Physiology & Behavior, Vol. 29, pp. 409–417. Pergamon Press, 1982. Printed in the U.S.A.

How Sensory Properties of Foods Affect Human Feeding Behavior

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Received 6 March 1982

ROLLS, B. J., E. A. ROWE AND E. T. ROLLS. *How sensory properties of foods affect human feeding behavior.* PHYSIOL. BEHAV. 29(3)409–417, 1982.—The sensory properties of food which can lead to a decrease in the pleasantness of that food after it is eaten, and to enhanced food intake if that property of the food is changed by successive presentation of different foods, were investigated. After eating chocolates of one color the pleasantness of the taste of the eaten color declined more than of the non-eaten colors, although these chocolates differed only in appearance. The presentation of a variety of colors of chocolates, either simultaneously or successively, did not affect food intake compared with consumption of the subject's favorite color. Changes in the shape of food (which affects both appearance and mouth feel) were introduced by offering subjects three successive courses consisting of different shapes of pasta. Changes in shape led to a specific decrease in the pleasantness of the shape eaten and to a significant enhancement (14%) of food intake when three shapes were offered compared with intake of the subject's favorite shape. Changes in just the flavor of food (i.e., cream cheese sandwiches flavored with salt, or with the non-nutritive flavoring agents lemon and saccharin, or curry) led to a significant enhancement (15%) of food intake when all three flavors were presented successively compared with intake of the favorite. The experiments elucidate some of the properties of food which are involved in sensory specific satiety, and which determine the amount of food eaten.

Food intake Pleasantness Sensory-specific satiety Satiety Variety

CABANAC and his colleagues [3, 4, 5, 6] have shown in man 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. They also 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 [5,8]. We have shown that during a meal the pleasantness of foods which have been eaten declines more than the pleasantness of foods which have not been eaten. These changes in pleasantness are apparent as soon as two minutes after the end of a meal, before there has been time for much absorption, so that they are probably caused in part by sensory or cognitive, rather than by post-absorptive factors [13]. Consistent with this, the decrease in pleasantness can be relatively specific to the particular food which has been eaten, even when some of the other non-eaten foods are nutritionally similar [13]. Further, in other experiments we have found specific decreases in pleasantness when the substance ingested had little energy content, e.g., low energy orange drink versus a meat extract flavored drink. Because these changes were partly specific to the sensory properties of each food we have termed the phenomenon "sensory-specific satiety" [9,13].

Given such relatively specific decreases in the pleasantness of a food eaten, it might be expected that if after a first food had been eaten a second was offered, further eating might occur, so that total food intake with a variety of foods might be greater than with a single type of food. This has been found in an experiment in which normal weight subjects were offered in succession sandwiches with four fillings for lunch, and ate 33% more than if sandwiches with the same filling were consumed throughout the meal. A similar result was obtained if the meal consisted of three flavors of yogurt which differed in flavor, color, and texture [12,15]. Thus sensory-specific satiety is evident not only as a relatively specific decrease in the pleasantness of foods which have been eaten, but also as a reduction in subsequent eating if the same food is offered again when compared to the eating which occurs when a different food is offered. This sensory-specific satiety is associated with enhanced food intake if a variety of foods is offered [13,14].

The sensory properties of foods which could contribute to the sensory-specific component of satiety and the enhancement of food intake by variety include the taste, smell, color, shape, texture and temperature of foods. Many of these properties could have contributed to the sensory-specific effects described above, and their relative importance was not investigated in those experiments. To investigate the importance of these different properties, in the experiments described here we determined the effects of manipulating separately the color, shape, or flavor (i.e., taste and smell), of food on the changes in the pleasantness of foods eaten, and on food intake.

Preliminary reports of these experiments have been presented [12,14].

GENERAL METHOD

Procedure

In each experiment twenty-four subjects, twelve male and twelve female, were selected from a subject pool of healthy young adults. Subjects receiving medication, smokers, dieters, and those who disliked any of the types of food used in the experiments were excluded in an initial screening test, and care was taken to exclude subjects who had prior knowledge of this type of experiment (psychology students were not used). The subjects also ranked their preference for the different foods used in the particular experiment. Subjects were instructed to come to the test location in approximately the same state of hunger on each test day, and this was confirmed by an assessment of hunger using a visual analog scale (100 mm line marked at one end "not hungry" and at the other end "extremely hungry") immediately before each test. Subjects were allowed to drink as much water as they wished before each test, but were not given water during the experiments.

Subjects were told that they were participating in an experiment on taste. It was clear at the end of the experiment that subjects had been unaware of the purpose of the experiment, and did not realize that the amount eaten was being recorded. Each test day was separated from the next by at least one day in order to minimize monotony effects which might be caused by over-exposure to the same foods on successive days. If more than one subject was tested on one day, care was taken to isolate the subjects from each other. Tests were arranged as meals with successive courses so that on any one day subjects were given either the same type of food in the successive courses, the "plain condition," or a different type of food in successive courses, the "variety condition." The tests were run at a time of day such that the foods used provided a reasonable replacement for a normal meal which might be eaten at that time. Experiments 2 and 3 were run at lunch-time, Experiment 1 was run 3 hrs later. A replication of Experiment 1 was run at lunch-time. Subjects were told to eat as much food as they wanted and they were given more in each course than they could eat. Throughout the experiment they did not know in advance which foods to expect in the successive courses and on the first test day they did not know the number of courses to be presented. The subjects were given a weighed plate containing the food at the beginning of each course, and at the end of each course the plates were removed and re-weighed and the weighed plate for the subsequent course was then given. Each course lasted 7 mins. This period was chosen, based on previous experiments [13,15] to be long enough to allow sufficiently large energy intakes and changes in pleasantness to occur, and to be short enough to minimize boredom in the experiment.

The subjective responses to the foods eaten in the experiment were determined by rating the pleasantness of the taste of all the foods used in an experiment using visual analog scales (100 mm lines), both before the first course was given and after the end of the last course on each test day. The 100 mm line was marked at one end "very pleasant," and at the other end "very unpleasant," and the subject was asked to mark the line at the point which represented how pleasant he found the taste of the food. Each visual analog rating scale was on a separate sheet of paper so that subjects could not refer to previous ratings. Subjects were asked to taste each food successively and between each to rate the pleasantness of the taste. The tasted foods were not swallowed and the mouth was rinsed with water between each food.

In a debriefing session on a separate day after the tests were completed, the subjects were weighed and asked to complete a questionnaire [18] to determine whether they were restrained or un-restrained eaters. To determine whether individual differences in response to variety were related to the subjects' sex, level of obesity or responsiveness to the sensory properties of the food, normalized intakes (the average of the intake of courses two and three expressed as a percentage of intakes in the first course) were compared with (a) sex, (b) a median split of the obesity index [7], and (c) a median split of the subject's restraint score for both the plain and the varied meals.

Statistics

Subjects were tested under all conditions of food presentation to permit a within-subjects analysis, and subjects were given the different conditions on different days. The order of presentation of meals to subjects was completely counterbalanced; the order of presentation of courses to subjects within the variety meal was partially counterbalanced so that the different food types were offered an equal number of times in each of the courses, as determined by a balanced Latin square. The total amounts of food eaten were compared by using the matched pairs t-test between the variety meal and the plain meal (or the average of the plain meals). The amounts of food eaten in each of the courses were compared by a two-factor within subjects analysis of variance, after logarithmic transformation to normalize the data, with type of meal and time (position of course) as factors, and by comparison of the appropriate error term from the analysis. The rates of decline of intake throughout the meal were compared by extraction of linear polynomials. Results are expressed as means (±S.E.M.). The significance of the number of subjects showing a greater intake in the varied meal than in the plain meal was determined by the Binomial test.

Changes in the subjective pleasantness of foods eaten or not eaten were determined in the plain meal condition, with a matched pairs t-test performed on the change in pleasantness for the food eaten versus (for each subject) the average of the changes in pleasantness for those not eaten.

EXPERIMENT 1

In this experiment the appearance of food was changed by varying its color to determine whether varying only the color of foods is sufficient for eaten colors to become less pleasant than uneaten colors after a meal, and to determine whether there is an enhancement of intake when a variety of colors is eaten. Other sensory properties and the content of the food were held constant.

METHOD

The subjects were schoolchildren, aged 16–19 years. All subjects had body mass indices within the normal range (18.0 to 22.0) and all were within 15% of normal body weights recommended by the Metropolitan Life Insurance tables maximum [10].

The foods eaten (Smarties, Rowntree Mackintosh Ltd) were small discs of chocolate covered with a thin colored sugar layer (similar to M and M's in America). The four

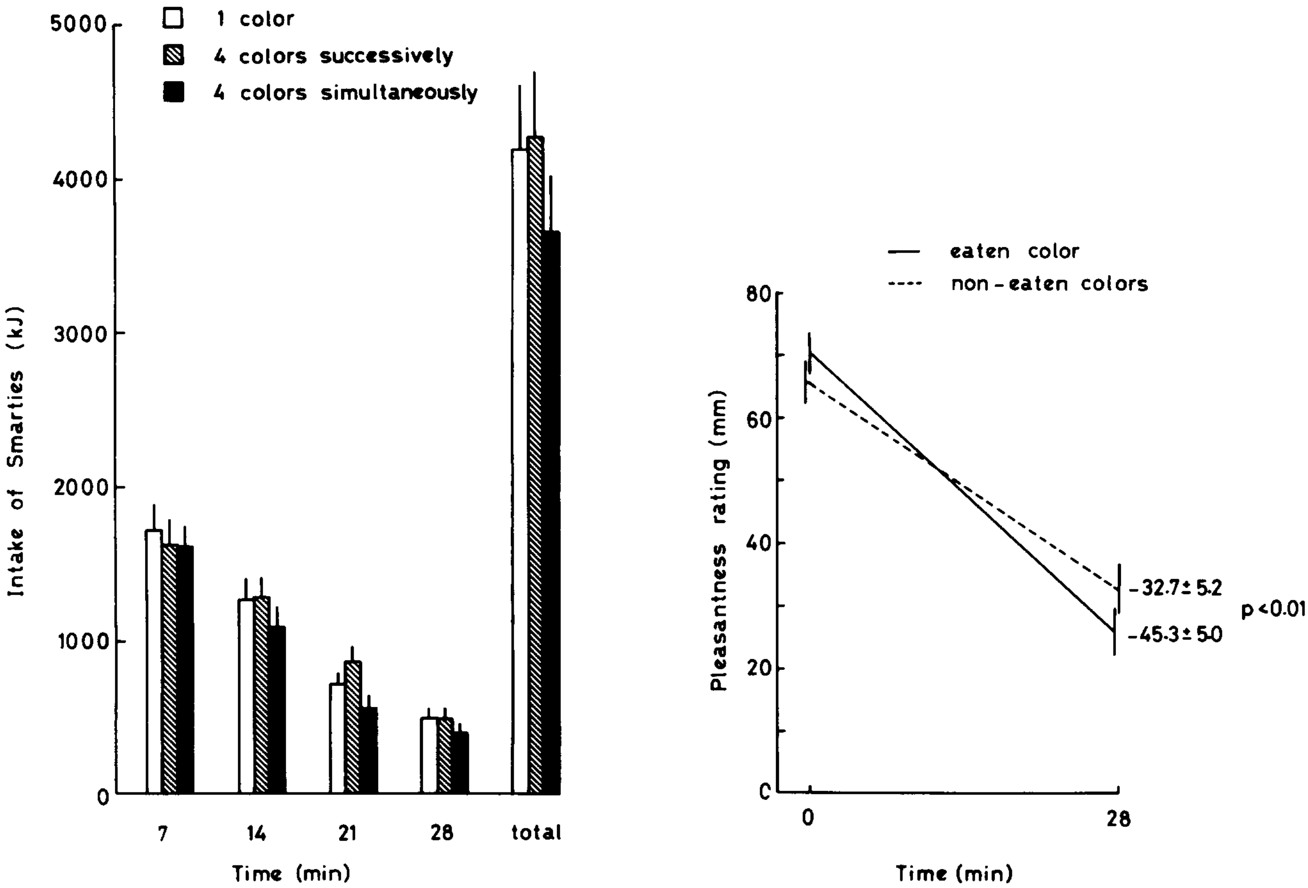

FIG. 1. Left: The mean±SEM amount of Smarties eaten in four successive 7 min courses when subjects (n=24) were given either just their favorite color, four colors successively, or four colors simultaneously. The mean total intakes for the three conditions are also shown. Right: The mean±SEM change in the pleasantness of the color of Smarties eaten and the colors not eaten from before to after the meal when just one color was consumed during the test.

colors used were: violet, pink, yellow and green. All the Smarties used in this experiment had the same content, taste, and smell; the only varying ingredient was the coloring, which was odorless and tasteless. Subjects were tested on three separate days, at 3:30 p.m. (more than two hours after lunch), and on each day they received one of three test conditions: The "plain condition," in which they received the same color which they had rated as the most preferred in the initial assessment procedure, in each of four 7 minute courses; the "variety condition," in which they received a different color in each of the four courses; the "simultaneous condition," in which they received an equal mixture of the four colors in each of the four courses. Each course consisted of 200 g of candies (approximately 200 individual candies) on a 200 mm aluminum foil pie tin; in the simultaneous condition the courses consisted of a mixture of 50 g of each color of food. The most preferred color was used in the plain condition to ensure that any enhancement of intake in the variety conditions was not because the most preferred color was available only in the variety conditions. (Ten subjects preferred violet color, nine pink, four yellow, and one subject preferred green.)

The four colors (one of each) were presented on a small paper plate for the subjective ratings of pleasantness before the meal began, between courses two and three, and after the fourth course. Subjects also rated the pleasantness of the taste of the candy they were eating in that course, at the beginning and end of each course. (In the simultaneous condition they tasted the favorite color at the beginning and end of each course.)

Because the results of this experiment were particularly interesting, a replication of this experiment was run, using 13–14 year old boys as subjects, and using Smarties as a replacement for the last course of lunch. Otherwise the design of the two experiments was identical.

RESULTS

Changes in Subjective Ratings

The mean ratings of the pleasantness of the taste of the Smarties are shown before and after the meal in the plain condition in Fig. 1. Before eating, all colors were rated as relatively pleasant, and the taste of the favorite color was rated more highly than the taste of the other colors. After the meal the pleasantness of the taste of all colors had declined, and all colors were rated as relatively unpleasant. However the decline in pleasantness was significantly greater for the colors eaten than for the colors tasted but not eaten in the plain condition (foods eaten −45.3±5.0 mm on the 100 mm visual analog scale; foods not eaten −32.7±5.2 mm,

$t(23)=2.9$, $p<0.01$). After the meal the favorite color, which had been eaten, was rated as less pleasant in taste than the three colors which had not been eaten.

Food Intake

The intake of Smarties in each course, and the total amount eaten in a meal is shown in Fig. 1.

Increasing the variety of a meal, either by simultaneous or successive presentation of different colors of candies in successive courses, did not lead to an enhancement of intake in a meal. (In fact, in the simultaneous condition there was, idiosyncratically in that it was not found in the replication described below, less eating than in the plain or the sucessive condition.) The pattern of intakes over the four courses was also similar in the plain, simultaneous and variety conditions (condition × course interaction, $F(6,207)=1.5$, NS), and intake declined at the same rate in the three conditions (time: $F(3,207)=122.0$, $p<0.001$; linear polynomial × condition $F(2,207)=1.9$, NS). There were no differences in the patterns of intake shown by male or female subjects, or subjects assessed as more or less restrained eaters, or subjects grouped by a median split of the body mass index.

In the replication of this experiment, we confirmed that there was a greater reduction in pleasantness for a color of Smarties eaten than for the colors of Smarties not eaten (food eaten -44.2 ± 5.1 mm, foods not eaten -25.0 ± 5.4 mm, $t(23)=4.4$, $p<0.001$). Also, as before, there was no increase in intake compared to the plain condition when a succession of different colored Smarties were eaten. In this experiment the amounts eaten in the plain and simultaneous conditions were not different.

DISCUSSION

This experiment showed that a greater decrease in the pleasantness of the taste of a color of food eaten occurred than of the taste of colors of food not eaten. Because we wished to be sure that this sensory-specific satiety could be reliably produced by color alone, we ran a complete replication of the experiment, and obtained the same result. This effect is remarkable, in that having eaten a food of a particular color, the pleasantness of the taste of that food was rated as being less pleasant than the taste of food of other colors. Although this effect was found, the magnitude of the effect with color alone differing between the foods was not sufficient to lead to increased intake in the variety condition. The finding that color can provide the basis for a sensory specific satiety effect is consistent with other evidence that color is an important cue in feeding. For example, it has been shown that color can markedly affect the recognition of food-related odors [2]. In the present experiment, other evidence that color is an important cue in feeding was that 14 out of 24 subjects reported in a debriefing session differences in taste between the Smarties (even though they were identical in all properties except color), and before eating, the food with the favorite color was rated as tasting a little more pleasant than the tastes of the other colors (see Fig. 1).

EXPERIMENT 2

The purpose of this experiment was to investigate whether, with other factors held constant, the shape of food can lead to sensory-specific decreases in the pleasantness of the food eaten, and whether offering a variety of shapes would lead to increased food intakes compared to intakes of one shape. The different shapes of food had different appearances, and produced different sensations in the mouth.

METHOD

The subjects were undergraduate students, aged 18–25 years. All subjects except one had body mass indices within the normal range (total range for the subjects 18.5 to 28.9).

After preliminary experiments pasta was chosen as the test food because it could be obtained in different shapes with the same composition and texture. It was served with tomato sauce. Three shapes of pasta were selected: bow ties—approximately 4 cm long when uncooked, hoops—0.5 cm in diameter and 1.5 cm long when uncooked, spaghetti—7.5 cm long when uncooked (manufactured by Ponte, energy content 14.2 kJ/g). These pastas were chosen because they provided a wide contrast of sensation when eaten and because the uptake of water in cooking was relatively uniform between them. The tomato sauce (Napolitan, manufactured by Go, energy content 3.6 kJ/g) was added to make the pasta more palatable.

The pastas were cooked separately in salted, boiling water. The hoops and spaghetti were cooked for 13 minutes, and the bow ties were cooked for 11 minutes according to the manufacturer's instructions. A constant proportion of pasta to water and salt was maintained to provide uniformity of taste and content. Thus 500 g of dry pasta were added to 1.9 l of water with 6 g of salt. The pasta was weighed before and after cooking and the uptake of water was determined. The range of percentage increases in weight of pasta after cooking was 222–290% (mean $256\pm1.8\%$). Sauce was then added in such quantity as to minimize variations in the ratios of dry pasta to sauce and cooked pasta to sauce. After preparation, the pasta with sauce was kept in covered bowls in a 200°C oven until it was used in the meal. Water losses in the oven were determined but were inconsequential, and the temperature of pasta and sauce at serving time was 47 ± 1°C.

Subjects were tested on two separate days between 12:30 and 1:30 p.m. On one day they received the same shape of pasta in each of three successive courses, the shape being the subject's most preferred as determined in the preliminary assessment (the plain condition). (Fifteen subjects preferred bowtie shapes, six subjects preferred spaghetti, and three subjects preferred hoop shapes.) On the other day they received the three different shapes in succession in the three courses (the variety condition). Before the meal small quantities of each of the pastas with sauce were provided on a plate and subjects were asked to taste and rate each pasta in turn for pleasantness using the 100 mm visual analog scales. Subjects were then given the cooked pasta and sauce to eat (approximately 300 g in each course) in three successive courses, and at the end of the meal they again tasted and rated the three shapes of pasta for pleasantness.

The amount eaten in each course was measured, and the amounts of dry pasta and sauce eaten in each course were then calculated from this proportion in the cooked pasta and sauce. The ratio of dry pasta to sauce was 2.3 ± 0.1 in the plain condition and 2.6 ± 0.3 in the successive condition, and the amount of sauce in cooked pasta and sauce was $19.3\pm0.9\%$ in the plain condition and $17.4\pm0.8\%$ in the variety condition. Energy intakes in each course were determined by multiplying the amounts of dry pasta and sauce by their energy contents.

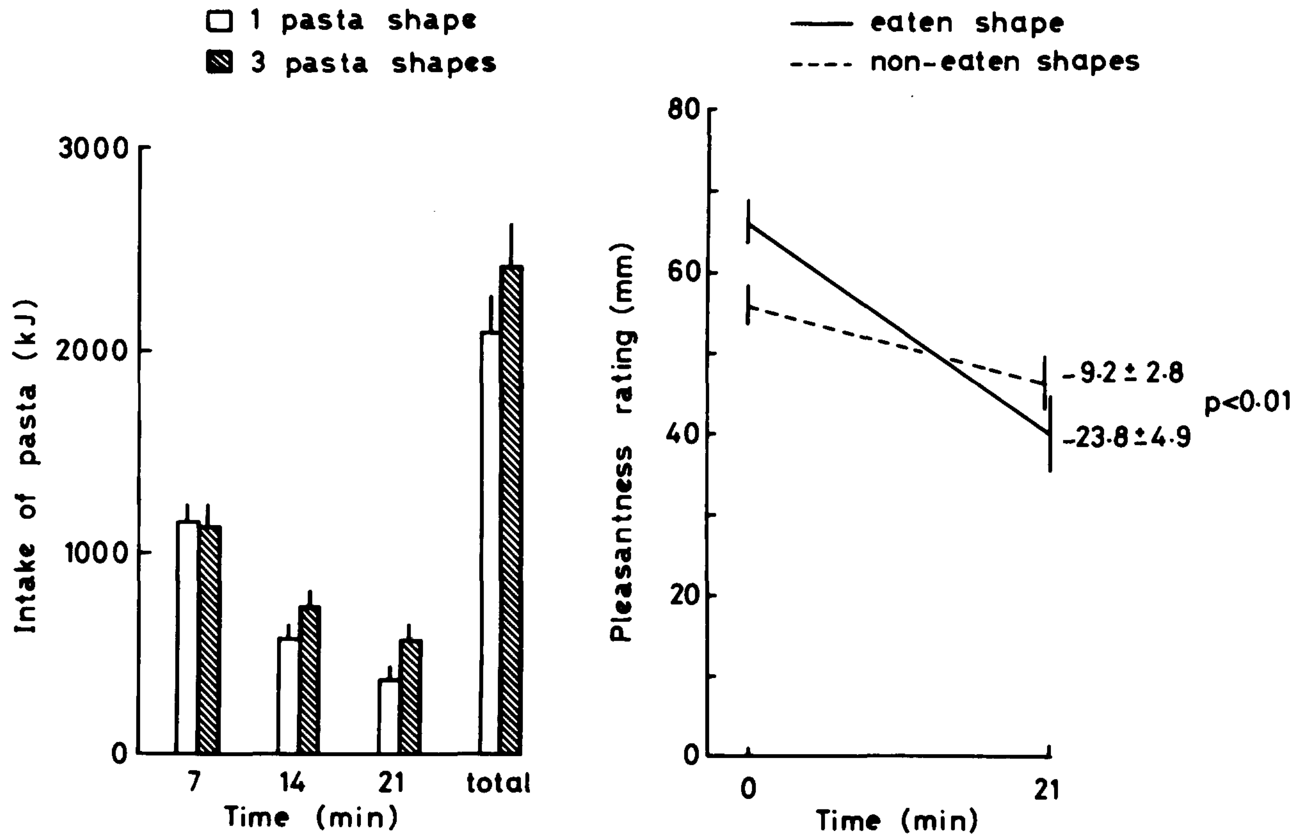

FIG. 2. Left: The mean±SEM amount of pasta eaten in three successive 7 min courses when subjects (N=24) were given either just their favorite shape, or three shapes successively. The mean total intakes for the two conditions are also shown. Right: The mean±SEM change in the pleasantness of the shape of pasta eaten and the shapes not eaten from before to after the meal when just one shape was consumed during the test.

RESULTS

Food Intakes

The mean energy intakes of cooked pasta and sauce in the three courses and the total intakes are shown for the plain and for the variety meals in Fig. 2.

Subjects had a significantly greater energy intake when offered the varied meal than when offered the plain meal of their favorite food, $t(23)=2.3, p<0.05$, and intake of the varied meal was enhanced by 14% compared with the plain meal. The analysis of variance also showed an overall increase in energy intake of the varied meal compared to the plain meal, $F(1,23)=5.0$, $p<0.05$. There was no significant difference in intakes in the first course of the meals, indicating that subjects were at similar baseline levels when the different experimental conditions were introduced.

Intake declined significantly in the two subsequent courses in the plain and variety conditions (time $F(2,92)=65.1$, $p<0.001$, interaction between meal type and time $F(1,92)=1.5$, NS). The decline of intake with time was greater for the plain meal than for the varied meal, although this difference was not statistically significant, $F(1,92)=2.8$, NS. Intakes in the second course were greater in the varied meals than in the plain meals although this difference was not statistically significant, $t(23)=1.7$, NS, and were significantly greater in the third course in the varied meal than in the plain meal, $t(23)=2.3$, $p<0.05$.

Seventeen of the 24 subjects had greater normalized intakes after the first course in the variety condition than in the plain condition (a significant number of subjects showed a greater response to variety, binomial test, $p<0.032$). Female subjects were more restrained eaters than the male subjects, $t(22)=3.6, p<0.01$. Male and less restrained subjects showed the same pattern of intakes in the plain meals as they showed in the varied meals, as indicated by the normalized intakes of the second and third courses, (normalized intakes for meals in the favorite meal 40.9±4.0%, in the varied meal 49.7±4.8, $t(11)=1.1$, NS; less restrained in the favorite meal 43.7±3.7%, in the varied meal 49.0±4.5%, $t(11)=0.9$, NS). However female and the more restrained subjects had greater normalized intakes in the varied condition than in the plain condition (normalized intakes for females in the favorite meal 46.9±5.8%, in the varied meal 64.8±6.5%, $t(11)=1.7$, $p<0.1$, NS, for more restrained subjects in the favorite meal 44.2±6.1, in the varied meal 65.5±6.6%, $t(11)=1.8, p<0.05$). There was no relationship between normalized intakes of the varied meal and body mass index in male subjects, but in female subjects the normalized intakes of the heavier subjects, were greater than those of the leaner subjects (heavier 67.2±13.5%, leaner 52.5±12.0%) although this was not statistically significant.

Changes in Subjective Ratings

Before eating, the taste of the favorite shape was rated as more pleasant than that of the other shapes (see Fig. 2, $t(23)=1.8$, $p<0.05$). The mean ratings of the pleasantness of the taste of the pastas are shown before and after the meal in Fig. 2. There was a larger decrease in the pleasantness of the taste of the shape of pasta eaten (-23.9 ± 4.9 mm on the 100 mm visual analog scale) than of the other shapes of pasta which were not eaten (9.2 ± 2.8 mm, $t(23)=2.9$, $p<0.01$).

DISCUSSION

This experiment showed that altering the shape of food (with other factors held constant) can lead to an increase in food intake, and to decreases in the pleasantness of food which are partly specific to the shape of food which has been eaten.

EXPERIMENT 3

In this experiment the flavor of food was varied and other sensory properties and the content of the food were held constant to determine whether differences in flavor cause sensory-specific changes in pleasantness as a consequence of eating, and whether a succession of different flavors causes an enhancement of intake in a meal.

METHOD

The subjects were undergraduate students, aged 19–25 years. All subjects except two had body mass indices within the normal range (18.2 to 23.7); one male and one female subject had body mass indices of 27.1 and 32.9, respectively.

The food eaten was cream cheese flavored with table salt, or lemon essence and saccharin, or curry, made up into small sandwiches with white bread. Each sandwich was approximately 6 cm long and 3 cm wide. The appearance of the different flavored sandwiches was made uniform by using food colorant (manufactured by Pearce Duff) which produced a yellow color. To increase the uniformity of texture of the bread, the crusts were removed. The cream cheese fillings were as follows: salt—450 g cream cheese (Kraft, Philadelphia®), 5 g table salt (sodium chloride), and food colorants (70 drops of yellow, 2 drops of blue, 4 drops of brown); lemon and saccharin—450 g of cream cheese, 0.12 g of saccharin sodium, lemon essence (32 drops—manufactured by Pearce Duff), and food colorants (yellow—70 drops, blue—2 drops, brown—4 drops); curry—450 g cream cheese, 4 g Madras curry powder (manufactured by Schwartz), and food colorants (yellow—30 drops, blue—1 drop, brown—1 drop). In a preliminary experiment (N=24) it was found that in some subjects there were large differences in the liking of the three flavors. Because in this study it was clear that large differences in liking were masking an effect of variety on intake, only subjects whose initial ratings of the pleasantness of the three flavors were less than 35 mm between the most and least preferred were included in the analyses of the experiment described here.

Subjects were tested on two separate days between 12:30 and 1:30 p.m. On one day they received the same flavor of cream cheese and bread in each of three successive courses (i.e., the "plain condition," the flavor being the most preferred as determined in the preliminary assessment). (Sixteen subjects preferred salt flavor, seven subjects preferred curry flavor, and one subject preferred lemon and saccharin flavor.) On the other day they received each of the three different flavored cream cheese sandwiches, one in each of the successive courses (i.e., the "variety condition"). One piece of bread with cream cheese of each flavor was placed on a small plate and the subjects were asked to taste and rate each in turn for pleasantness using the 100 mm visual analog scales. Subjects were then given the sandwich pieces to eat (approximately 200 g in each course) in three successive courses, and at the end of the meal they again tasted and rated the three flavors for pleasantness.

The amount eaten in each course was measured and the amount of bread and cream cheese eaten in each course was then calculated from their proportions in the sandwich pieces. The ratio of bread to cream cheese by weight in the pieces was 1.23 ± 0.03 in the plain condition and 1.29 ± 0.03 in the variety condition. Energy intakes in each course were calculated by multiplying the amount of bread and cream cheese eaten by their respective energy contents (bread 15 kJ/g, cream cheese 10.9 kJ/g).

RESULTS

Food Intakes

The mean energy intakes of the bread and cream cheese pieces in the three successive courses, and the total energy intakes are shown for the plain and varied meals in Fig. 3.

Subjects had a significantly greater energy intake when offered the varied meal than when offered the plain meal, $t(23)=1.8$, $p<0.05$, and intake of the varied meal was enhanced by 15% compared with the plain meal. The analysis of variance also showed an overall increase in energy intake of the varied meal compared with the plain meal, $F(1,23)=6.6$, $p<0.05$. There was no significant difference in the intakes in the first courses of the meals, indicating that subjects were at similar baseline levels when the two experimental conditions were introduced.

Intake declined significantly in the two subsequent courses in each of the plain and varied conditions (time $F(1,92)=124.7$, $p<0.001$, interaction between meal type and time $F(2,92)=1.4$, NS). The decline of intake with time was greater for the plain meal than for the varied meal, although this difference was not statistically significant, $F(1,92)=2.6$, NS. Intakes were significantly greater in the varied meals than in the plain meals in the second course, $t(23)=2.1$, $p<0.05$, and in the third course, $t(23)=2.5$, $p<0.02$. The normalized intakes after the first course were similar in male and female subjects, in more or less restrained subjects, and in subjects grouped by a median split of body mass index.

In the preliminary study it was found that large differences in initial liking between the flavors obscured the effect of variety on food intake. A median split of the greatest difference between the initial liking of the foods lead to this conclusion in that there was no enhancement of intake in the variety condition in subjects with initial liking differences greater than 35 mm (variety/plain meal ratio of intakes: $95.3\pm6.9\%$, N=12), whereas there was an enhancement of intake in the variety condition when the initial liking of the foods differed by less than 35 mm (variety/plain meal ratio of intakes: $128.5\pm10.9\%$, N=12). These ratios of the amounts eaten in the variety and plain conditions were significantly greater in the subjects with the small differences in initial liking than in the subjects with the large differences in initial liking, $t(22)=2.2$, $p<0.05$.

Changes in Subjective Ratings

Before eating, the favorite flavor was rated as more

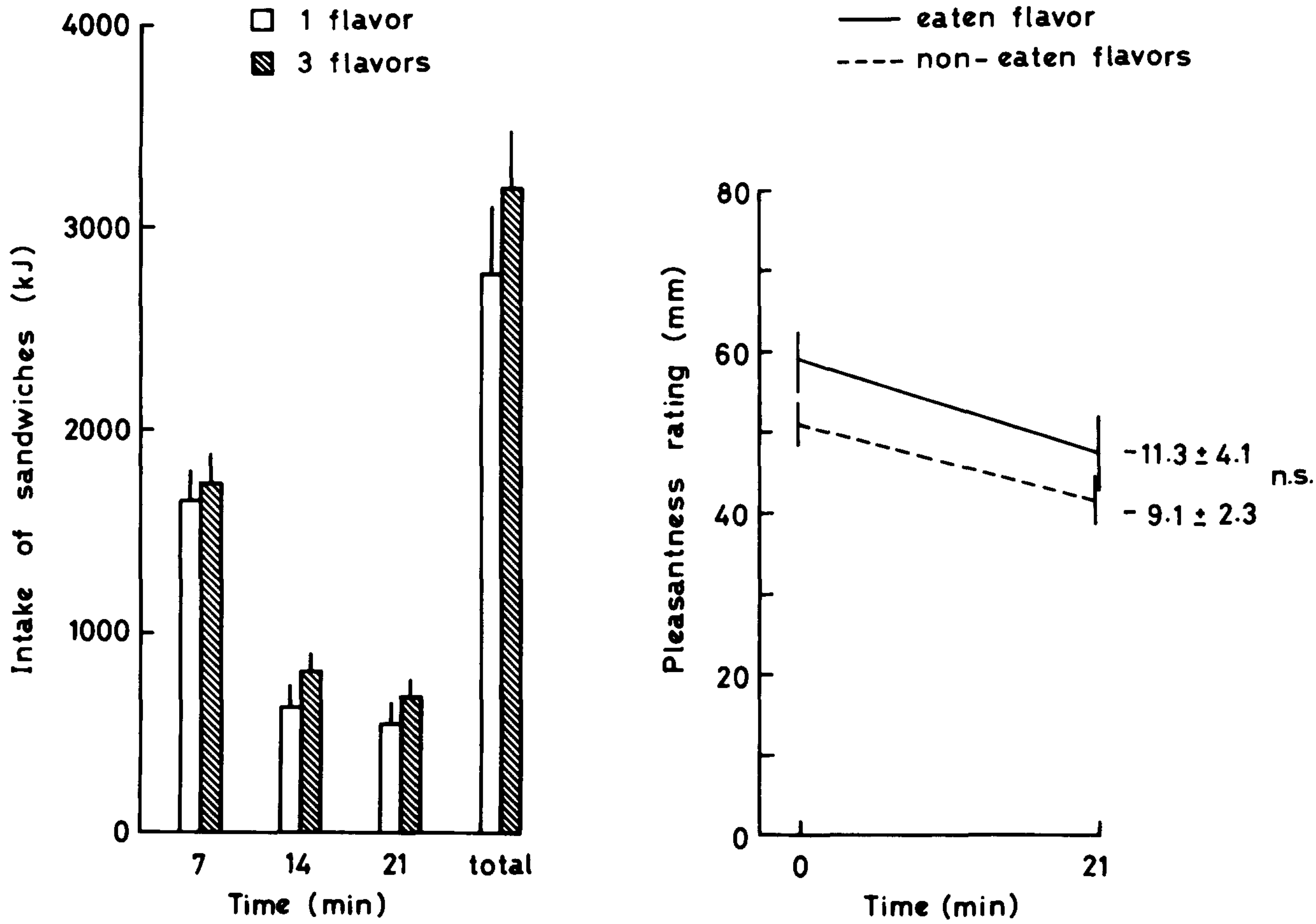

FIG. 3. Left: The mean±SEM amount of sandwiches eaten in three successive 7 min courses when subjects (n=24) were given either just the favorite flavor, or three flavors successively. The mean total intakes for the two conditions are also shown. Right: The mean±SEM change in the pleasantness of the flavor of sandwiches eaten and the flavors not eaten from before to after the meal when just one shape was consumed during the test.

pleasant that the other foods (see Fig. 3, $t(23)=1.8$, $p<0.05$). The decline in pleasantness of the food eaten (the favorite) was only marginally greater in this experiment than the decline in pleasantness of the foods which had been tasted but not eaten (food eaten −11.3±4.1, foods not eaten −9.1±2.3, $t(23)=0.5$, NS).

DISCUSSION

Despite the importance of flavor in sensory specific satiety shown by this experiment, we have previously reported two experiments in which changes in flavor alone did not enhance intake relative to the intake in the plain condition with one flavor of food. The foods available in these two studies were either three flavors of yogurt (strawberry, raspberry, or cherry) [12,15], or three flavors of chocolates (mint, orange, or coffee) [12]. It seems likely, in view of the positive finding in the present experiment, that although the foods in the previous studies were distinctive in flavor, they were not treated as different because of the strong background flavors from the yogurt or chocolate and the fact that all were sweet. In the present study where the foods differed more, i.e., were sweet, salty, or curry flavored, there was a significant enhancement of intake by variety.

The main problem in designing an experiment in which flavor alone changes radically is to find foods which are palatable, of the same nutrient composition, and of similar appearance and texture. The cream cheese sandwiches fulfilled these criteria, but a number of subjects found one of the flavors unacceptable. This problem, however, led to the conclusion that if the foods used in experiments on variety are not all palatable, a refusal to eat any of the foods in the variety condition will mask potential positive findings.

GENERAL DISCUSSION

In these experiments, some properties of food which can lead to a decrease in the pleasantness of that food after it is eaten, and to enhanced food intake if that property of the food is then altered, have been investigated. It was shown that properties of foods which could lead to such effects include its appearance (in terms of its color in Experiment 1), its shape (which affected both its appearance and the sensation it produced in the mouth, Experiment 2), and its flavor

(Experiment 3). The fact that changing even one property of the food such as its color can lead to these specific satiety effects supports the description of the effect as a "sensory-specific satiety" effect [13], since in all cases in these experiments the nutritional content of the foods was not altered.

In previous studies in which flavor, appearance and texture all differed between the foods, larger sensory specific effects were found [13] than in the present experiments, in which only one property of the foods was changed. For example, in an experiment with different sandwich fillings, there was a 33% enhancement of intake when a variety of fillings was offered as compared to a single type of filling [12,15]. In the present experiments, variation in texture alone led to a 15% enhancement of intake (Experiment 2), of flavor alone to a 14% enhancement of intake (Experiment 3), (Experiment 1). The sensory specific decreases in the pleasantness of foods eaten were also less marked when, in the present experiments, only one property of the food was varied. The smaller sensory specific satiety effect found when one property alone differs between the foods is to be expected, as the constancy of the other properties leads to satiety signals which are common to the different foods. The larger sensory specific satiety effects found when several factors differ between foods indicates of course that the different factors can combine, and has obvious implications for how to manipulate appetite.

As just noted, the fact that only one factor differed between the foods provides one reason why the sensory-specific satiety effects were sometimes small in these experiments. For example, the absence of an enhanced intake when color was varied would have been partly due to the strong satiating properties which the Smarties had in common (sweet chocolate), leading to a small sensory specific satiety which did not manifest itself above the baseline variation of the amounts eaten. Another factor important in determining whether sensory specific satiety effects are found when only one sensory property of food is varied is the success in selecting foods which differ markedly along the dimension of interest. It is thus quite possible that in subsequent investigations an enhancement of intake by varying color alone will be found. Another factor which may have contributed to the absence of enhanced intake when color was varied is that in the experimental design, an effect of variety on intake must exceed any greater intake which the subjects may have for their favorite food, which is offered in the plain condition. It is necessary to use the favorite food in the plain condition in order to ensure that any apparent effects of variety are not due simply to the availability for at least some of the time of the subject's favorite food. However, there are two other reasons why, as in the color experiment, there may be a sensory specific decrease in pleasantness without a significant enhancement of intake in a variety condition. The first is that when a sensory specific decrease in pleasantness is measured at the end of an experiment, this should predict whether subsequent eating will occur, rather than being related to the intake which has already occurred. Thus, if a food tastes relatively pleasant (because it has not been eaten already), then it is likely that subsequent eating of this food will occur (but not of a food which tastes less pleasant because it has been eaten). This has been found [13]. The second reason is that the degree of pleasantness of a food may affect whether a food will be selected for ingestion, but the amount actually ingested will then depend to a considerable extent on the satiating power of that particular food. Thus the pleasantness of food may be expected to correlate better with the probability that that particular food will be eaten than with the quantity ingested. This may well be particularly important for the sight of food, which might be expected to have a stronger influence on whether a food is selected for consumption than on the actual amount consumed.

The greater decreases in the pleasantness of food which occurred after that food had been eaten are not just because the initial value for the eaten food was higher than that of the foods not eaten, for the eaten food actually became less pleasant after eating than the foods which had not been eaten (see Figs. 1 and 2). The failure of the food eaten to decline much (and significantly) more in pleasantness than the foods not eaten in Experiment 3 could be related to the fact that only a relatively small decline in pleasantness occurred in this experiment and to the other factors discussed above.

These experiments were designed to provide information on the mechanisms of sensory-specific satiety. The fact that sensory-specific satiety was found for the color of food, when taste, nutritional content, texture etc were held constant, shows that sensory-specific satiety can be based on a learned association between a food with a particular property, in this case a visual stimulus, and its ingestion, such that after ingestion of that food, it becomes less pleasant. It is interesting that the effect of this learning results in reinterpretation of the taste of the food as being less pleasant. In the particular experiment performed, the subjects rated the taste of the color of Smarties they ate as less pleasant that the taste of other Smarties which they had not eaten, even though the Smarties differed only in color. For some other properties of food, such as the mechanical sensation it produces in the mouth, or its flavor, the sensory-specific satiety mechanism could be a similar association learned between the relevant sensory property of the food and its ingestion, or it could be a neurophysiological mechanism similar to adaptation, but at a level where the reward value of food is represented, rather than at a purely perceptual level. The reason for the latter distinction is that it may be primarily the hedonic or motivation-related quality of the food which is changed by sensory-specific satiety, rather than the appreciation simply of the intensity of the sensation, in the majority of subjects [11].

This learning mechanism for sensory-specific satiety is probably similar to the conditioning mechanism for satiety described by Booth [1], in which humans or animals learn to adjust the magnitude of their intake of a particular flavor based on the amount of energy derived previously from ingestion of the food with that flavor (see also [9]). One difference is that the sensory-specific satiety described here has been investigated mainly so far as an intra-meal control of intake (though there could well be longer-term effects), whereas the conditioning mechanism described by Booth is primarily related to how the energy derived from a food eaten at one meal affects eating in subsequent meals.

When sensory-specific satiety was originally observed in our experiments, it was found that the sight of a food which a monkey had eaten to satiety ceased to activate hypothalamic neurons, whereas the sight of other foods which the monkey had not just eaten still activated these neurons. In this case the decrease in responsiveness (of neurons) was to the sight of a particular food. In the present experiments, the decrease was in the pleasantness of the taste of a food of a particular appearance which had been eaten to satiety. It will be interesting in future work to determine whether an equivalent of the neurophysiological observation occurs, namely that in humans there is a sensory-specific decrease in the pleasantness of the sight (rather than the taste, as in Experiment 1) of food which has been eaten. If such a decrease is found, it will elucidate a further part of the mechanism by which foods are selected for ingestion, and eaten [16,17].

Part of the interest of the present experiments lies in the fact that they provide further information on which variables affect the quantity of food ingested. It is clear from these experiments that simply varying the shape and flavor of food can each increase the amount of a food which is eaten. This has implications for diet control, as well as for how to continually stimulate the palate. An implication for dieting is that limiting the variety of the sensory aspects of food which are readily available (while of course maintaining an adequate nutritional content) will assist in limiting intake. An implication for stimulation of the palate is that variation in as many sensory aspects of food as possible will enhance appetite.

ACKNOWLEDGEMENTS

We gratefully acknowledge the support of the Medical Research Council and the supply of Smarties from Rowntree Mackintosh Ltd. Dr. N. McNaughton provided valuable advice on the statistical analyses. We thank the following students who helped with the running of the experiments: J. Benson, R. Hillman, P. Little, V. Patterson, and C. Stanford. We are grateful to the following schools and their pupils for their cooperation in the experiments: St. Edward's School and the Crescent School, Oxford; and the Minster School, Leominster.

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