The Association between Perceived Sweetness Intensity and Dietary Intake in Young Adults

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Abstract: Individual differences in taste perception may influence dietary habits, nutritional status, and ultimately nutrition-related chronic disease risk. Individual differences in sweetness intensity perception and the relationship between perceived sweetness intensity, food behaviors, and dietary intake was investigated in 85 adults. Subjects (body mass index [BMI] = 21 ± 3, 21 ± 4 y) completed a food and diet questionnaire, food variety survey, 2 24-h food records, and a perceived sweetness intensity measurement using the general labeled magnitude scale (gLMS). There was interindividual variation in perceived sweetness intensity (0 to 34 gLMS units, mean 10 ± 7). One-way analysis of variance (ANOVA) revealed no difference between perceived sweetness intensity and degree of importance placed on not adding sugar to tea or coffee ($P = 0.2$) and the degree of importance placed on avoiding sugar-sweetened or fizzy drinks ($P = 1.0$). Independent *t*-test analysis revealed no significant association between perceived sweetness intensity and the food variety measure for sugar and confectionary intake ($P = 0.6$) and selected fruit and vegetable intake ($P = 0.1$ to 0.9). One-way ANOVA also demonstrated no difference between tertiles of sweetness intensity and BMI ($P = 0.1$), age ($P = 0.3$), and food variety score ($P = 0.5$). No correlation was observed with regards to perceived sweetness intensity and mean total energy (kJ) intake ($r = 0.05$, $P = 0.7$), percent energy from total fat, saturated fat, protein, carbohydrate, and grams of fiber ($r = –0.1$ to 0.1, $P = 0.2$ to 0.8) and also for intake of the micronutrients: folate, magnesium, calcium, iron, and zinc ($r = 0.1$ to 0.2, $P = 0.1$ to 0.4). Only modest correlations were observed between sodium ($r = 0.3$, $P < 0.05$), vitamin C ($r = 0.3$, $P < 0.05$), and potassium ($r = 0.2$, $P < 0.0$) intake and perceived sweetness intensity. Overall, perceived sweetness intensity does not appear to play a role in food behaviors relating to sugar consumption and dietary intake in adults.

Keywords: dietary intake, food behaviors, health, sweet taste, taste intensity

Introduction

Taste perceptions from foods and beverages are considered to be one of the main drivers of food selection and appear to play a pivotal role in determining one's food preference and habitual diet (Glanz and others 1998; Tepper and Ullrich 2002; Garcia-Bailo and others 2009). Individual differences in taste perception may therefore influence dietary habits that may in turn affect nutritional status and nutrition-related chronic disease risk (Garcia-Bailo and others 2009). The increasing incidence of nutrition-related chronic diseases such as obesity, cardiovascular conditions, type 2 diabetes (T2DM), and some cancers (World Health Organization 2003; Daar and others 2007) necessitates an increased understanding of the drivers of food intake.

Taste is 1 of 5 senses (sight, smell, hearing, and touch) that provides humans the capability to assess the nutritive or toxic value of food to be ingested (Rawson and Li 2004). To date, the majority of research linking taste with food acceptance and selection has been carried out using the bitter compound, 6-n-propylthiouracil (PROP) (Tepper 2008). These studies have generally shown that those sensitive to this compound tend to dislike specific bitter-tasting vegetables and consume a smaller quantity of vegetables in general (Bell and Tepper 2006; Dinehart and others 2006; Duffy and others 2010). Very little research has been conducted on the other 4 taste qualities (and on the potentially new taste, fat) in terms of taste sensitivity, dietary intake, and preference. A recent study by Hayes and others (2010) found that those most sensitive to PROP tend to report a greater salt intensity from foods, and consume more sodium compared with those who are less PROP sensitive. With regards to the putative fat taste, those who were orally sensitive to fatty acids, consumed a lower amount of total fat and energy (Stewart and others 2010).

With regards to sweet taste, 2 studies have examined the relationship between sweet intensity, preference, intake, and sensitivity to the bitter taste of PROP and quinine. These studies found that those who tasted PROP as more bitter and quinine as less bitter reported a greater sweetness from sucrose and foods high in added sugar, had a lower preference for sweet foods, and lower intake of sugar; consumption of macro- and micronutrients was not investigated however (Duffy and others 2003; Hayes and Duffy 2008). Yeomans and others (2007) also reported that a high percentage of individuals most sensitive to PROP were sweet dislikers and rated the intensities of sweet tastes as greater compared to those less sensitive to PROP; however as with the previous study, dietary intake was not assessed. To date, only 1 study has examined sweet taste sensitivity together with sugar and macronutrient intake (but not micronutrient intake) and found no association between these variables (Mattes 1985).

An elevated preference for sweet taste has also been associated with a greater intake of added sugars, sweet foods, and carbohydrate-rich foods (Mattes and Mela 1986; Looy and

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Weingarten 1992; Holt and others 2000; Duffy and others 2003). This may be partially related to suggested neurochemical changes in brain regions involved in reward (Kim and others 1998; Pomonis and others 2000; Colantuoni and others 2001; Levine and others 2003). Recently, sweet taste receptors (T1r2 and T1r3) located on the tongue have also been found in the endocrine cells of the gut and are involved in the secretion of gastrointestinal satiation peptides with potential effects on glucose homeostasis, regulation of insulin secretion, appetite, and gut motility (Jang and others 2007; Scalfani 2007; Kokrashvili and others 2009; Treesukosol and others 2011; Yee and others 2011). Furthermore, glucose transporters (GLUTs), sodium–glucose cotransporters (SGLTs), and APT-gated K^+ (K_{ATP}), which play an important role in glucose homeostasis and metabolism throughout the body and in specific organs (that is, gut), have been suggested to be T1r-independent mechanisms for detecting sugars (Yee and others 2011). Therefore, an individual's sensitivity to sweet taste may be linked to the number of sweet receptors present in both the oral cavity and gut, and may affect the type and quantity of food consumed, as noted for the putative fat taste (Stewart and others 2010).

Due to the lack of research conducted thus far the objective of the present study was to investigate the relationship between perceived sweetness intensity, food behaviors relating to sugar consumption, and dietary intake.

Materials and Methods

Subjects

One hundred and thirty university students enrolled in a food and nutrition unit completed the following assessments as part of their course work: a food and diet questionnaire, 2 24-h food records, a food variety survey, and a perceived sweetness intensity measurement. All students were invited to participate in the current study and 85 provided written consent to participate (response rate 65%). Ethical approval was obtained from the Deakin Univ. Human Research Ethics Committee (EC253–2006 and EC12–2007).

Food, diet, and demographic information

A food and diet questionnaire was developed based on questions used in previous studies examining the eating habits of adults (Georgiou and others 1997; Soriano and others 2000). The questionnaire included 29 items asking subjects about their dietary activities and food beliefs related to health. The degree of importance subjects placed on certain dietary activities was assessed by asking the subjects if they considered the activity: not important; important; very important; and not sure. Examples of the dietary activities assessed include: "how important is not adding sugar to tea or coffee?" and "how important is avoiding sugar-sweetened or fizzy drinks?" The degree of importance subjects placed on certain food-related beliefs was assessed by asking subjects if they considered the beliefs: not important; slightly important; moderately important; very important; and extremely important. An example of a food-related belief assessed is "how important is taste when choosing food?" Nutrient intakes were assessed using 2 24-h food records completed over 1 weekday and 1 weekend day (Karvetti and Knuts 1992). Each participant was instructed to record what they ate or drank as they consumed the food item and the quantity consumed using household measures, they also listed the brand name and any additions made to the food or beverage. To aid in the recording of consumed food and beverages, subjects were provided with a printed table that included prompts for recording the time of day, food or drink item, brand name, and quantity. The average nutrient intake of the subjects was determined using the dietary analysis program specific to Australia, FoodWorks 2007 (Xyris Software Version 5, Queensland). A food variety survey (Savige and others 1997) was used to determine the various foods normally consumed in an individual's diet. A numerical score was given for each food consumed in the checklist if 2 tablespoons or more of the food had been consumed in the last 7 d (Savige and others 1997). A score of above 30 per wk (out of 52) was considered to be ideal (Savige and others 1997). Demographic information collected from the subjects included: gender, age, self-reported height and weight, and smoking status. Body mass index (BMI) was calculated based on self-reported height and weight.

Sweetness intensity measurement

All sensory testing took place in the Sensory Laboratory at Deakin Univ. The general labeled magnitude scale (gLMS) was used to determine a subjects' sensitivity to sweet taste. Subjects were asked to refrain from consuming food and drink (except room temperature water) 2 h prior to testing; adherence to these instructions was assumed unless otherwise stated by a subject. Prior to data collection, subjects were instructed in how to use the gLMS scale (Bartoshuk and others 2004). The gLMS is a labeled scale of intensity that requires individuals to rate perceived intensity along a vertical axis containing the following adjectives: barely detectable = 1.5, weak = 6, moderate = 17, strong = 35, very strong = 52, and strongest imaginable sensation of any kind = 100. The adjective placement was derived experimentally and yields data equivalent to magnitude estimation. The adjectives but not their corresponding numbers are visible to subjects. Numerical data are generated from the scale (Green and others 1993; Green and others 1996; Bartoshuk and others 2004). After familiarization with the scale, subjects were asked to rate a list of 9 remembered or imagined oral sensations (that is, the coolness of an ice-cold beverage and the burn of a whole chili pepper) for their intensity on the gLMS. Feedback was given by the researchers as to where the general population rated those stimuli for intensity, helping the subjects to better understand the proper usage of the scale. Subjects were then supplied with references for barely detectable (sweetness of a 50 mM, 17.1 g/L sucrose solution), weak (warmth of lukewarm water), and moderate (irritation of carbonated soda water) and asked to evaluate and rate on the scale. For strong, very strong, and strongest imaginable, subjects were given hypothetical examples.

A sucrose solution (200 mM, 68.5 g/L) was used as the stimulus for the current study (Cicerale and others 2009; Pepino and others 2010). Soda water (supplied by Kirks Classics, Melbourne, Australia) was also included in the study as a control stimulus to aid in determining if the subjects were using the scale idiosyncratically (Lawless and Heymann 1999). Subjects rated the irritation intensity elicited by carbon dioxide (CO_2) in the soda water. All testing took place in a sensory testing facility comprising 7 individual booths. Each participant was isolated from other individuals by vertical dividers to eliminate interaction between subjects. Subjects also wore nose clips to eliminate olfactory cues from the stimuli.

An aliquot of 15 mL of the sucrose solution and soda water was presented in 30-mL polyethylene medicine cups (McFarlane Medical, Surrey Hills, Australia). Subjects rinsed their mouths with filtered (FI) water (8-μm particulate filter with an activated charcoal filter, Dura®, Reece, Melbourne, Australia) at least

3 times over a 2-min period before commencement of testing. Each subject sampled and rated (using the gLMS) a sucrose solution for sweetness intensity and soda water for CO_2 irritation intensity. Subjects placed the samples in their mouth for 5 s, expectorated the solution, and then rated the overall perceived intensity on the gLMS.

Data analysis

SPSS Version 17.0 software (SPSS, Chicago, Ill., U.S.A.) was used for the statistical analysis of the data. Numerical data are expressed as means ± standard deviations (SDs). Descriptive statistics were employed to describe demographic information, perceived sweetness intensity, food behaviors, total food variety score, and dietary intake. Analysis of the frequency distributions of sweetness intensity showed a deviation from normality, with the distribution being skewed to the left, consistent with square root distributions. Ratings were therefore converted to square root values before further analyses (that is, analysis of variance [ANOVA] and independent *t*-test) were conducted, however when discussing the descriptive statistics for sweetness intensity ratings, the unadjusted means ± SDs were presented. Perceived sweet intensity and its relation to dietary activities and food beliefs related to health were analyzed by a one-way ANOVA with a Tukey post hoc. With regards to the food variety measures of sugar and confectionary and selected fruit and vegetable intake, subjects were separated according to their consumption of that particular food (that is, did or did not consume), independent *t*-tests were then applied to examine the relationship between those measures and perceived sweetness intensity. Upon grouping perceived sweetness intensity into tertiles, a one-way ANOVA with a Tukey post hoc was used to analyze the relationship between perceived sweetness intensity and food variety score, BMI, and dietary intake. Pearson's product-moment coefficients correlations were conducted to also analyze the relationship between perceived sweetness intensity and total food variety score, BMI, dietary intake, and CO_2 intensity. Results were considered to be statistically significant when $P < 0.05$.

Results

Participant characteristics

A total of 85 subjects (21 ± 4 y, BMI of 21 ± 3) (89% female) participated in the study. The majority were nonsmokers ($n = 81$) and 73% described their nationality as "Australian."

Sweetness intensity

Among the 85 subjects, the minimum and maximum sweetness intensity ratings were 0 and 34, respectively. The average sweetness intensity rating was 10 ± 7 (Figure 1). No correlation between sweetness and CO_2 intensity ratings was found ($r = 0.13$, $P = 0.24$), indicating that sweetness ratings were independent of idiosyncratic use of the gLMS. No association was identified between perceived sweetness intensity and age ($r = 0.002$, $P = 1.0$) or BMI ($r = 0.07$, $P = 0.6$) and similarly there were no differences in tertiles of sweetness intensity, age, and BMI ($P = 0.1$ and 0.3, respectively).

Sweetness intensity, dietary activities, and food beliefs related to health

The majority of subjects considered taste "extremely important" or "very important" (82%) when choosing food. Independent *t*-test analysis revealed there was no difference between perceived sweetness intensity and degree of importance placed on: not adding sugar to tea or coffee ($P = 0.2$), avoiding sugar-sweetened or fizzy drinks ($P = 1.0$), and taste when choosing food to consume ($P = 0.6$).

Sweetness intensity and food variety

The mean food variety score was 32 ± 6 and no association between perceived sweetness intensity and food variety score ($r = 0.03$, $P = 0.8$) was observed. Further to this, total food variety score did not differ between tertiles of sweetness intensity ($P = 0.5$). No significant associations were observed between perceived sweetness intensity and the food variety measure for sugar and

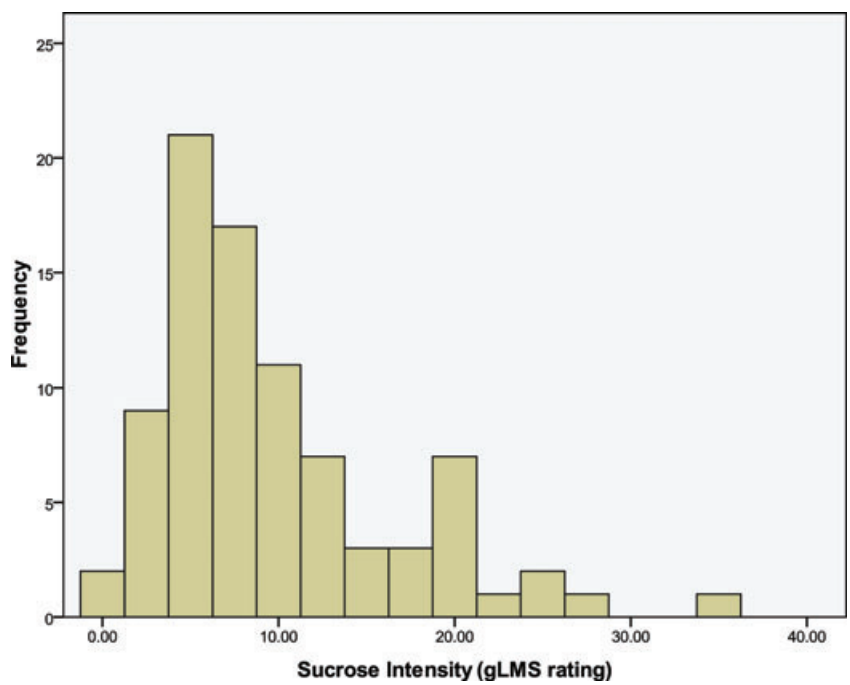

Figure 1–Distribution frequency of individual perceived sweetness intensity.

confectionary intake ($P = 0.6$) and selected fruit and vegetable consumption ($P = 0.1$ to 0.9).

Sweetness intensity and dietary intake

No correlation was observed between perceived sweetness intensity and mean total energy intake, percent energy from total fat, saturated fat, protein, carbohydrate, and grams of fibre. Furthermore, there were no correlations between perceived sweetness intensity and the micronutrients: folate, magnesium, calcium, iron, zinc and modest correlations for sodium, vitamin C, and potassium intake. No significant differences were observed between tertiles of sweetness intensity and the macro- and micronutrients investigated except for sodium ($P < 0.05$) and a trend toward significance was found for total energy ($P = 0.09$) and total fat ($P = 0.05$) (Table 1).

Discussion

The present study focused specifically on individual differences in perceived sweetness intensity and the relationship between perceived sweetness intensity, food behaviors, and dietary intake in a convenience sample of adults. Although a range of perceived sweetness intensity was observed, there was no significant association between perceived sweetness intensity, food behaviors relating to sugar consumption and taste, and dietary intake.

This study is, to our knowledge, the first to investigate if perceived sweetness intensity is related to specific food behaviors and nutrient intake and no associations were found. Studies by Yeomans and others (2007) and Hayes and others (Hayes and Duffy 2008) have demonstrated weak associations between taste intensity, liking, and dietary intake. The results in this study do not support a relationship between sweetness intensity and dietary intake, despite observing a range of perceived sweetness intensity previously noted by others (Pepino and others 2010). These data are not unexpected as the relationship between perceived sweetness and level of preference for sweet foods is complex and nonlinear (Duffy and others 2003). Moreover, sensitivity to sweet has not been shown to consistently identify why some individuals like or dislike increasing concentrations of sucrose (Looy and Weingarten 1992). We must also consider that the relationship between tasting a solution, liking, and consumption of whole foods and ultimately diets may be weak (Pangborn and Pecore 1982; Mattes 1985; Lucas and Bellisle 1987). While perceived taste intensity may be important to individuals, the perception of taste solutions may not be related to liking and may be only 1 small component of overall dietary intake (Duffy and others 2003).

A number of limitations that may have influenced the results must be acknowledged. The subjects were relatively homogenous with regards to ethnic background, age, BMI, and only a small number of males participated in the study. Therefore, caution should be taken when generalizing the current findings to the broader population. Height and weight were self-reported and although self-reporting is prone to errors, large studies have found that differences in self-reported height and weight, compared with measured height and weight, are only statistically significant amongst individuals aged >60 y, and that self-reported height and weight can be useful in studies using younger adults (Kuczmarski and others 2001). A single measure of sweet taste was used and perhaps differing measures of sweet taste (that is, thresholds) may yield different data. Furthermore, 1 concentration of sucrose was used to measure sweetness intensity and there is potential that varying sucrose concentrations may have produced different results. However, if there was a robust association between sweetness intensity and dietary intake, we should have observed one.

Table 1–Macro- and micronutrient intakes ($n = 85$); correlations between perceived sweetness intensity and nutrient intakes; and analysis of variance between sweetness intensity tertiles and nutrient intakes.

Nutrient	Dietary intake (mean ± SD)	Correlation	Analysis of variance
Total energy (kJ)	8099 ± 2838	$r = 0.05$, $P = 0.7$	$P = 0.09$
Total fat (%)	32 ± 6	$r = -0.1$, $P = 0.2$	$P = 0.05$
Total sat fat (%)	14 ± 4	$r = -0.1$, $P = 0.4$	$P = 0.6$
Protein (%)	20 ± 6	$r = 0.06$, $P = 0.6$	$P = 0.4$
CHO (%)	46 ± 8	$r = 0.07$, $P = 0.5$	$P = 0.6$
Fibre (g)	22 ± 9	$r = 0.03$, $P = 0.8$	$P = 0.2$
Vit C (mg)	150 ± 104	$r = 0.3$, $P = < 0.05$	$P = 0.2$
Folate (μg)	301 ± 110	$r = 0.2$, $P = 0.1$	$P = 0.2$
Na (mg)	2604 ± 1504	$r = 0.3$, $P = < 0.05$	$P < 0.05$
K (mg)	3065 ± 1086	$r = 0.2$, $P = < 0.05$	$P = 0.1$
Ca (mg)	852 ± 369	$r = 0.1$, $P = 0.2$	$P = 0.4$
Mg (mg)	298 ± 92	$r = 0.1$, $P = 0.2$	$P = 0.1$
Fe (mg)	12 ± 4	$r = 0.1$, $P = 0.4$	$P = 0.2$
Zn (mg)	11 ± 5	$r = 0.1$, $P = 0.2$	$P = 0.4$

Conclusion

In conclusion, perceived sweetness intensity measured *via* a sucrose solution did not play a role in specific food behaviors, sweet food consumption, or more generally the dietary intake of young adults. The importance of taste when choosing food to consume was considered to be extremely or very important for the majority of subjects in the current study. Therefore, although taste is an important consideration with regards to dietary choice, perceived sweetness intensity alone does not have a significant influence on food behavior and dietary intake.

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