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Sensory Specific Satiety in Man[1]

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ROLLS, B. J., E. T. ROLLS, E. A. ROWE AND K. SWEENEY. *Sensory specific satiety in man.* PHYSIOL. BEHAV. 27(1) 137–142, 1981.—To investigate the specificity of satiety in man, subjects (n=32) rated the pleasantness of the taste of eight foods, were then given one of the foods to eat for lunch, and re-rated the pleasantness of the taste of the eight foods 2 and 20 min after the end of the meal. The pleasantness of the food eaten decreased more than that of the foods not eaten ($p<0.001$). In a second experiment it was shown that this relative specificity of satiety influenced subsequent food intake. Before a first course, subjects (n=24) rated their liking for the taste of eight foods, were then given one of the foods to eat for lunch, and 2 min after finishing eating re-rated their liking for the taste of the eight foods. Again liking decreased more for the food eaten than for foods not eaten. These changes in liking for the foods eaten and not eaten were highly correlated ($p<0.001$) with the amounts of those foods eaten in an unexpected second course. Thus in man satiety can be partly specific to foods eaten and this specificity may be an important determinant of the foods selected for consumption.

Specificity of satiety   Taste   Food intake

WHILE recording from lateral hypothalamic neurons which responded to the sight and/or taste of food in the alert behaving monkey, E. Rolls and his colleagues observed that the responses of these neurons became attenuated to the sight and/or taste of the food on which the animal was satiated, but continued to respond to other foods which had not been used to produce satiety [2, 17, 18, 19]. It was also observed that the monkeys continued to accept these other foods while rejecting the food on which they had satiated. This finding suggests that satiety may not be completely general, but rather may be at least partly specific to the particular food consumed. This led to the present investigation of satiety and its specificity in man.

In relation to satiety in man it has been shown that the pleasantness of the taste or smell of food-related test stimuli was decreased by a 50 g load of glucose which was either swallowed or delivered intragastrically [3, 4, 6, 7]. Cabanac and his colleagues [6,8] showed that the glucose load decreased the pleasantness of sucrose solutions but not of salt solutions, and that eating a meal decreased the pleasantness of food-related odors but not of non-food-related odors. They have argued from these findings that there is modulation of the hedonic responses to food produced by the internal nutritional state which could be important in controlling feeding, and have called the phenomenon "alliesthesia" (literally, changing sensation) [3].

On the basis of these findings in the monkey and man, we performed the experiments described here, to investigate whether in man there is a satiety mechanism specific for foods eaten. In Experiment 1, the possibility that the pleasantness of the taste of food might decline more for a food eaten than for other foods not eaten was investigated. It was found in this experiment that there was a decline in pleasantness which was at least partly specific for a food which had been eaten. This raised the possibility that after one food has been eaten to satiety and its pleasantness has declined, only little of that food may be eaten subsequently, whereas for foods which have not been eaten and remain relatively pleasant to taste, relatively more is eaten. This was investigated in Experiment 2. Part of the design of these experiments was that real foods were tasted and eaten, in order to obtain results as relevant as possible to normal eating.

EXPERIMENT 1

The aim of this experiment was to determine whether consumption of one food decreased the pleasantness of the taste of that food more than it decreased the pleasantness of other foods which were not eaten.

METHOD

Each subject rated the pleasantness of the taste of eight foods (listed in Fig. 1), was then given one of the foods to eat to satiety for lunch, and then re-rated the pleasantness of the taste of eight foods at 2 and 20 min after the termination of eating. Each type of food was eaten by four subjects and each subject was tested once. The ratings at 2 min after the termination of eating were taken to assess relatively fast changes produced by the consumption which contributed to the termination of eating, and the ratings at 20 min to assess how long the changes of pleasantness persisted after eating, and whether they changed as absorption and metabolism of the food eaten progressed.

The 32 volunteer subjects were healthy normal weight male (N=17) and female (N=15) students aged 18–29 years. All subjects except one were within 15% of the maximum

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desirable weight for height and frame size given in the Metropolitan Life Insurance Tables [10]. They were instructed to eat a normal breakfast and to come to the laboratory for lunch. Subjects tasted the eight foods successively, and between each rated the pleasantness of the taste. The foods were not swallowed and the mouth was rinsed with water between each food. Subjects were then provided with one of the foods to eat (the meal, which was assigned at random) in greater quantity than they could eat and were instructed to eat until they felt satisfied. Two and 20 min after the end of the meal subjects re-rated the eight foods tasted previously. The foods tasted were chicken, beef (high protein content); walnuts, diabetic chocolate (high fat content), cookies (high carbohydrate and fat content) and raisins, white bread, tinned potatoes (high carbohydrate content). The rating scale for the pleasantness of the taste of food was similar to that used by Cabanac [3], and was +2 (very pleasant), +1 (pleasant), 0 (neutral), −1 (unpleasant), −2 (very unpleasant), with subjects being encouraged to use half points. A separate rating sheet was used for the three times when ratings were made (i.e. pre-eating, and 2 and 20 min after the termination of eating), and the experimenter collected each rating sheet as soon as it had been completed. When the subjects had finished the experiment the remainder of the test meal was weighed and the amount eaten calculated.

RESULTS

The change in the pleasantness of each of the foods eaten at 2 and 20 min after the subjects had eaten to satiety is shown in Fig. 1. The change in pleasantness is calculated throughout this paper by subtracting the pre-eating rating of the pleasantness of the taste of food on the +2 to −2 scale, from the rating of the pleasantness of the taste of the same food on the same scale at 2 or 20 min after the termination of eating. A negative change in pleasantness means that the food has become less pleasant. In Fig. 1 each of the hatched bars below a food indicates the mean change in pleasantness for the four subjects who ate that food to satiety. For comparison, the mean change in pleasantness for the seven foods tasted but not eaten for each set of four subjects is shown by the corresponding open bars in Fig. 1. Averaged over the 32 subjects, the change in pleasantness between the ratings taken before eating and the ratings taken 2 min after the termination of eating was for the food eaten -0.97 ± 0.12 SEM and for the foods not eaten -0.27 ± 0.05 (see TOTAL histograms, Fig. 1). This difference between the change for the food eaten vs the change for the foods not eaten was highly significant (matched pairs t test, $t(31)=5.47$, $p<0.001$; one factor repeated measures analysis of variance, of the eight tasted food conditions, with one food condition the food eaten, and the other seven the foods not eaten, $F(7,224)=4.6$, $p<0.001$, with a Newman-Keuls analysis showing that the decline in pleasantness was greater for the food which had been eaten than for the seven foods not eaten, $p<0.01$ in each case, which latter did not differ significantly from each other). These statistical results with the rating scale used were confirmed using non-parametric tests, including the Wilcoxon matched pairs signed-ranks test and the Friedman analysis of variance. A greater reduction in the pleasantness of a food eaten compared to the other foods tasted but not eaten was also found when most of the foods were considered individually. For example, the taste of chicken had altered in pleasantness by −1.25 two min after it had been eaten to satiety,

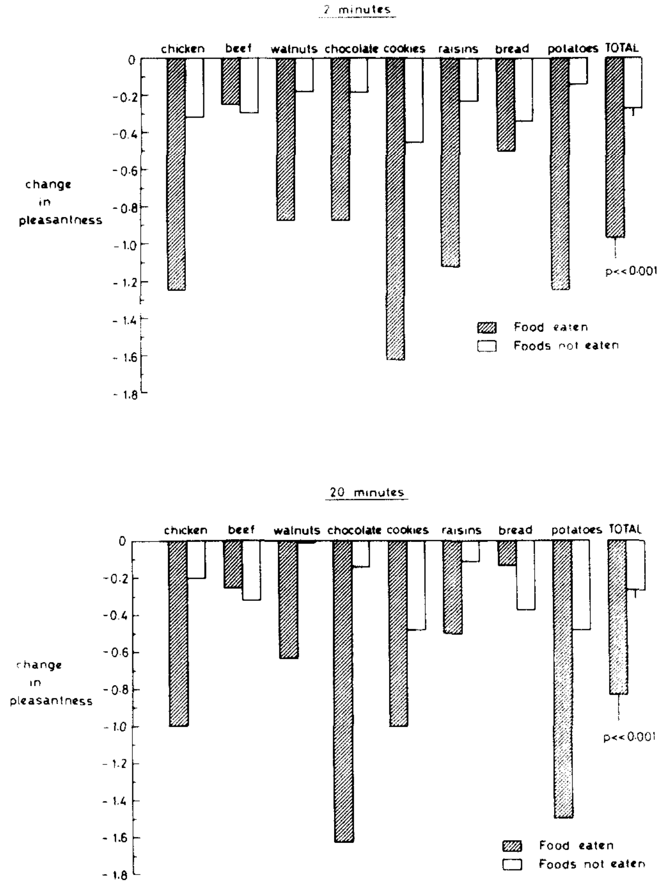

FIG. 1. The effect of eating one food to satiety on the subjective pleasantness of that food and other foods which had not been eaten. Subjects (N=32) rated eight foods on a scale where +2 was very pleasant and −2 very unpleasant. After this initial rating they ate one of the foods to satiety (four subjects per individual food). The figure shows the mean changes in subjective pleasantness when the foods were tasted again 2 min (upper figure) and 20 min (lower figure) after the end of the meal. The "total" figures show that the mean (±SEM) decrease in pleasantness was significantly greater for all of the foods which had been eaten than for all of the foods which had not been eaten.

TABLE 1

TASTE RATINGS OF FOODS BEFORE AND AFTER SATIETY

N	First Course (eat as much as like)	Unexpected second course (eat as much as like)
8	Sausage	Sausage
8	Cheese on cracker	Cheese on cracker
4	Sausage	Cheese on cracker
4	Cheese on cracker	Sausage
	do ratings	do ratings 2 min after meal
	Δrating	

Subjects were given a first course followed by a second course of either the same or a different food. Subjects rated the food they were given in the first course and seven other foods for how much they liked the taste and how much they would like to eat before and 2 min after the first course. They were unaware that they would receive the second course until the second rating was complete.

while the pleasantness of the other seven foods not eaten had altered by −0.32 (see Fig. 1). This effect was found for seven of the foods (chicken, walnuts, chocolate, cookies, raisins, bread and potatoes), but not for the roast beef (which remained pleasant to our undergraduate subjects even after they had eaten it!) Twenty minutes after the termination of eating one of the foods to satisfaction, there was still a relatively greater reduction in the pleasantness of the foods eaten (average change= -0.83 ± 0.15) compared to the foods not eaten (average change= -0.26 ± 0.05) (see TOTAL histograms, Fig. 1). Tested as before, this difference was still highly significant ($t(31)=3.6$, $p<0.001$, $F(7,224)=2.77$, $p<0.025$, with the Newman-Keuls analysis showing that the decline in pleasantness was greater for the food which had been eaten than for the seven foods not eaten, $p<0.05$ in each case, which latter did not differ significantly from each other). As before these statistical results were confirmed using the non-parametric Wilcoxon matched pairs signed-ranks test and the Friedman analysis of variance.

DISCUSSION

These results show that after hungry human subjects have eaten as much as they want of a food, the pleasantness of the taste of that food declines, while the pleasantness of the taste of other foods is much less affected. This was demonstrated both 2 and 20 min after the end of eating and for seven of the eight foods eaten. Thus at least some specificity in the satiating effects of individual foods is demonstrated.

EXPERIMENT 2

The aim of this experiment was to determine whether the partly specific reduction in the pleasantness of a food eaten relative to foods not eaten, which was demonstrated in Experiment 1, might be associated with relatively little consumption of the food just eaten, but relatively much consumption of foods not just eaten.

METHOD

Each subject rated the pleasantness of the taste of eight foods, was then given one of the foods to eat to satiety for lunch, re-rated the pleasantness of the taste of the eight foods 2 min after he had finished eating, and was then unexpectedly given a second course of food, which was either the same as or different from that which he had just eaten (see Table 1). The amounts eaten in the second course could then be related to whether that food had become much less pleasant because it had been eaten in the first course. In this experiment although eight foods were tasted, there were only two types of food eaten. These two foods were sausages (English pork sausages, which are relatively unseasoned, and which are relatively high in protein; 14%) and cheese (mild cheddar) on crackers (Crawford's cheddars). These foods have similar digestible energy contents (sausage 18 kJ/g; cheese 20 kJ/g; crackers 22 kJ/g from published values and confirmed calorimetrically) and in pilot experiments were found to be eaten in approximately equal amounts. There were 24 subjects, eight of whom had sausages for the first and second courses, eight of whom had cheese on crackers for the first and second courses, and eight of whom had different first and second courses (four had sausages followed by cheese on crackers, and four had cheese on crackers followed by sausages). Subjects were randomly assigned to the different groups.

The details of the experiment were generally similar to those in Experiment 1, except where noted below. The 24 volunteer subjects (22 male) were normal weight students aged 19–25 years. All subjects except two were within 15% of the maximum desirable weight for height and frame size given in Metropolitan Life Insurance tables [10]. They were instructed to eat a normal breakfast and to come to the laboratory for lunch. Before the first course, they were given similar typed instructions to those used previously. First they rated by tasting without swallowing how much they liked the taste of the eight foods, and how much they wanted to eat. In this experiment 'liking' was substituted as an alternative for 'pleasantness,' and results were similar to those obtained in Experiment 1. For ratings of liking of the taste the scale was: +2=very strong liking, +1.5=strong liking, +1=mild liking, +0.5=very mild liking, 0=indifferent, −0.5=very mild dislike, −1=mild dislike, −1.5=strong dislike, −2=very strong dislike. For ratings of the amount of a particular food a subject would like to eat the scale was: +2=very large amount, +1=large amount, 0=medium amount, −1=small amount, −2=none at all). The mouth was rinsed with water between each tasting. The foods tasted were cheese on crackers (high protein, carbohydrate and fat content); sausages (high protein and fat content); chicken (high protein content); walnuts (high fat content); cookies (high carbohydrate and fat content); bread, raisins and bananas (high carbohydrate content). Then the subjects were given a plate of food with instructions that this was their lunch, and that they should eat as much as they wanted. As noted above, for 12 subjects the meal consisted of sausages, and for 12 of cheese on crackers. Two min after they finished their meal they re-rated the eight foods tasted previously. Then they were offered the unexpected second course, of either cheese on crackers or sausages, which was either the same as or different from the first course, and were instructed to eat as much of it as they wanted.

RESULTS

The changes in the liking of the different foods, and in the quantities the subjects wished to eat, 2 min after the first course of sausages (12 subjects) or cheese and crackers (12 subjects) are shown in Fig. 2. The average change in liking for the food eaten (averaged over sausage and cheese on cracker) was -1.06 ± 0.18, and for the seven foods not eaten was $+0.01\pm0.03$. This difference was significant, $t(23)=6.7$, $p<0.001$. An analysis of variance with the foods tasted as one factor (with one level the foods tasted and eaten, and the other seven levels the foods tasted but not eaten) and with the food eaten (either cheese on crackers or sausages) as the other factor showed a significant difference between the change in ratings after food was eaten, $F(7,154)=10.8$, $p<<0.001$. Subsequent Newman-Keuls analysis showed that the decrease in the liking of the foods eaten was greater than that of the seven foods not eaten, $p<0.01$. This finding, that in general there is a greater decrease in the pleasantness for or liking of foods eaten relative to foods not just eaten confirms the results of Experiment 1. In Fig. 2, it is also possible to see how the liking for all the foods tasted is affected by eating either sausages or cheese on crackers. It is notable, and consistent with the interactions observed in Experiment 1, that eating sausages decreased the liking of chicken (another meat), and that eating sausages or cheese on crackers tended to increase the liking of sweet foods such as cookies, raisins, or bananas. (The Newman-Keuls analysis described

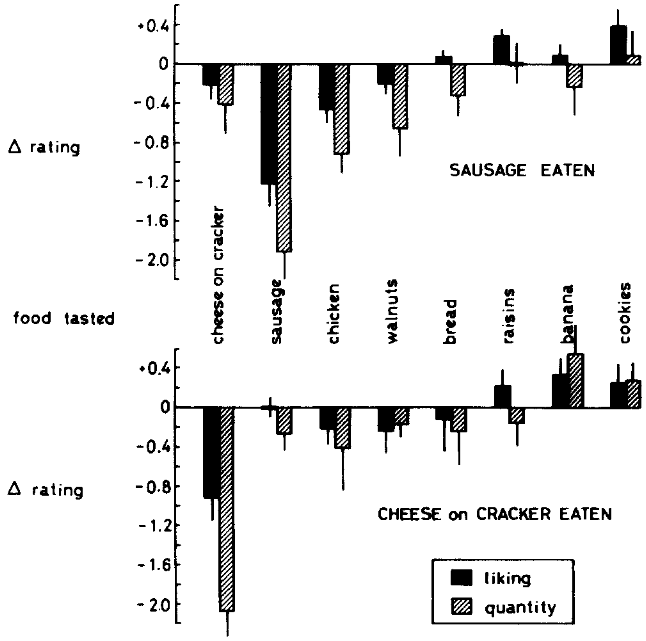

FIG. 2. The mean change in ratings (+SEM) of liking of the taste and the quantity subjects wanted to eat from before the first course to two minutes after the first course, for the food eaten in the first course and seven other foods. The results are shown separately for sausage (upper figure) and cheese on crackers (lower figure) in the first course.

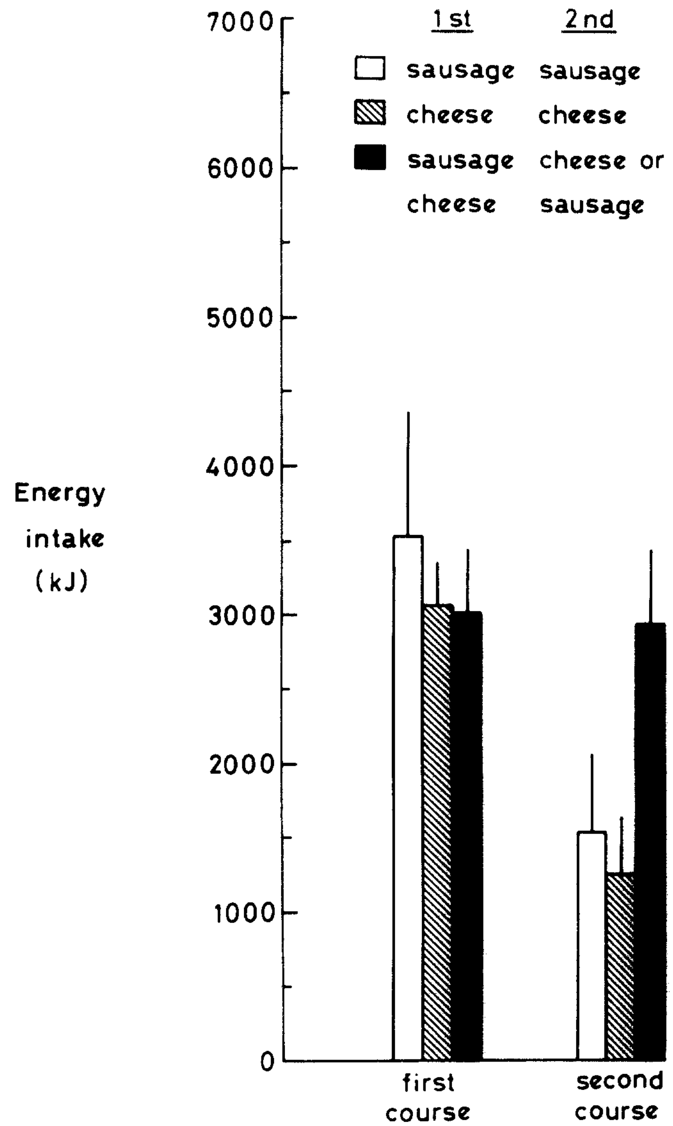

FIG. 3. The mean energy intakes (+SEM) in the first course and the second course, for subjects eating the same food in the second course (shown separately for sausages N=8 and cheese on crackers N=8) and for the subjects eating a different food in the second course from the first course (data for sausages and cheese on crackers combined N=8).

above showed that the decrease in the liking of chicken was different from the change of liking of the foods eaten, $p<0.01$, and different from the change in liking of raisins, bananas and cookies, each $p<0.05$). The changes in the ratings of the quantity of a food the subjects wanted to eat are also shown in Fig. 2 (quantity) and show a similar suppression to liking for foods eaten (−2.0±0.19) compared to that for foods not eaten (−0.2±0.1, $t(23)=15.6$, $p<0.001$; analysis of variance as above, $F(7,149)=17.0$, $p<0.001$; Newman-Keuls analysis as above, $p<0.01$).

The energy intakes in the first and second courses are shown in Fig. 3. It is clear that in the second course, the subjects ate more when they were given a different food than when given the same food (2937±525 kJ for the different food, N=8, 1394±323 kJ for the same food, N=16, $t=2.8$, $p<0.01$). An analysis of variance showed that the amounts eaten in the first course did not differ, and that more was eaten of the different food than of the same food in the second course, ($p<0.01$).

The relation between the decrease in the liking for a particular food, and the amount of it eaten in the second course, is shown in Fig. 4. The change in liking for the food eaten in the first course averaged over sausages and cheese on crackers, was −1.2±0.2, and the amount of the same food eaten in the second course was 98±7.2% of that eaten in the first course (N=8). There was a significant correlation of 0.68 (Spearman rank correlation coefficient, df=22, $p<0.001$) between the change in liking in the first course and the energy intake in the second course (expressed as a percentage of the intake in the first course). Similar effects were found for the rating of the quantity of food the subjects wanted to eat; this was decreased for the food just eaten and the degree of this change was correlated with the amount subsequently eaten in the second course (Spearman's rho=0.66; df=22; $p<0.001$).

DISCUSSION

When the liking for a particular food is decreased because it is eaten in a first course, this decrease in liking is associated with a lower intake of that particular food in a second course. If the food was not eaten in the first course, the liking

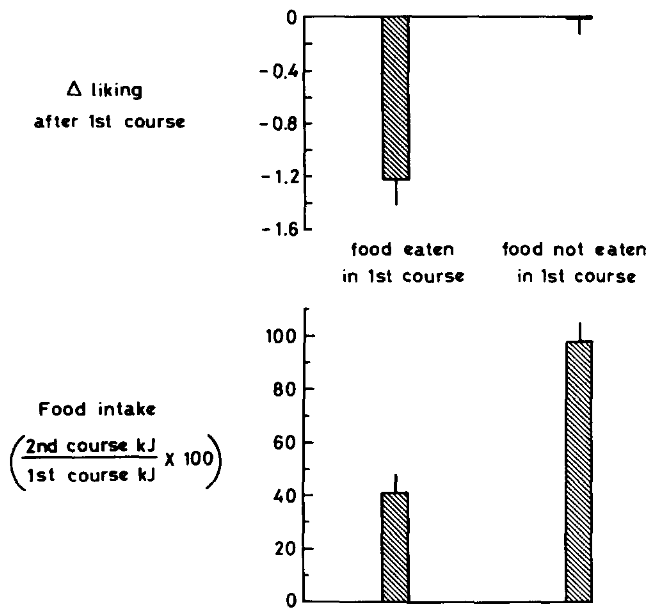

FIG. 4. Upper figure: the change in the subjective liking after the first course for food eaten (sausages or cheese on crackers) and for the food not eaten (cheese on crackers or sausages) after the first course. Lower figure: the corresponding food intakes in the second course expressed as a percentage of the first course for the subjects given the same food in the second course as in the first, or the different food in the second course. There is a strong correlation between the change in liking for a food and the amount that will be eaten.

for it was only little, if at all decreased and this was associated with a relatively large quantity of it eaten in the second course.

GENERAL DISCUSSION

The results of Experiments 1 and 2 show that satiety in man is at least partly specific. In both experiments, after subjects had eaten one food to satiety, the pleasantness of its taste decreased more than that of other foods tasted, but not eaten. In Experiment 1 it was found that the change in rating was of rapid onset but was not just transient, and persisted for long enough to hold off further eating of foods already consumed throughout the remainder of a normal length meal. The depression in the ratings was found to be relatively specific to the food eaten even if the foods were of similar composition (e.g. high protein, carbohydrate, or fat content). In Experiment 2 it was shown that the subsequent eating was closely associated with the relatively specific reduction in the pleasantness of the food eaten. Relatively little food was eaten if it was offered in a second course when the pleasantness of the taste of the food had been reduced after the first course. In contrast other uneaten foods remained relatively pleasant after the first course, and relatively much was eaten in the second course.

Factors which may be important in the clear changes in liking or pleasantness found in these experiments are that the foods were carefully chosen to be well liked, and different from one another in taste, texture and appearance although of approximately equal energy densities. Also, the subjects were instructed to eat until they were satisfied, rather than being given a fixed, and perhaps only partly satiating portion. Clearly, it will be of interest to investigate on what bases interactions between different foods eaten occur.

Although changes in ratings of pleasantness, from an initial pre-eating value to the value after eating, have been presented so far, it is interesting to consider also the absolute values of the ratings given by the subjects. One finding was that the pleasantness of the taste of food was on average close to '0' (i.e. rated as indifferent, neither pleasant nor aversive) after that food had been eaten to satiety. In Experiment 1 the absolute pleasantness rating was -0.33 ± 0.15 (mean$\pm$SEM), N=32, and in Experiment 2 was 0.08 ± 0.19, N=24, after a food had been eaten to satiety compared to absolute values of 0.78 ± 0.13 (Experiment 1) and 1.06 ± 0.12 (Experiment 2) for the same foods before they had been eaten to satiety. (In other experiments, the mean absolute rating of the pleasantness of foods after they had been eaten was -0.10 ± 0.17, N=32.) Thus it may be suggested that on average a food is eaten until it has stopped tasting pleasant, so that eating stops before it has become aversive.

In relation to this suggestion it is of interest that in the neurophysiological experiments [2, 17, 18, 19] described in the introduction, neurons were found in the hypothalamus of the monkey which ceased to respond to a food with which the monkey had been fed to satiety (yet which still responded to other foods). Additional evidence consistent with the suggestion that the responses of these neurons are involved in whether a food is accepted (or rewarding) is that these neurons were activated by rewarding electrical stimulation of some brain sites, and that brain-stimulation reward in the region of these neurons was attenuated after the monkeys were fed to satiety [20] (see also [16]).

Booth [1] has found that foods rated as very pleasant at the start of a meal decrease more in pleasantness after eating than do foods initially rated as less pleasant. This does not account for the greater decline in pleasantness of foods eaten than foods not eaten over a meal in the present experiments because the absolute rating of the food eaten became lower after the meal than that of the food not eaten (e.g. in Experiment 2 the absolute value after eating of the food eaten was 0.08 ± 0.19 and of the food not eaten, i.e. either sausages or cheese on crackers, was 0.85 ± 0.17, $t(23)=3.5$, $p<0.01$). Also, although there was a positive correlation between the initial pleasantness of the food eaten and the reduction in pleasantness produced by eating (e.g. r=0.31, df=22, n.s., Experiment 2), this was low and not statistically significant.

The present results are consistent with the view that, though working in conjunction with internal satiety signals, external factors such as the sight, smell, taste, and texture of food provide some degree of specificity to satiety. It is worthwhile to consider some of the possible mechanisms through which such specific satieties might act. Cabanac and his colleagues suggested that the change they observed in the pleasantness of sucrose solutions or food-related odors after a preload of glucose was due to changes in the internal state or need for particular nutrients [3,8]. The decrease in pleasantness was found only if the substance ingested was similar to that tasted, i.e. glucose affected sucrose but not salt. This decrease in the pleasantness of sucrose solutions developed slowly after a glucose load, and maximal changes were seen about 45 min after the load. If sucrose was swilled in the mouth, but expectorated rather than swallowed, there was no change in the pleasantness of sweet solutions. Changes in pleasantness were also observed when the glucose was tubed directly into the stomach or the duodenum [5]. Thus these results favor the post-ingestive consequences of a load as being necessary for the changing sensation. Other studies, however, favor the hypothesis that the sensory qualities of the load or meal at least contribute to the decrease in pleasantness. The non-nutritive sweetener, cyclamate, has been found to be nearly as effective as glucose in reducing the pleasantness of sucrose [19]. In other experiments we have found that a low energy orange drink reduced the pleasantness of itself, and low energy meat-flavored soup reduced the pleasantness of itself, but these drinks produced little reduction in the pleasantness of each other. Metabolic effects of the liquids probably had minimal effects on the change in pleasantness in this experiment. Also our present studies while not discounting the possibility that post-absorptive factors are involved, indicate that either sensory or cognitive factors must be important in that the change in pleasantness was found just two minutes after the end of the meal when there had been little opportunity for absorption. Another point is that the change in pleasantness tends to be specific to the food eaten. Because this phenomenon can be at least partly specific for the sensory qualities of the food eaten, and is not solely dependent on metabolic feedback, we call the phenomenon "sensory-specific satiety" [9].

If the phenomenon we are studying is sensory, is it simply due to sensory adaptation or habituation? We cannot discount these possibilities but the effect lasted for at least 20 min and there was no indication that when doing the ratings subjects were unable to taste the food they had been eating. Also, when Mower *et al.* [11] studied the effect of a meal on olfactory stimuli, although they observed some decreases in pleasantness, there were no changes in the perceived intensity of the stimuli. There is no way at present of knowing how important cognitive factors are for the change in sensation. It is possible that since people appear to learn how much of a particular food they can eat [1], when this limit is exceeded the food becomes unpleasant.

Having a variety of foods available aids the selection of a nutritionally balanced diet. The present studies indicate that there is an inbuilt mechanism which helps to ensure that a variety of foods, and thus of nutrients, is consumed. As a particular food is eaten its taste is liked less, but the taste of the other foods and the desire to eat them remains relatively unchanged. Thus to keep palatability at a high level a varied diet is selected. The changes in liking for foods eaten and not eaten are highly correlated with the amounts of those foods which will be eaten if an unexpected second course is offered. This implies that more will be eaten of a varied meal than of one consisting of a single food. In other studies we have shown that food intake during a meal is enhanced by providing either a variety of sandwiches with different fillings or different flavors of yogurt which vary in taste, texture and appearance [12, 13, 14, 15]. The long-term effects of variety on the maintenance of body weight are not yet established but it may be suggested that having a variety of foods readily available could contribute to the development of obesity because of the specific component of satiety investigated in this paper.

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