Susceptibility to Overeating Affects the Impact of Savory or Sweet Drinks on Satiation, Reward, and Food Intake in Nonobese Women

Graham Finlayson, Isabelle Bordes, Sanne Griffioen-Roose, Cees de Graaf, and John E. Blundell

Abstract

Taste is involved in food preference and choice, and it is thought that it can modulate appetite and food intake. The present study investigated the effect of savory or sweet taste on satiation, reward, and food intake and according to individual differences in eating behavior traits underlying susceptibility to overeating. In a crossover design, 30 women (BMI = 22.7 ± 2.3, age = 21.9 ± 2.6 y) consumed a fixed energy preload (360 kJ/g) with a savory, sweet, or bland taste before selecting and consuming items from a test meal ad libitum. Sensations of hunger were used to calculate the satiating efficiency of the preloads. A computerized task was used to examine effects on food reward (explicit liking and implicit wanting). The Three Factor Eating Questionnaire was used to compare individual differences in eating behavior traits. Satiation and total food intake did not differ according to preload taste, but there was an effect on explicit liking and food selection. The savory preload reduced liking and intake of high-fat savory foods compared to sweet or bland preloads. The eating behavior trait disinhibition interacted with preload taste to determine test meal intake. Higher scores were associated with increased food intake after the sweet preload compared to the savory preload. Independent of preload taste, disinhibition was associated with lower satiating efficiency of the preloads and enhanced implicit wanting for high-fat sweet food. Savory taste has a stronger modulating effect on food preference than sweet or bland taste and may help to preserve normal appetite regulation in people who are susceptible to overeating. J. Nutr. doi: 10.3945/jn.111.148106.

Introduction

It is understood that the taste of food can influence the amount consumed over the course of a meal. Regarding the sensory qualities of taste, an important distinction can be made between savory and sweet domains (1), which include the majority of foods in the diet (2). Evidence suggests that sweet-tasting foods generally have a positive effect on the expression of appetite that can lead to the facilitation of eating (3). Sweet taste is likely to exert a potent action on appetite through 2 G-coupled receptor proteins, T1R2 and T1R3, which form a broadly tuned taste receptor. Interestingly, this taste receptor is found in the mouth and the intestine, where it is linked to the secretion of peptides (glucagon-like peptide 1 and gastric inhibitory peptide) that have a function in metabolism and satiety (4).

The effect of savory taste on appetite is less amenable to experimental study given its less specific properties compared to “pure” tastes (i.e., sweet, sour, salt, and bitter). There has been some debate whether the flavor of certain glutamates may represent another pure taste (i.e., “umami”) and an interesting property of these compounds is their association with savory taste. Umami, translated from the Japanese to mean “pleasant savory taste,” describes the taste of glutamate and nucleotides, which are common to foods such as fish, vegetables, and cheeses. Glutamate and other savory amino acids share a common subunit of the T1R receptor with sweet molecules and are detected by the T1R1 and T1R3 heterodimer (5), which are also expressed in the gastrointestinal tract with possible implications for nutrient absorption and satiety (6). The presence of sweet and savory receptors in the mouth and gut presumably evolved to allow organisms to find and recognize foods rich in sugar and protein. The central processing of sweet and savory taste signals typically activate feeding circuits as well as brain reward systems that promote specific appetites (7).

Few studies have examined the appetitive effects of savory-tasting compared to sweet-tasting foods or their effect on food intake. De Graaf et al. (8) reported a stronger net effect of savory foods compared to sweet foods on subsequent appetite for a meal. Although these differences did not influence food intake at the next meal, they did influence the quantity of foods consumed...
from the same sensory domain. More recently, Griffioen-Roose et al. (9) developed equi-palatable, savory- or sweet-tasting versions of identical rice-based meals. In separate studies, the authors demonstrated no differential effects of these savory or sweet foods on self-selected meal size and satiation (1) or post-meal satiety and subsequent intake of snacks varying in taste and energy value (9). In both studies, the authors reported stronger effects of savory taste on food preference (avoidance of savory) compared to sweet (equal preference for savory or sweet).

Research suggests that savory and sweet tastes are qualities that have a generally positive effect on the expression of appetite and this can lead to a facilitation of eating (10). However, some people may be particularly susceptible to these effects while others will be resistant (11). The combination of sweet taste with energy-dense nutrients like fat, and its contrast with equi-palatable savory food, may be of particular importance to appetite control (3), and females may be at higher risk than males (12,13).

The present study sought to further investigate the effect of savory or sweet food on satiation and food intake by considering differences in the susceptibility to overeating according to eating behavior traits measured by the TFEQ7 (14). Equi-palatable, fixed-energy drinks with a savory, sweet, or bland taste were compared on satiating efficiency and their effects on food reward and energy intake in a test meal. We predicted that women with greater susceptibility to overeating would demonstrate weaker satiation and consume more food. Comparisons between preloads yielded information about the effect of taste on the susceptibility to overconsume and the sensory regulation of appetite.

Methods

Participants. Healthy females (n = 30) aged 18–30 y (21.9 ± 0.5) (mean ± SE) who were not obese (BMI = 22.7 ± 0.4) were selected from an initial screening process to exclude those who were currently following a weight loss/maintenance routine or who reported a history of eating or psychological disorders in the previous 3 y. The criterion for inclusion was acceptance of the study foods (assessed during a screening visit). Participants were familiarized with the study procedures and told that they would be participating in a study to investigate the effect of food on mood.

Measures

TFEQ. The TFEQ (14) measures three eating behavior traits based on the concepts of restrained eating and latent obesity. The three factors measured are cognitive restraint (21 items), disinhibition (16 items), and susceptibility to hunger (14 items). The TFEQ has been widely used in appetite research in obese and nonobese samples. Disinhibition has been identified as a trait that reflects an individual’s relationship with the obesogenic environment and a predisposition to overconsume (15).

Satiating efficiency. Measures of subjective hunger were recorded at fixed times during each test day using a 100mm VAS anchored at each end with the statements “not at all” and “extremely.” The satiating efficiency of the preloads was assessed by the SQ concept adapted from Green et al. (16). Scores on the SQ represent change in hunger ratings in mm/100 kcal (~420 kJ) of ingested food.

Food reward. Explicit liking and implicit wanting components of food reward were assessed by the Leeds LFPQ (17,18). The LFPQ measures explicit and implicit reward motivation for food. For the explicit measure of liking, 16 foods are rated according to “how pleasant would you find the taste of this food right now?” For the implicit measure, the same foods were presented in a series of randomized pairs and participants had to “select the food which you most want to eat right now” as quickly and accurately as possible. During the latter procedure, reaction times were measured. Following previous research (9), reaction times were transformed to a standardized d-score using a validated algorithm (19): the lower the standardized d-score, the greater the implicit wanting for that food category relative to other categories in the task.

Test foods

Preload development. Three milk-based drinks were developed that were precisely controlled for energy, volume, and macronutrient composition, and matched for perception of texture, intensity, and palatability (Supplemental Table 1). The savory preload was mushroom flavored and savoriness was enhanced by using monosodium glutamate (Ajinomoto). The sweet preload was chocolate flavored and sweetened with sucrose. The bland preload contained powdered skimmed milk and corn flour.

The preloads were validated using a panel of blinded raters (n = 25). They sampled aliquots (~10 mL) of each preload in a rotated order between participants. The preloads did not differ on ratings of creaminess (P = 0.27). Savory and sweet preloads did not differ in pleasantness (P = 0.59). The sweet preload was rated as sweeter (P < 0.0001) and the savory preload was rated as more savory (P < 0.0001).

The volume of the preload given to each participant was calculated according to individual energy requirements using Schofield equations. In this way, each preload represented 10% of the estimated daily energy requirement (~710–1050 kJ/200–300 mL) for moderately active women aged 18–29 y (20).

Simultaneous choice test meal. The test meal comprised food items that were chosen to vary in their fat content and taste properties to produce a matrix of high-fat or low-fat and sweet- or savory-tasting foods. Eight foods were chosen to form four pairs that were matched in terms of energy density and macronutrient composition but differed in sweet or savory taste (Supplemental Table 2). The test meal foods were presented in large portions, ~3 times a normal serving, and participants were told they could have more of any food on request. Total energy intake and food selection from each food category was calculated by weighing each food item on its dish before and after consumption.

Procedures. Participants attended the Human Appetite Research Unit on four different days. A screening visit was necessary to verify inclusion criteria and to measure height, weight, and body composition (bioelectrical impedance). During screening, participants tasted and confirmed the acceptability of all foods involved in the study. All participants underwent three experimental test sessions separated by a minimum wash-out period of 3 d. They were instructed to consume their usual breakfast pattern on the morning of each test session and to refrain from eating, drinking (except water), and engaging in vigorous physical activity from the evening prior to their appointment. Participants were randomized to a rotated order of preload condition and test sessions took place around midday in purpose-built rooms at the research unit. During each session, participants were given 10 min to drink the entire preload. Following a 30-min rest, participants were given the test meal and allowed 20 min to eat until they were comfortably full. After the final test session, they completed the TFEQ. During debriefing, participants were asked to describe the objectives of the study, but none correctly guessed the hypotheses.

Ethics. This research was subject to ethical guidelines for human nutrition research and ethical approval was granted from the Institute of Psychological Sciences (University of Leeds) Ethics Committee and in accordance with the Helsinki Declaration of 1975 as revised in 1983. Written informed consent was obtained before participation in study-related procedures.

Data analyses. A priori power calculation [G*Power (21)] showed that 30 participants were sufficient to detect a significant difference (P < 0.05) in food choice (test meal intake) between preload conditions given
a small to moderate effect size (\(r^2 = 0.20-0.22\)) as indicated by previous testing (1-\(\beta = 0.8, \alpha = 0.05\)). Order of preload condition, oral contraceptive use, and menstrual phase were tested by mixed ANOVA for effects on food intake (all F-ratios < 0.34; \(P > 0.77\)). Therefore, these factors were excluded from further analyses. Preliminary analyses to assess the effect of preload condition on food intake and appetite variables were conducted by ANOVA. To examine the influence of eating behavior traits on appetite variables, restraint, hunger, and disinhibition were correlated with food intake in each condition. Significant traits were then examined as covariates in repeated-measures ANCOVA. Therefore, total food intake was examined by 1-way ANCOVA. Food intake selection according to fat content (high or low) and taste (savory or sweet) was examined by \(3 \times 2 \times 2\) ANCOVA. Satiating efficiency of the preloads measured at 3 time points (+10, +20, +30 min after preload) were examined by \(3 \times 3\) ANCOVA. The impact of the preload on explicit liking and implicit wanting for the 4 categories of food image (taste: savory or sweet; and fat content: high or low) were examined by separate \(3 \times 2 \times 2\) ANCOVA. Where appropriate, Greenhouse-Geisser probability levels were used to adjust for sphericity. Where significant interactions between outcome variables and eating behavior traits were revealed, these were examined using point estimates of lower and upper tertile scores on each scale. Data were analyzed using SPSS for Windows (version 16) and presented as mean ± SE. Significance was set at \(P < 0.05\).

**Results**

**Participant characteristics and food intake.** BMI was normally distributed and ranged from moderately underweight (17.5 kg/m\(^2\)) to moderately overweight (27.0 kg/m\(^2\)). Mean food intake at the test meal was similar across preload conditions (Table 1). When intake was examined according to food category, high-fat foods contributed more energy than low-fat foods (\(P < 0.0001\)) and more savory foods were consumed than sweet (\(P < 0.05\)). Furthermore, the taste of the preload influenced intake at the test meal according to taste (\(P < 0.01\)) and by the combination of taste and fat properties of the foods selected (\(P < 0.05\)). Less energy was consumed from high-fat savory foods after consuming the savory preload compared to the sweet preload. In contrast, consumption of sweet foods did not differ according to preload condition (Fig. 1).

**Effect of preload taste on satiating efficiency and food reward.** There was an impact of the preloads on SQ scores with an increase in satiation after consumption followed by a partial return to baseline (\(P < 0.01\)). There were no differences in the satiating efficiency according to preload taste. Analyses of food reward revealed no differences according to taste or fat properties of the images. However, there was an interaction of preload condition on explicit liking according to the taste properties of the foods (\(P < 0.05\)). Savory-tasting foods were rated lower after the savory preload compared to the bland or sweet preloads. There were no differences in implicit wanting according to taste or fat properties of the images and scores did not differ according to preload condition (all F-ratios < 2.2).

**Effect of eating behavior traits on food intake and food selection.** Scores on restraint, disinhibition, and hunger and bivariate correlations between eating behavior traits and food intake for each preload condition showed that disinhibition was highly correlated with total food intake after consumption of the sweet preload (\(r = 0.59, P < 0.001\)). There were no relationships between other eating behavior traits and food intake (Table 1). On further examination, this finding was confirmed by an interaction between disinhibition and preload condition on food intake at the test meal (\(P < 0.01\)). Post hoc comparison of upper (\(M = 10.0 \pm 1.6\)) and lower (\(M = 4.5 \pm 1.5\)) tertiles showed that higher disinhibition scores consumed the most energy after the sweet preload and least after consuming the savory preload. Low scorers consumed less energy overall and their intake did not differ according to preload condition (Fig. 2). When intake was examined in more detail according to the taste and fat properties of foods in the test meal, no interactions were found with disinhibition and preload conditions (all F-ratios < 2.3; \(P > 0.21\)). Therefore, greater intake associated with disinhibition was not category specific.

**Effect of eating behavior traits on satiating efficiency and food reward.** There was an effect of disinhibition on SQ of the preloads (\(P < 0.05\)) and a disinhibition by time interaction (\(P < 0.05\)) but no interaction according to preload taste. Overall, higher disinhibition scores were associated with weaker satiation and a more rapid return to baseline SQ levels compared to lower scores (Fig. 3).

Analysis of food reward revealed an effect of disinhibition on explicit liking (\(P < 0.0001\)) but no interaction according to preload condition or for specific categories of food. Overall, high disinhibition scores were associated with higher liking for all

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**TABLE 1** Participant characteristics, eating behavior traits, and bivariate correlations with energy intake following savory-, sweet-, or bland-tasting PL

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Mean ± SD</th>
<th>Savory PL</th>
<th>Sweet PL</th>
<th>Bland PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>(r)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>21.9 ± 2.6</td>
<td>-0.32</td>
<td>-0.31</td>
<td>-0.34</td>
</tr>
<tr>
<td>BMI, kg/m(^2)</td>
<td>22.7 ± 2.3</td>
<td>0.15</td>
<td>0.23</td>
<td>-0.22</td>
</tr>
<tr>
<td>TFEQ</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Restraint</td>
<td>8.0 ± 4.4</td>
<td>0.14</td>
<td>0.30</td>
<td>-0.17</td>
</tr>
<tr>
<td>Hunger</td>
<td>6.0 ± 3.1</td>
<td>0.25</td>
<td>0.24</td>
<td>0.18</td>
</tr>
<tr>
<td>Disinhibition</td>
<td>7.1 ± 3.2</td>
<td>0.33</td>
<td>0.59*</td>
<td>-0.08</td>
</tr>
<tr>
<td>Energy intake, kJ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Savory PL</td>
<td>3560 ± 1260</td>
<td>—</td>
<td>0.72*</td>
<td>0.21</td>
</tr>
<tr>
<td>Sweet PL</td>
<td>3810 ± 1310</td>
<td>—</td>
<td>—</td>
<td>-0.17</td>
</tr>
<tr>
<td>Bland PL</td>
<td>3650 ± 1190</td>
<td>—</td>
<td>—</td>
<td></td>
</tr>
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</table>

\(^1\) Values are mean ± SD, \(n = 30\), or the Pearson product-moment correlation coefficient. \(^*P < 0.001\). PL, preload; TFEQ, Three Factor Eating Questionnaire.

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**FIGURE 1** Energy intakes by nonobese women following savory, sweet, and bland preloads by fat level and savory or sweet properties of foods eaten in the test meal. Values are means ± SEM, \(n = 30\). \(^*\)Means differ, \(P < 0.05\). HF, high-fat; LF, low-fat; PL, preload.
evaluated foods (Fig. 4). For implicit wanting scores, there was no overall effect of disinhibition on implicit wanting and no interaction according to preload condition. There was an effect of disinhibition according to food category ($P < 0.05$), with greater implicit wanting for high-fat sweet food in higher scorers compared to lower scorers (Fig. 4).

**Discussion**

This study examined the effect of savory, sweet, or bland food on appetite and food intake in relation to individual differences in the susceptibility to overeating. It was predicted that a savory-tasting food, consumed as a preload, would exert a stronger effect on food preference than a sweet or bland-tasting version of the same food and that those women with a higher susceptibility to overeating would demonstrate weaker satiety and consume more energy at a test meal.

The results showed that the preloads did not differ in their satiating efficiency and did not influence overall energy intake at the test meal. However, there was an effect of preload taste on the type of food consumed, with lower intake of high-fat savory food following the savory preload. This was supported by a reduction in explicit liking for savory-tasting foods after the savory preload as measured by the LFPQ. This is consistent with the concept of sensory-specific satiety, thought to contribute to the inhibition of eating via a decrease in sensory pleasure during exposure to a taste (22).

Tordoff and Alleva (23) found that chewing sweet-tasting gum caused a small, transient suppression of hunger followed by an overall enhancement of hunger compared to nonsweet gum. Furthermore, when sweet taste is uncoupled from energy by comparing solutions of artificial sweeteners to glucose (matched for taste intensity) or water, sweet taste has been shown to increase sensations of hunger and desire to eat (24). Less is known of the effect of savory taste on appetite. It is thought that monosodium glutamate enhances the depth of savory taste when added to soups and this has been shown to facilitate flavor acceptance and subsequent intake of soup (25). Enhancing savory broth with MSG as a mid-morning preload was associated with a shorter suppression of hunger compared to broth without additional MSG (26). More recently, MSG supplementation in a double-preload design (the first consumed with breakfast and the second mid-morning) was found to decrease hunger in the period following the second preload compared to no-MSG control (27). However, neither of these preload studies found effects of MSG on energy intake at the subsequent test meal (26,27).

In the present study, it was possible to simultaneously compare the effects of savory- and sweet-tasting preloads to a bland-tasting control preload. Interestingly, in terms of the effect on food selection at the test meal and explicit liking in the LFPQ, the bland preload fell somewhere between the differences observed between the savory and sweet preloads. This suggests that the bland preload was an appropriate control and that sweet and savory sensory domains can be experimentally investigated along a continuum as well as by nominal categories.

Previous research comparing consumption of the savory- and sweet-tasting foods on energy intake concur with these results. De Graaf et al. (8) found no difference in overall intake of savory and sweet snacks following consumption of savory- or sweet-tasting carbohydrate preloads (comprising 250, 500, or 750 kcal energy load) but reported effects (that increased in line with preload energy content) according to the sensory domain of foods consumed. In a series of experiments, Griffioen-Roose et al. (1,9,28) investigated sensory influences on the regulation of food intake and/or food choice was revealed compared to sweet taste.

A further objective in the present study was to examine the effects of savory- and sweet-tasting preloads according to individual differences in the predisposition to overeat. An association between preference for fat and adiposity was previously established (29), although preference may not in itself determine dietary fat intake (30,31). There is also evidence that higher preferred concentrations of sweetness and fat are associated with subsequent weight gain in an obesity-prone population (32). Variability in the perception of sweet or savory taste may influence food preferences and dietary habits, affecting energy intake and weight gain. For example, polymorphisms in the T1R receptor gene have been linked to differences in dietary patterns between and within populations (33).
In the present study, susceptibility to overeating was assessed according to eating behavior traits measured by the TFEQ and disinhibition was identified as a correlate of overall energy intake. Specifically, higher scorers on this trait were shown to consume more energy than low scorers after the sweet preload compared to savory or bland preloads. Nevertheless, disinhibition has been linked to the loss of control over eating (34,35), tendency to overconsume (36,37), and susceptibility to gain weight (11,38,39). A recent review on the role of disinhibition in appetite and weight regulation proposed that this trait is a predictor of opportunistic eating (15). In connection with the effects on food intake observed in the present study, disinhibition scores were associated with lower satiating efficiency of the preloads. Recently, it was reported that females scoring high on disinhibition had a lower sensitivity to the satiating effects of a high-carbohydrate, sweet-tasting breakfast and consumed more energy during a subsequent food intake test (40).

We also found that disinhibition was associated with greater explicit liking for foods presented in the LFPQ. As previously mentioned, research has suggested a link between high food liking and susceptibility to obesity (11,30,32). However, other research suggests that lean and obese individuals do not differ in normal weight young adults. J Nutr. 2009;139:2093–8. Satiation due to equally palatable sweet and savory meals does not differ in normal weight young adults. J Nutr. 2009;139:2093–8.

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There were some limitations in the present study. The majority of participants were young (mean age 21.9 ±) and recruited from near a university campus. This strategy reduces the relevance of our research for understanding the interaction of taste and susceptibility to overeating in the wider context. The restricted sample size may also have limited the ability to detect smaller effect sizes associated with reward and SQ measures.

Future research should apply the procedures for assessing mechanisms of appetite used in the present study (LFPQ and SQ) in obese participants or clinical settings. For example, sensations of hunger, food selection, and the dual monitoring of liking and implicit wanting may help to characterize specific phenotypes of diabetes, obesity, and eating disorders. Early identification of traits that predispose individuals to overconsume, and the specific behavior driving overconsumption, could help to optimize nutritional strategies such as the use of sensory properties of food to prevent weight gain (10,49–51).

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