
36. Saelens BE, Epstein LH. Reinforcing value of food in obese and non-obese women. Appetite 1996;27:41–50.