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BRIEF COMMUNICATION

Sweet Tooth Reconsidered: Taste Responsiveness in Human Obesity

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DREWNOWSKI, A., J. D. BRUNZELL, K. SANDE, P. H. IVERIUS AND M. R. C. GREENWOOD. *Sweet tooth reconsidered: Taste responsiveness in human obesity* PHYSIOL BEHAV 35(4) 617–622, 1985 —Taste responses of normal-weight, obese, and formerly obese individuals for sucrose and fat containing stimuli were examined using a mathematical modelling technique known as the Response Surface Method The subjects accurately rated intensities of sweetness, fatness, and creaminess of 20 different mixtures of milk, cream, and sugar, and no mixture phenomena or inter-group differences were observed. In contrast, hedonic taste responses varied across subject groups, and were affected differentially by the sucrose and lipid content of the stimuli. Normal-weight subjects optimally preferred stimuli containing 20% lipid and less than 10% sucrose. Obese subjects preferred high-fat stimuli (>34% lipid) that contained less than 5% sucrose, while formerly obese subjects showed enhanced responsiveness to both sugar and fat. Hedonic responsiveness as measured by the optimal sugar/fat ratio was negatively correlated with the degree of overweight (body mass index: weight/height^2). We hypothesize that sensory preferences for dietary sugars and fats are determined by body-weight status and may affect the patterns of food consumption.

Lipids and sucrose Taste responsiveness Human obesity Weight reduction Response Surface Method

HEIGHTENED responsiveness to sweet-tasting foods, commonly known as a "sweet tooth," is often cited as a factor in the development and persistence of human obesity [24,25]. To the obese, it is claimed, "many of the most attractive, almost irresistible foods are those that are rich in carbohydrates, especially sugar" [25]. As a result, published dietary guidelines commonly recommend reducing sugar consumption, and chocolate, ice cream, and other desserts are the first to be eliminated from any calorie-restricted diet [4,6].

However, the popular belief that obese individuals are over-responsive to sweet taste has not always found support in the laboratory. Studies on the psychophysics of sweet taste employing threshold detection, taste recognition and magnitude estimation procedures have generally failed to reveal differences in sensory functioning between normal-weight and obese individuals [10, 11, 13]. Studies on the perceived pleasantness (hedonics) of sweet taste have often produced equivocal results depending on the nature of the stimuli employed and the type of obesity studied. Some investigators reported increased liking for sweet taste among moderately obese subjects [1, 17, 23], but others have not found this effect [10–13, 20]. In clinical studies, severely obese patients generally rated sweet solutions as less pleasant than did normal-weight subjects, and preferred weaker rather than stronger sucrose concentrations [10]. The degree of overweight, whether expressed in terms of total fat cell number or percentage body fat has been reported to be negatively correlated with hedonic ratings for sweet taste [10,20].

This apparent disagreement between anecdotal reports and some of the clinical and laboratory data may be due to the fact that sugar in dessert-type foods is normally consumed in combination with dietary fats. Calorie for calorie, foods such as chocolate and ice cream contain more fat than carbohydrate [21]. Yet laboratory research on taste prefer-

TABLE 1

SUMMARY OF SUBJECT CHARACTERISTICS

	Weight (kg)	Body mass index (kg/m^2)	Fat cell size (μg lipid/cell)	Lipase activity	
				per cell	per gram
Normal weight	58.8	21.6	0.54	105.5	193.7
(n=15)	(1.1)	(0.5)	(0.02)	(16.3)	(28.0)
Obese	95.8	34.4	0.61	132.4	216.9
(n=12)	(4.8)	(1.7)	(0.02)	(8.8)	(13.9)
Reduced obese	67.9	23.6	0.58	133.0	226.0
(n=8)	(3.3)	(0.9)	(0.03)	(21.3)	(28.8)

Note: Lipoprotein lipase activity (milliunits) is defined as equal to 1 neq of free fatty acid hydrolyzed per minute and is expressed both per 10^6 fat cells and per gram of fat

The data are means and standard errors of the mean (in parentheses)

TABLE 2

SUMMARY OF EXPERIMENTAL DESIGN FOR 20 TASTE STIMULI

	Fat per 100 g	Sucrose levels (% weight/weight)			
Skim milk	0.1	0	5	10	20
Milk	3.5	0	5	10	20
Half and half	11.7	0	5	10	20
Heavy cream	37.6	0	5	10	20
Cream and oil	52.6	0	5	10	20

ences in human obesity has been limited almost exclusively to the study of sugar solutions in water [10–12, 20]. Consequently, the contribution of dietary lipids to taste responsiveness of obese patients remains unclear. In an earlier study [5], we showed that taste preferences of normal-weight college students were strongly influenced by the lipid content of sweet-tasting stimuli. Optimal ratings were obtained for heavy cream (37% fat w/w) sweetened with only 10% sucrose, which was rated higher than comparably sweet mixtures of 10% sucrose in skim milk (0.1% fat w/w). Persistent anecdotal reports of a "sweet tooth" among the obese may therefore refer to enhanced taste preferences for sweet desserts, which in reality are higher in fat than in carbohydrate.

The role of taste factors in obesity and during weight reduction represents a clinically important issue since dietary non-compliance is a major problem in the management of obesity and associated diseases such as diabetes. Previous studies have shown that the perceived pleasantness of sugar solutions in water increases following sustained dieting and weight reduction [1, 12, 17]. It may be that hedonic responsiveness to sweetened high-fat foods also varies as a function of the subjects' weight status and is enhanced in obese or dieting relative to normal-weight individuals.

METHOD

In the present study, obese (n=12), stable reduced-obese (n=8), and normal-weight subjects (n=15) were recruited among patients and hospital personnel at the University of Washington School of Medicine. Subject data are summarized in Table 1. Reduced-obese patients originally weighed 99.0±6.9 kg and had lost a mean of 31.0±6.7 kg (range 13.6 to 63.0 kg) by following a balanced low-calorie diet of mixed foods more than one year prior to the start of the experiment. Criterion for inclusion in the reduced-obese group was a loss of minimum 13.6 kg body weight that was sustained for at least one year. All subjects were women, with the exception of one reduced-obese man. Their mean age was 33.5±1.7 years (range 20–60). To determine whether the patterns of taste preference are related to parameters of fat cell metabolism, adipose tissue samples were obtained from the buttock by needle aspiration in the morning following an overnight fast. Lipoprotein lipase activity was measured and expressed as neq free acid released per minute. Adipose cell size was also measured and lipase activity was expressed per cell as well as per gram of adipose tissue [3]

Taste stimuli included commercially available skim milk (0.1% fat w/w), whole milk (3.5%), half-and half (11.7%), heavy cream (37.6%), and heavy cream blended with a 15% admixture of safflower oil (>50% fat w/w), Each of these products contains between 3% and 5% endogenous carbohydrates [21]. Added sucrose levels were set at 0, 5, 10, and 20% weight/weight. The experimental design is summarized in Table 2. We used a measure of w/w sucrose rather than the more common percentage weight by volume in order to have a direct means of comparison both with previous studies on sweetened real foods [13] and with our current research on semi-solid and solid food systems [18]. The resulting 20 liquid samples were chilled to 5°C and presented to subjects in 10 ml plastic cups for taste and hedonic evaluations [5]. The subjects tasted each sample and rated it on four 9-point category scales. For the scaling of pleasantness, the subjects used a standard 9-point hedonic preference scale, ranging from "dislike extremely" to "like extremely" [16]. For the scaling of sweetness and fat content the subjects used three unipolar 9-point category scales: Sweet, Fat, and Creamy, with each quality ranging from "absent" to "extreme." Two separate adjective scales (Fat and Creamy) were used to track the increasing fat content of the taste stimuli in an attempt to distinguish between the oily, mouthcoating quality and the creamy consistency of the samples. Inevitably, qualitative differences between the products were expected to result in major differences in perceived flavor or texture;

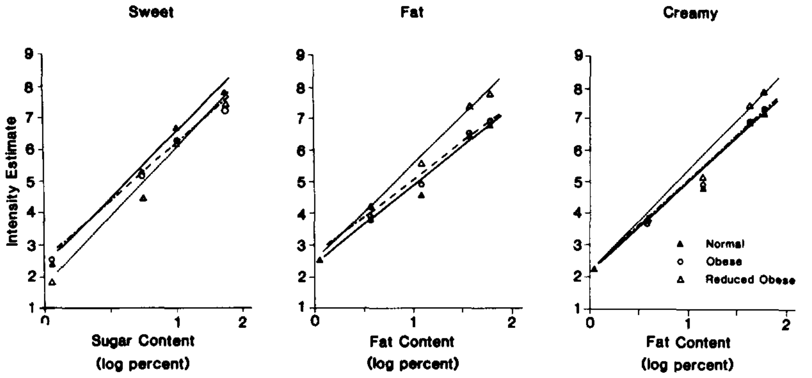

FIG. 1. Relations between mean estimates of sweetness, fatness, and creaminess and sucrose and lipid content of the stimuli. Sweetness intensity scores have been averaged across the five levels of dairy fat (0.1, 3.5, 12.7, 37.6, and 52.6% w/w), while estimates of fatness and creaminess have been averaged across four sucrose levels (0, 5, 10, and 20% w/w). All concentrations are expressed as log percentages w/w. Straight lines represent least-squares fits of logarithmic functions (see Table 3).

however, the present aim was not to assess the complete sensory profile of each product but to focus on the subjects' ability to track increasing sucrose and lipid contents under naturalistic conditions.

The stimuli were presented in a randomized order to reduce potential biases due to the loss of discrimination or taste fatigue. The subjects were instructed to rinse their mouth with water between samples. Two tests were conducted: shortly following a balanced meal of mixed foods (Fed), and again following a 6–12 hour fast (Fasted). In agreement with previous results [5], neither intensity estimates nor hedonic responses were affected by this manipulation and the data were averaged over the fed and fasted conditions.

RESULTS

Intensity ratings of sweetness and perceived fat content showed no evidence of discernible mixture phenomena. Perceived intensity of sweetness was not affected by the lipid content of the samples, while estimates of fatness and creaminess were generally independent of sucrose levels. As seen in Fig. 1, intensity estimates were found to follow the logarithmic function:

$$\text{Intensity} = a_0 + a_1 (\log C)$$

where C is stimulus concentration [5]. Equation parameters and the values of r^2 are shown in Table 3. Analyses of variance for each set of intensity ratings showed no significant differences between normal-weight, obese and reduced obese subjects, $F(2,32)<1.5$, suggesting that the perception of stimulus sugar and fat content remains unaffected even by long-term differences in metabolic status.

In contrast to these estimates of stimulus intensity, hedonic response ratings were strongly interactive, suggesting that hedonic optima exist for specific combinations of sucrose and lipid. Analyses of variance of hedonic responses scores showed main effects of sucrose, $F(3,96)=6.60$; $p<0.01$, and lipid levels, $F(4,128)=17.61$; $p<0.01$, and a significant sucrose by lipid interaction, $F(12,384)=6.33$; $p<0.01$. Hedonic ratings for the fat and sugar containing stimuli thus depended on the relative proportions of the two ingredients. Different profiles of hedonic response were also obtained for each of the three subject groups. The sucrose by group interaction, $F(6,96)=3.55$; $p<0.01$, was significant, while the sucrose by lipid by group interaction was only marginal, $F(24,384)=1.48$; $0.01>p>0.05$.

Changes in hedonic taste responsiveness for this two-component system were modelled with the help of a mathematical technique known as the Response Surface Method [8,14]. The present model (see [5]) assumes that the hedonic response is a function of both sucrose (S) and fat (F) levels, so that:

$$\begin{aligned}\text{Hedonic response} = {} & a_0 + a_1(\log S) + a_2(\log F) \\ & + a_3(\log S)^2 + a_4(\log F)^2 \\ & + a_5(\log S)(\log F)\end{aligned}$$

Solving the algorithm for the six unknown coefficients (a_0 through a_5) allowed the precise simulation of the hedonic

TABLE 3

PARAMETERS OF THE LOGARITHMIC FUNCTIONS FOR THE ESTIMATES OF SWEETNESS, FATNESS, AND CREAMINESS AS A FUNCTION OF WEIGHT STATUS

	Normal-weight	Obese	Reduced-obese
Sweet			
a_0	2.27	2.48	1.74
a_1	4.19	3.66	4.29
r^2	0.99	0.99	0.99
Fat			
a_0	2.50	2.75	2.45
a_1	2.47	2.37	3.05
r^2	0.97	0.98	0.99
Creamy			
a_0	2.37	2.51	2.50
a_1	2.85	2.84	3.16
r^2	0.98	0.98	0.98

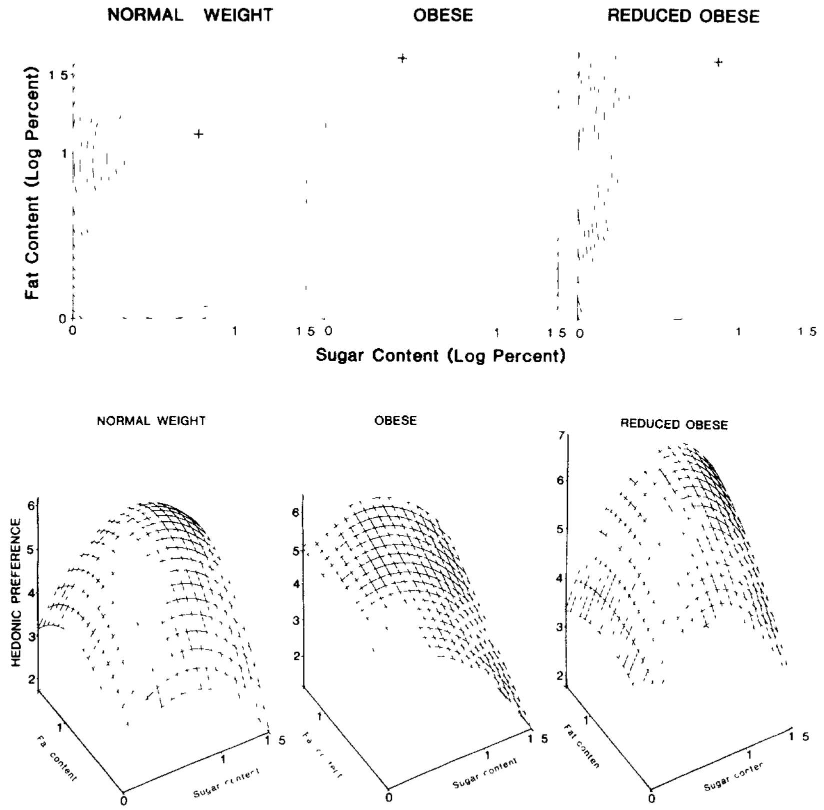

FIG 2 Hedonic response surfaces for the average subject are shown in the top panel expressed in terms of iso-hedonic contours. The axes represent sucrose (x-axis) and fat content (y-axis) of the stimuli, expressed as log percentages w/w. Regions of optimal preference as derived by the Response Surface Method are denoted by + signs Three dimensional projections of hedonic response surfaces created using SAS/Graph and plotted on a Calcomp plotter are shown in the bottom panel. The axes represent sucrose (x-axis) and fat content (y-axis) of the stimuli, with ratings of hedonic responsiveness (z-axis) serving as the dependent variable

response surface within the present range of ingredient levels. In effect, the model was used to interpolate a number of predicted data points to create a more accurate representation of the 3-dimensional hedonic surface than could be obtained purely on the basis of the 20 empirical data points. Three different hedonic response profiles were obtained by applying the model to data obtained for normal-weight, obese and reduced-obese subject populations. Goodness of fit of the model, as determined by the least squares method, was significant in every case ($p<0.01$).

Isohedonic contours and the corresponding three-dimensional projections of the hedonic response surface are shown in Fig. 2. For normal-weight subjects, hedonic ratings for the stimuli were found first to rise and then to decrease as a function of increasing sucrose content (x-axis), showing a sucrose "breakpoint" at below 10% sucrose w/w, in agreement with previous results [5]. Increasing lipid content (y-axis) led to enhanced hedonic ratings that peaked in the region of 20% lipid w/w. Fat-containing stimuli were liked significantly better than equally sweet but low-fat stimuli. Application of the RSM model predicted a region of optimal hedonic responsiveness for stimuli composed of 20.7% fat and 7.7% sugar.

Hedonic responses of obese subjects for the sugar and fat mixtures were also strongly modified by the lipid content of the stimuli. Obese subjects liked sweetened high-fat stimuli as much as normal-weight subjects, but actually disliked equally sweet solutions of sucrose in fat-free milk. Hedonic ratings for sweetness at near-zero fat content (x-axis) declined with increasing levels of sucrose in skim milk. These data are consistent with previous reports that obese subjects dislike intensely sweet sucrose solutions in water [10,20]. Increasing lipid content of the stimuli, (y-axis) resulted in elevated hedonic responses with no suggestion of a fat "breakpoint." These data are consistent with reports that obese subjects liked sweet-tasting and presumably fat-containing chocolate milkshakes more than did normal-weight individuals [17]. Optimal hedonic ratings as predicted by the RSM model were obtained in the region of 34.4% fat and only 4.4% sucrose.

Hedonic responses of reduced obese subjects were numerically elevated relative to those obtained for the obese and normal-weight groups. The optimally preferred lipid level obtained for this group (35.1%) was comparable to that for obese subjects, while the optimally preferred sucrose level (10.1%) was higher than predicted by the model for the obese subject group. It appears that sustained dieting and weight loss may lead to increased hedonic responsiveness for the taste of sweetened stimuli, relative to that observed in the obese state.

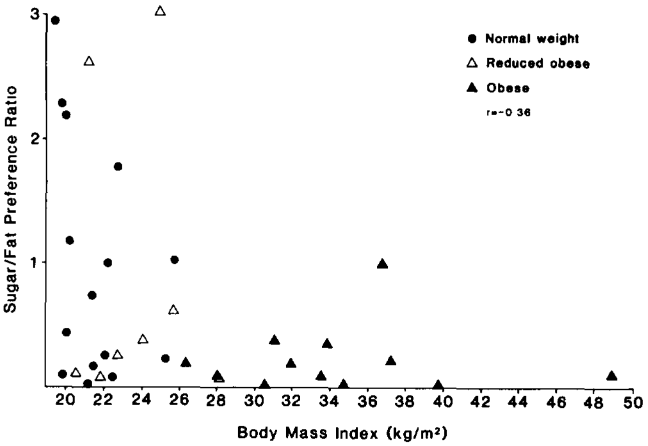

FIG. 3. Relationship between the optimally preferred sugar/fat ratios and body mass indices (kg/m^2) of normal-weight, obese and reduced obese subjects. Low sugar/fat ratio denotes preferences for fat over sweet taste, while high ratio preferences for sweetness over fat.

Successive application of the RSM model to individual hedonic preference data yielded predictions of optimally preferred sucrose and lipid levels for individual subjects. The measure of optimally preferred sugar/fat ratio was then used as a relative index of sweetness preference to characterize hedonic responsiveness of individual subjects. One-way analysis of variance produced a main effect that was only marginal, $F(2,32)=2.64$; $0.10>p>0.05$. However, post-hoc t-tests using the error mean square of the analysis of variance showed a significant difference in responsiveness between normal-weight and obese subjects, $t(32)=2.16$; $p<0.05$. All obese subjects preferred stimuli containing more lipid than sucrose, while some normal-weight and two of the reduced-obese subjects preferred a higher ratio of sugar to fat. The comparison between obese and reduced-obese subjects was only weakly significant, $t(32)=1.71$; $p<0.05$, one-tailed, and no significant differences in the sugar/fat ratio were obtained between normal-weight and reduced-obese subjects.

Figure 3 shows individual values of the sugar/fat ratio and its relationship to body fatness. There was a negative correlation ($r=-0.36$; $n=35$; $p<0.05$) between the sugar/fat ratio and the value of body mass index (wt/ht^2), used here as a measure of body fatness. Although hedonic responsiveness appears to be influenced by body-weight status, the issue whether hedonic responses have a metabolic basis and are directly influenced by some index of glucose or lipid metabolism remains unresolved. Among metabolic factors that track the degree of overweight and might be likely to affect hedonic taste response are adipose cell size or the activity of lipoprotein lipase in adipose tissue. In a recent study, levels of lipoprotein lipase in a group of former smokers served to predict the magnitude of individual weight gain following the cessation of smoking [2]. However, the present correlation coefficients between the optimally preferred sugar/fat ratio, and measures of lipoprotein lipase activity per cell ($r=-0.30$; $n=32$) or per gram ($r=-0.31$; $n=32$), while also negative, failed to reach significance ($0.10>p>0.05$). More complete, integrative factors or metabolic indices, including other plasma and tissue measures may need to be developed, and these additional factors are currently under investigation.

DISCUSSION

The present study shows that laboratory results obtained with single-ingredient systems such as water solutions may not be applicable to all real-life situations. The finding that the obese subjects' hedonic responsiveness was influenced by the viscosity, mouthfeel, or the lipid content of the stimuli may help explain why past studies of taste responsiveness in obesity have produced equivocal results, and why divergent response profiles have been obtained for sucrose solutions [10], chocolate milkshakes [17], or apricot nectar [22]. Because the nature of taste stimuli appears to be important to the obese [22], several investigators [5, 15, 22] have suggested that research on taste preferences in obesity should also include complex sensory stimuli that are more representative of foods commonly encountered in the diet. In particular, studies of human taste responsivenss to dietary fats should present the fats in combination with other macronutrients, since humans tend to dislike the taste of fats presented alone [5].

In previous studies [17] hedonic ratings for milkshakes were related to their consumption under laboratory conditions. The question arises whether taste responsiveness to dietary fats is likely to influence food choices and the patterns of food consumption of obese and formerly obese individuals. Although ambulatory food intake was not assessed in the present study, the data are consistent with some clinical [7,9] and other anecdotal reports that starches and desserts figure prominently among dietary choices of obese women [7,9]. The sensory role of dietary fats in relation to preferences for and the consumption of fat-containing foods deserves further investigation.

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