Taste preferences and body weight changes in an obesity-prone population

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ABSTRACT

Background: Taste preferences for highly palatable foods rich in sugar and fat may underlie the current epidemic of obesity.

Objective: This study aimed to determine whether the hedonic response to sweet and creamy solutions differs between whites and Pima Indians and whether a preference for these tastes predicts weight gain.

Design: One hundred twenty-three Pima Indian and 64 white volunteers taste tested solutions of nonfat milk (0.1% fat), whole milk (3.5% fat), half and half (11.3% fat), and cream (37.5% fat) containing 0%, 5%, 10%, or 20% sugar by weight. Solutions were rated for perceived sweetness, creaminess, and pleasantness (hedonic response) on a 100-mm visual analogue scale. Follow-up body weight was measured in 75 Pima Indians 5.5 ± 3.0 y (± SD) after baseline taste testing.

Results: The Pima Indians had a significantly (P = 0.006) lower hedonic response than did the whites (repeated-measures analysis of variance). Neither body size (P = 0.56) nor adiposity (P = 0.86) was a significant predictor of the hedonic response. There was a positive correlation (r = 0.28, P = 0.01) between the maximal hedonic response at baseline and subsequent weight gain in the Pima Indians.

Conclusion: Although the Pima Indians liked sweet and creamy solutions less than the whites did, a heightened hedonic response for these solutions among the Pima Indians was associated with weight gain.


KEY WORDS Taste perceptions, hedonic responses, obesity, Pima Indians, palatability and weight gain, food intake

INTRODUCTION

Food choices are influenced by a broad range of economic, social, and behavioral variables, including food availability. However, the desire to select one food over another is more closely linked to taste and other sensory properties of foods. Hedonic value results from the interaction between the reward value of a particular food and the immediate psychological and physiologic status of the organism (1–3).

The hedonic reward value of food is closely linked to the perception of taste, and for many individuals, taste is the driving force behind food consumption (4). As commonly defined, taste encompasses the chemical senses of taste and olfaction as well as the oral perception of texture (4). Identification of the sweet (5), bitter (6), and umami (7) taste receptors and the location of the genes encoding these receptors has recently been published. In contrast, fat is generally thought to be recognized in the mouth not by its taste but by the textural properties it imparts or mouth feel (8). Recent studies suggest, however, that there may be a taste component in human fat perception, although a specific fat taste receptor in humans has not yet been identified (9).

The increasing prevalence of obesity in the United States (10) has been paralleled by an increase in energy intake (11, 12). Two highly palatable dietary ingredients, sugar and fat, account for almost 60% of the daily energy content of the typical American diet: sugar accounts for 22% and fat accounts for 37% (13). Although it has been suggested that a preference for these highly palatable food components may underlie the current epidemic of obesity (14), the data are somewhat conflicting (15–21).

Early studies among obese women reported that body mass index (BMI) was inversely related to hedonic ratings for sweet solutions but positively related to hedonic ratings for fat (15). Further investigation showed that whereas women appeared to prefer high-fat, high-sugar foods, men preferred high-fat, high-protein foods (16). This observation was confirmed in a more recent study by Blundell’s group in which BMI was positively correlated with the consumption of high-fat, high-sugar foods in women, whereas the reverse was true for men (17). However, habitual consumption of low- or high-fat foods was not found to be related to a taste preference for fat (18). Mela and Sacchetti (19) reported that a sensory preference for fat correlated with adiposity in lean subjects, but no consistent relation was found between fat taste preference and dietary fat intake. Finally, neither hedonic ratings for foods chosen freely (20) nor hedonic ratings assigned to 50 common foods (21) were significantly different between lean and obese consumers. The question of...
whether hedonic preferences for sweet or fat tastes actually predispose individuals to weight gain was not addressed in these studies.

The current study was undertaken to determine whether Pima Indians, a population highly prone to the development of obesity (22), have a greater preference for sweet and creamy solutions than do whites. In addition, we hypothesized that a preference for sweet and creamy solutions would predict weight gain among Pima Indians.

SUBJECTS AND METHODS

Subjects

From 1991 to 2001, 187 volunteers participating in clinical research studies on the pathophysiology of obesity and type 2 diabetes at the National Institutes of Health in Phoenix, AZ, underwent taste testing. Pima Indian subjects (70 men, 53 women) were recruited from the Gila River Indian Community located in Sacaton, AZ, ∼64 km (40 miles) southeast of Phoenix. White subjects (37 men, 27 women) were recruited from the greater Phoenix area through advertisements. Before participation, all subjects were screened through a medical history, physical examination, and laboratory tests and were found to be healthy. Because type 2 diabetes is known to affect hedonic responses to sweet and fat foods (23), subjects with diabetes (as determined by a 75-g oral-glucose-tolerance test; 24) were not included in the present study. All subjects were informed as to the aim, nature, and risks of the study before giving their written informed consent. These studies were approved by the Institutional Review Board of the National Institute of Diabetes and Digestive and Kidney Diseases and the Tribal Council of the Gila River Indian Community.

Methods

After ≥3 d of a weight-maintenance diet and an overnight fast, the subjects were given a standard breakfast consisting of scrambled eggs and low-fat cheese wrapped in a flour tortilla and accompanied by orange juice. The breakfast was calibrated to contain ∼25% of the subject’s daily weight-maintenance calorie needs. Pepper, spicy sauces, coffee, and tea were not permitted. Moreover, the subjects were allowed to rinse their mouths after breakfast but not to brush their teeth or use mouthwash.

Ninety minutes after breakfast, the subjects were presented with a tray of 16 randomly ordered solutions consisting of nonfat milk (0.1% fat), whole milk (3.5% fat), half and half (11.3% fat), and cream (37.5% fat) and containing 0%, 5%, 10%, or 20% sugar by weight. The subjects were instructed in the “sip-and-spit” technique, whereby they first rinsed their mouth with fresh water, took a mouthful of the first solution, swirled it in their mouth, rated the solution, expectorated, and used the same procedure on the next highest numbered solution (15). The subjects rated the solutions for sweetness, creaminess, and pleasantness (the hedonic response) by using a 100-mm visual analogue scale anchored with the descriptors “not at all” and “extremely” (sweet, creamy, or pleasant).

Body composition was determined by using hydrodensitometry with determination of residual lung volume by helium dilution (25) or by total-body dual-energy X-ray absorptiometry (DPX-L; Lunar Corporation, Madison, WI; 26). Percentage body fat, fat mass, and fat-free mass were calculated as previously described (27), and a conversion equation (28) was used to make the measurements comparable between the 2 methods.

Follow-up weight and height data were collected in 75 Pima Indian subjects (41 men, 34 women) ≥3 mo after the baseline taste test. Rate of change in weight (kg/y) was calculated by dividing change in weight (weight at follow-up − weight at initial visit) by years of follow-up. The subjects included in this longitudinal analysis were known to be free of diabetes at both baseline and follow-up. Follow-up taste testing was conducted in 18 Pima Indian subjects (8 men, 10 women) after a mean (±SD) follow-up interval of 2.4 ± 3.2 y to determine whether changes in hedonic response were related to changes in weight.

Statistical analyses

All procedures were carried out by using SAS for WINDOWS (version 8; SAS Institute Inc, Cary, NC). Linear regression (PROC GLM) was used to assess racial and sex differences in the anthropometric variables. Repeated-measures analysis of variance was used to assess within-subject differences due to sugar and fat content; these analyses were conducted by using general linear models that controlled for between-subject differences due to race, sex, age, BMI, and percentage body fat. The response surface method, calculated by using the SAS RSREG procedure, was used to approximate a maximal hedonic response and the corresponding sugar and fat concentrations at this maximum (29). The procedure determines an optimal quadratic response surface by least-squares regression by using the hedonic values of all combinations of sugar and fat concentrations. Spearman rank correlation coefficients were used to assess hedonic influences on longitudinal weight change with the maximal hedonic response obtained from the response surface method calculations.

RESULTS

The Pima Indians were significantly (P = 0.05) younger than the whites (Table 1). Although the men were significantly heavier than the women, there were no racial differences in body weight. Because the Pima Indians were significantly (P < 0.0001) shorter than the whites, BMI was significantly (P = 0.01) higher in the Pima Indians (data not shown). Adiposity was significantly higher in the women than in the men (P = 0.0001), and, as previously observed (30), significantly (P = 0.05) higher in the Pima Indians than in the whites. Although there were no racial differences in fasting plasma glucose concentrations, the Pima Indians had significantly (P = 0.05) higher 2-h plasma glucose concentrations than did the whites. There were no significant race-by-sex interactions in the anthropometric variables.

The major predictor of the sweetness response was the sugar content (P < 0.0001) of the solutions (Figure 1); ratings increased as the solutions became sweeter. Using repeated-measures analysis of variance, we found that the Pima Indians rated the solutions as tasting sweeter than the whites did (P = 0.05), and the women rated the sweetness of these solutions higher than did the men (P = 0.01). Even though the Pima Indians were younger than the whites and the sweetness ratings were inversely related to age (P = 0.04), there was no interaction between race and age as a predictor of the sweetness response (P = 0.82). Neither adiposity (percentage body fat; P = 0.62) nor
body size (BMI; $P = 0.53$) was a significant predictor of the sweetness response.

The mean creaminess ratings for all solutions increased with increasing fat content of the solutions ($P < 0.0001$); however, creaminess ratings generally increased with increasing sugar content as well ($P < 0.02$; Figure 2). Race ($P = 0.37$), sex ($P = 0.62$), body size ($P = 0.94$), adiposity ($P = 0.99$), and age ($P = 0.33$) did not significantly affect the creaminess ratings.

Race ($P = 0.006$) was the only significant predictor of the hedonic response. Age ($P = 0.69$), body size ($P = 0.56$), and adiposity ($P = 0.86$) were not significant predictors of the hedonic response. Significant within-subject effects for the hedonic

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**TABLE 1**

Physical and metabolic characteristics of the white and Pima Indian subjects

<table>
<thead>
<tr>
<th></th>
<th>White</th>
<th>Pima Indian</th>
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<tbody>
<tr>
<td></td>
<td>Men</td>
<td>Women</td>
<td>Race</td>
</tr>
<tr>
<td>n (%)</td>
<td>37 (58)</td>
<td>27 (42)</td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>32.7 ± 10.0$^2$</td>
<td>32.1 ± 8.5</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>90.2 ± 21.8</td>
<td>87.5 ± 26.3</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>177 ± 7</td>
<td>166 ± 5</td>
<td></td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>22.8 ± 9.6</td>
<td>33.5 ± 8.2</td>
<td></td>
</tr>
<tr>
<td>Fasting glucose (mg/dL)$^3$</td>
<td>87 ± 9</td>
<td>90 ± 12</td>
<td></td>
</tr>
<tr>
<td>2-h Glucose (mg/dL)$^3$</td>
<td>103 ± 25</td>
<td>114 ± 32</td>
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$^*$ Data were analyzed by using linear regression (general linear models procedure). There were no significant race-by-sex interactions.

$^2$ SD.

$^3$ Fasting plasma glucose and 2-h plasma glucose concentrations obtained during the oral-glucose-tolerance test.
response included sugar concentration ($P = 0.001$) and interactions between fat content and race ($P = 0.0007$), sugar content and race ($P = 0.0002$), and sugar content and sex ($P = 0.001$): the whites preferred sweeter and creamier solutions than did the Pima Indians, and the men preferred sweeter solutions than did the women.

The hedonic response surface curves for the Pima Indian and white men and women are shown in Figure 3. For both the Pima Indian men and women, the quadratic response surface model was significant ($P < 0.0001$), and the model identified a peak with the following coordinates: for men, hedonic response = 51.3 mm, sugar concentration at this response = 7.9%, and fat concentration at this response = 1.0%; for women, hedonic response = 46.9 mm, sugar concentration at this response = 1.3%, and fat concentration at this response = 0.7%. In contrast, in the white men and women, the quadratic response surface model was not significant ($P = 0.45$ and $P = 0.57$, respectively) and a peak could not be identified.

Prospective data were obtained in 75 Pima Indian subjects (41 men, 34 women) after a mean (±SD) follow-up time of 5.5 ± 3.0 y; the mean rate of change in weight for these 75 subjects was 1.9 ± 2.3 kg/y (Table 2). The rate of change in weight was significantly correlated ($r = 0.28, P = 0.01$; Figure 4) with the maximum hedonic response predicted from the quadratic response surface model at baseline.

The longitudinal results tracking changes in taste test responses in 18 Pima Indians (8 men, 10 women) who gained weight over time are shown in Figure 5. The subjects underwent repeated taste tests over a mean of 2.4 ± 3.2 y; at both time points, body weights were also measured. There was no indication of an effect of weight gain on the hedonic response.

**DISCUSSION**

In the present study, the Pima Indians had a significantly lower hedonic response to sweet and creamy solutions than did the whites. Neither body size nor adiposity was a significant covariate of the hedonic response. There was a positive correlation between the hedonic response to sweet and creamy solutions measured at baseline and weight gain = 5 y later in the Pima Indians.

Previous reports suggested an inverse relation between the hedonic response to sweetened solutions and weight, especially among women (15, 16). In the present study, the hedonic response was not related to body size, adiposity, or sex; however, there was a significant racial effect such that the hedonic response of Pima Indians was lower than that of whites. Moreover, the Pima Indians rated these solutions as tasting sweeter than did the whites, and the hedonic response among the Pima Indians decreased as the solutions became sweeter. This is inconsistent
with our hypothesis that Pima Indians would express a greater preference for sweet and creamy solutions because of their diet-induced obesity. However, several explanations for this inconsistency are possible.

The hedonic response may be elevated in persons at risk of obesity but may decline once the phenotype develops. Previous reports in Pima Indians documented similar effects for other risk factors for obesity (31). For example, individuals who are insulin resistant may show an increased preference for sweet and creamy solutions, which is consistent with our hypothesis. The quadratic response surface model identified a peak with the following coordinates: men, $P = 51.3$ mm, $S = 7.9\%$, $F = 1.0\%$; women, $P = 46.9$ mm, $S = 1.3\%$, $F = 0.7\%$. In the white men and women, the quadratic response surface model was not significant and a peak could not be identified.

### TABLE 2

Prospective data in Pima Indian subjects

<table>
<thead>
<tr>
<th></th>
<th>Men ($n = 41$)</th>
<th>Women ($n = 34$)</th>
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<tbody>
<tr>
<td><strong>Baseline</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>$29.4 \pm 7.5$ (18–43)</td>
<td>$28.9 \pm 6.8$ (19–51)</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>$98.3 \pm 27.6$ (63–189)</td>
<td>$85.9 \pm 19.8$ (61–132)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>$172.2 \pm 5.4$ (159–185)</td>
<td>$159.5 \pm 5.9$ (147–173)</td>
</tr>
<tr>
<td>Body fat (%)</td>
<td>$28.6 \pm 7.2$ (8–42)</td>
<td>$37.4 \pm 5.3$ (25–47)</td>
</tr>
<tr>
<td>Predicted hedonic response (mm)</td>
<td>$68 \pm 24$ (3–113)</td>
<td>$63 \pm 22$ (4–103)</td>
</tr>
<tr>
<td><strong>Follow-up</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time elapsed (y)</td>
<td>$4.9 \pm 3.0$ (0.3–9.8)</td>
<td>$6.1 \pm 3.0$ (0.7–10.9)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>$107.3 \pm 30.0$ (74–195)</td>
<td>$94.8 \pm 22.2$ (65–158)</td>
</tr>
<tr>
<td>Change in weight (kg)</td>
<td>$9.0 \pm 10.8$ (–16.4–36.7)</td>
<td>$8.9 \pm 9.0$ (–7.4–30.8)</td>
</tr>
<tr>
<td>Rate of change in weight (kg/y)</td>
<td>$2.3 \pm 2.8$ (–2.9–9.3)</td>
<td>$1.4 \pm 1.3$ (–1.0–4.1)</td>
</tr>
</tbody>
</table>

$\bar{x} \pm SD$; range in parentheses.
sensitive are at greater risk of weight gain, but the development of obesity is accompanied by a decline in insulin sensitivity (32). Our prospective analysis in Pima Indians indicates that a high hedonic response to sweet and creamy solutions is associated with weight gain 5 y later. This finding is, to the best of our knowledge, the first to lend support to the hypothesis that a preference for highly palatable food components is associated with the development of obesity. Although the amount of variability in the change in body weight explained by the hedonic response is admittedly small (~8%), it is not very different from many of the risk factors for obesity identified in this Native American population (31). Unlike most of the previously identified risk factors, however, the hedonic response does not seem to consistently decrease in response to weight gain, and this mechanism cannot be invoked to explain the lower hedonic response in the Pima Indians than in the whites.

Pima Indians may not express a greater hedonic response for any class of tastants or any other pleasurable stimuli compared with whites if they suffer from some form of generalized hypo-hedonism. The dopaminergic system is chiefly involved in modulating the reward properties of many stimuli, including taste (33). It was recently shown that dopamine D2 receptor availability is diminished in the brain of obese individuals (34), and we previously reported that the serine to cysteine mutation at amino acid 311 (Ser311Cys) of the dopamine D2 receptor gene is frequent among Pima Indians (35). However, if a lower number or impairment of the dopamine D2 receptor results in a reward deficiency condition, one would expect a low, not a high, hedonic response to predict weight gain among Pima Indians. Furthermore, we were unable to identify an effect of the Ser311Cys mutation on the taste-test responses of participants in the present study (data not shown).

Typical food choices among Pima Indians do not include many sweet items; breakfast generally consists of eggs, bacon, and fried potatoes, whereas Mexican and Southwestern-style dishes such as tacos, burritos, chili, and bean stews are popular lunch and dinner choices (36). Although regular consumption of sweet-tasting foods such as fruit and desserts is reportedly infrequent in the population, consumption of sweetened beverages such as Kool-Aid (Kraft Foods) and soda pop containing 10–12% sugar (37) is widespread (ADS, unpublished observation, 1999).

There are limitations to the use of dairy liquids for assessing taste preferences that should be mentioned. Because fat perception in liquid stimuli is largely attributable to the textural properties fat imparts (8), the sensory preference for fat in liquid stimuli may not be equivalent to that in solid foods (38). However, sugar preferences reportedly remain constant across food types (38). In addition, whereas lactose intolerance to dairy products in the United States is reportedly 15% among whites, 53% among Mexican Americans, and 80% among blacks (39), the prevalence among Native Americans is unknown. Although we did not specifically test for lactose intolerance, none of the sub-

FIGURE 4. The rate of change in weight was significantly correlated ($r = 0.28, P = 0.01$; Spearman rank correlation coefficients) with the maximum hedonic response predicted from the quadratic response surface model at baseline in 41 Pima Indian men (■) and 34 Pima Indian women (▲).

FIGURE 5. Longitudinal results tracking changes in taste-test responses in 8 Pima Indian men (■) and 10 Pima Indian women (▲) who gained weight over time. The subjects underwent repeated taste tests over a mean (±SD) of 2.4 ± 3.2 y; body weights were measured at the first visit and at the follow-up. There was no indication of an effect of weight gain on the hedonic response.
jects included in the present study population reported lactose intolerance in their medical history.

Taste preferences for highly palatable ingredients such as sugar and fat may be important indicators of a desire for an energy-dense diet, but because food intake is influenced by many factors, including economic, demographic, psychological, and sociocultural variables, the role of taste preference in predicting weight gain may be difficult to discern. To be effective, dietary advice to obese individuals attempting control their weight should account for taste preferences.

In conclusion, we showed that even though the Pima Indians liked the sweet and creamy solutions less than the whites did, a heightened hedonic response for these solutions among the Pima Indians was associated with weight gain. This finding lends support to the hypothesis that a preference for highly palatable foods is associated with the development of obesity.

We thank John Graves and the dietary staff and Carol Massengill and the nursing staff of the NIH Clinical Unit. We are also indebted to Eric Ravussin and Etet Larson for initiating the study and to Robert Hanson, Robert Lindsay, Norbert Stefan, and Michael Stumvoll for assistance in statistical analysis. Most of all, we thank the volunteers for their participation in the study.

ADS was responsible for the design of the experiment, collection and analysis of the data, and writing of the manuscript. ADP was responsible for significant advice and consultation. REP was responsible for the design of the study.

REFERENCES