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Ability to Taste 6-*n*-Propylthiouracil and BMI in Low-income Preschool-aged Children

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Background: Sensitivity to the bitter compound 6-*n*-propylthiouracil (PROP) is genetically mediated. Sensitivity to PROP has been associated with weight status in both adults and children.
Objective: To determine whether there is an association between PROP sensitivity and BMI in low-income children of diverse race/ethnicity, among whom there is a high prevalence of obesity.
Methods and Procedures: Eighty-one preschool-aged children attending Head Start tasted a solution of 560 μmol/l PROP and reported whether it tasted "like water" or "like something else". Mothers reported child's race, age, maternal education, maternal weight and height, child's reluctance to sample new foods via the Food Neophobia Scale (FNS), and child's dietary intake using a food frequency questionnaire. Child weight and height were measured. BMI was calculated and for children, expressed in *z*-scores. Regression analyses were used to evaluate the relationship between child's PROP taster status and BMI *z*-score, testing covariates child's age, gender, race, maternal education and BMI, and child's FNS score. Children's dietary intake was compared by PROP taster status.
Results: PROP tasters, compared with nontasters, had significantly higher BMI *z*-scores (0.99 (s.d. 1.24) vs. 0.03 (1.12), $P = 0.004$) and had a significantly higher prevalence of overweight (31.8% vs. 5.6%, $P = 0.025$), but demonstrated no differences in reported dietary intake. The most parsimonious model predicting the child's BMI *z*-score included only maternal BMI and the child's PROP taster status ($R^2 = 22.3\%$).
Discussion: A genetically mediated ability to taste bitter may contribute to obesity risk in low-income, preschool-aged children.

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INTRODUCTION

The prevalence of childhood obesity continues to increase (1), with apparent growing disparities based on race and socioeconomic status (1,2). The prevalence of obesity among preschool-aged children attending Head Start, a federally funded preschool program for low-income children, has been reported to be ~50% higher than in the general population of preschoolers (15.5% vs. 10.4%) (3). The reasons underlying these disparities are multifactorial and poorly understood. Although the rapid secular rise of obesity supports a significant role of environment in promoting obesity risk, genes presumably interact with the environment to confer differing obesity risk in individuals.

One such genetic factor is bitter taste perception, which appears to be in large part mediated by the *TAS2R38* gene (4). The insensitivity to the bitter compounds 6-*n*-propylthiouracil (PROP) and phenylthiocarbamide, mediated by this gene, is estimated at ~30% in European populations. There is, however, wide variation among racial/ethnic groups worldwide (for an extensive review, see ref. (5)), as well as by gender, with women being more likely to be tasters (5).

The presumed interaction of PROP taster status with the environment to confer differential obesity risk is illustrated by the rather inconsistent findings in samples of different ages. Being a PROP taster (compared to a nontaster) has been associated with having a lower BMI in adults (6–10) as well as in African-American grade school students in 1966 (11). Three prior studies in preschool-aged children, however, have had conflicting results. Two have not detected a difference in BMI based on PROP taster status (12,13), while one found that PROP taster girls had higher BMIs than nontasters, while PROP taster boys had lower BMIs than nontasters (14). All three of these prior studies were conducted in a university preschool attended primarily by children who were white and of middle- to upper-socioeconomic status (13). The prevalence of overweight in these populations of preschoolers has therefore been relatively low.

The genetic variability in bitter taste perception has been hypothesized to confer selective advantage; greater sensitivity

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to bitter taste may protect against the consumption of poisonous foods, but insensitivity to bitter may promote the consumption of a wider array of foods (and therefore a healthier dietary pattern) (15,16). Several studies have linked the ability to taste PROP with having more food aversions (17,18), a dislike for vegetables (12,19), a greater perception of vegetables as bitter, and a lower consumption of vegetables (20). In a free-choice situation, preschool-aged children who were PROP tasters consumed fewer bitter vegetables and fewer vegetables (both bitter and nonbitter) overall than children who were nontasters (13). Taster preschool-aged children have also been reported to rate raw broccoli (12,13), grapefruit–orange juice (21), and spinach (22) as less palatable than do nontaster children.

These potential effects of PROP taster status on an individual's eating behavior could underlie specific effects of PROP taster status on obesity risk in low-income children. Young children are relatively reluctant to sample new foods (23,24), and emerging data (13) would suggest that children who are PROP tasters would be particularly reluctant to eat vegetables. Parents may respond to a child's rejection of vegetables by purchasing and preparing them in more palatable ways, by introducing the same vegetable repeatedly in an attempt to increase liking (even though it may be rejected and wasted), or by purchasing a wider variety of vegetables (of varying cost) to encourage the child's intake. Low-income children, however, often live in families with limited food resources. Parents may not have the resources for or access to a wide variety of more palatable or preferred vegetables, and often cannot afford to serve vegetables that may be rejected and wasted. Parents in this situation may simply feed the child foods they know the child will accept, which may equate to highly palatable, but also unhealthy foods (25). In short, being a child who is a PROP taster living in poverty may be particularly associated with low intake of vegetables, and consequently a higher risk of overweight. This study therefore sought to test the hypothesis that lower vegetable intake would occur among PROP taster children in a low-income preschool-aged sample, and that these PROP tasters would be at higher risk of overweight.

METHODS AND PROCEDURES

Participants

Eighty-one 3- to 6-year-old children were recruited from a local Head Start. Head Start is a federally funded program providing free preschool to children living in families with incomes at 100% of the federal poverty line or less ($20,000 per year for a family of four in 2006) (26). Thus, all children in this study were living in poverty. Exclusion criteria were a history of allergic or adverse reaction to food, developmental language delay reported by the parent, nonfluency in English in either parent or child, significant medical problems, or febrile illness within the last 36 h. Each parent completed written informed consent and the study was approved by the University of Michigan Institutional Review Board.

Identification of PROP taster status

PROP tasting was conducted in a quiet but familiar area of the child's Head Start that was without distractions. Children were seated with the researcher at a child-size table. Each child's PROP taster status was tested by the same individual, with whom the children were familiar. Before tasting, children rinsed with spring water. We closely replicated the forced choice procedure developed by Keller *et al.* (12,14), who found high reliability using this method with 4- to 5-year-old children attending a university preschool. The method has subsequently been used in children as young as 3.5 years (13). Children were presented with a single 5 ml sample of a 560 μmol/l solution of PROP (Aldrich Chemical, Milwaukee, WI) and were verbally asked the question "Does that taste like water or something else?" (Keller *et al.* had asked "Do you taste anything?", but we found that the children in our sample responded more readily to the slightly altered question.) Following Keller's methodology, children who reported that the solution tasted "like water" were classified as nontasters, and children who reported that it tasted "like water" but showed classic rejection signs, such as grimacing or frowning (27), were classified as tasters. When children in Keller's protocol reported that the solution had a taste, they were further queried regarding what it tasted like. We found that the children in our sample did not possess the vocabulary to describe taste characteristics that Keller's sample apparently did, which may be due to the differing socioeconomic characteristics of the samples. Therefore, the children were asked, "Is it yucky or yummy?" on the premise that children who identified the taste as "yummy" were unlikely to be tasters. As will be shown below, all but one of the children who reported that it tasted "like something else" subsequently responded that it tasted "yucky".

Anthropometric data

Children were weighed without shoes or heavy clothing using a balance scale to the nearest 0.1 kg. Children's heights were measured without shoes using a wall-mounted stadiometer to the nearest 0.5 cm. Heights and weights were used to calculate BMI z-score based on the age- and sex-specific Centers for Disease Control National Center for Health Statistics growth charts (28). BMI z-scores are necessary as opposed to raw BMI given that BMI changes rapidly during this period, and the pattern of change differs by gender. Mothers self-reported height and weight by questionnaire and BMI was calculated. Maternal BMI was available for 72 mothers. One mother would not provide her specific weight, but indicated that her weight was above a particular number which would have categorized her as obese; maternal obesity status was therefore available for 73 mothers. Eight mothers declined to report their weight.

Covariates

Mothers reported the child's birth date, race, and maternal education level (more than high school vs. a high school diploma or less). Mothers completed the Food Neophobia Scale (FNS), a standardized and validated 10-item rating scale of children's reluctance to sample new foods (29). Each question on the FNS is answered on a seven-point Likert scale. Items are reverse-scored where appropriate, and the total score is obtained by summing across the 10 items. Total scores therefore range from

10 to 70 with higher scores indicating greater food neophobia. Three mothers did not complete the FNS, and complete data were therefore available for 78 children.

Mothers reported children's dietary intake using a modified 70-item version of the 90-item Block Kids Questionnaire—Ages 2–7 (30). The Block Food Frequency Questionnaires are validated and reliable indices of dietary intake (31,32). The Block Kids Questionnaire was developed from the National Health and Nutrition Examination Surveys III dietary recall data, and the nutrient database was developed from the US Department of Agriculture Nutrient Database for Standard Reference. The questionnaire does not ask parents to report on individual portion sizes. Food frequency questionnaires were completed by all 81 mothers.

Statistical analysis

χ^2-Analyses, *t*-tests, and ANOVA were used for unadjusted bivariate comparisons based on PROP taster status. We used Akaike Information Criteria to identify the most parsimonious regression model with the best fit predicting the child's BMI *z*-score from covariates PROP taster status, child's age, race, gender, maternal education, maternal BMI, and FNS score (Model 1). Although the outcome, child BMI *z*-score, is standardized for age and gender, inclusion of age and gender as predictors in the model is appropriate given that obesity risk increases with age and differs by gender. Given the significant association of both PROP taster status and obesity risk with race in prior literature (5), we retested Model 1 including race as a covariate (Model 2). In addition, given the significant association of both PROP taster status and obesity risk with gender in prior literature (5), as well as reported differing relationships between PROP taster status and weight status in male vs. female preschool-aged children (14), we retested Model 1 including gender as a covariate (Model 3).

We hypothesized that taster status affected either food neophobic behavior or vegetable consumption, which in turn predicted the child's BMI *z*-score. Thus, we tested the possible mediating effects of FNS score and percent of calories from vegetables on the relationship between PROP taster status and the child's BMI *z*-score by assessing whether the parameter estimate was changed after adding either of these individually to Model 1 (Models 4 and 5).

To evaluate dietary intake by PROP taster status, we performed selected comparisons as done by others previously (14), including: total energy intake per day in kilocalories; percent of energy intake in fat, carbohydrate, and protein; percent of total energy intake per day and servings per day for each food group; cholesterol, saturated fat, and fiber intake; and grams of sugar per day and percent of energy from sugars.

RESULTS

Characteristics of the sample are provided in **Table 1**. The children were on average 4.2 years old. The sample of children was 41% male and 47% white. Forty percent of the mothers were obese (BMI ≥30), and 26% of the children were overweight (BMI ≥95th percentile for age and gender on Centers for Disease Control National Center for Health Statistics growth charts). Few (36%) of the mothers had education beyond a high school diploma. Of the 81 children, 56 reported that the 560 μmol/l solution of PROP tasted like "something else" and that it tasted "yucky" and were therefore classified as tasters. Seven children reported that it tasted like water, but grimaced or frowned during tasting, and thus were classified as tasters. These seven children did not differ from the rest of the sample by age, gender, race, or maternal education level. Seventeen children reported that the solution tasted like water and were classified as nontasters. One child reported that it tasted like "something else" but that the something else tasted "yummy" and was therefore classified as a nontaster. Thus, 63 of 81 children (77.8%) were classified as tasters.

Unadjusted bivariate comparisons are shown in **Table 1**. There was no difference by PROP taster status in child's gender, race, age, or FNS score, or in maternal education, maternal obesity status, or maternal BMI. PROP taster children were, however, significantly more likely to be overweight (BMI ≥95th percentile for age and gender), as well as significantly more likely to be "at risk for overweight" (BMI ≥85th percentile for age and gender). PROP taster children also had higher BMI *z*-scores than nontasters. We were unable to detect any differences in dietary intake based on PROP taster status.

We sought to determine which covariates (PROP taster status, child's age, race, gender, maternal education, maternal BMI, and FNS score) best predicted the child's BMI *z*-score. The most parsimonious model with the best fit included just child's PROP taster status (taster vs. not) and maternal BMI (**Table 2**). These two variables accounted for 22.3% of the variance in the child's BMI *z*-score.

The additional models are shown in **Table 2**. Race was neither a significant predictor of the child's BMI *z*-score (Model 2), nor did it significantly alter the relationship between PROP taster status and the child's BMI *z*-score. We also considered that the relationship between PROP taster status and BMI *z*-score may have differed by race, but the interaction term in this model also was not significant ($P = 0.39$). Gender was not a significant predictor of the child's BMI *z*-score (Model 3), and the relationship between PROP taster status and BMI *z*-score did not differ by gender ($P = 0.57$ for the interaction term). Neither FNS score (Model 4) nor the proportion of daily caloric intake composed of vegetables (Model 5) mediated the relationship between PROP taster status and the child's BMI *z*-score.

We also assessed the main effect of gender on the nutritional intake outcomes, as well as an interactive effect of gender and PROP taster status on nutritional intake. These analyses did not reveal any consistent, statistically significant associations. We repeated the analyses excluding the seven children who identified the solution as water but grimaced or frowned during tasting, because it is possible that these children may have been misclassified as "tasters". The results of the analyses did not change with these subjects excluded. We also repeated our analyses restricted to children >3.5 years ($n = 67$) and the results did not differ.

Table 1 Unadjusted bivariate comparisons of covariates by PROP taster status (n = 81)

	Total (*N* = 81)	Taster (*N* = 63)	Nontaster (*N* = 18)	
	n (%)	*n* (%)	*n* (%)	*P* value
Sex				0.86
Male	33 (40.7)	26 (41.2)	7 (38.9)	
Female	48 (59.3)	37 (58.7)	11 (61.1)	
Race				0.40
White	38 (46.9)	28 (44.4)	10 (55.6)	
Nonwhite	43 (53.1)	35 (55.6)	8 (44.4)	
Maternal Education				0.80
≤High school diploma	52 (64.2)	40 (63.5)	12 (66.7)	
>High school diploma	29 (35.8)	23 (36.5)	6 (33.3)	
Child's BMI ≥95th percentile				0.025
Yes	21 (25.9)	20 (31.8)	1 (5.6)	
No	60 (74.1)	43 (68.3)	17 (94.4)	
Child's BMI ≥85th percentile				0.02
Yes	32 (39.5)	29 (46.0)	3 (16.7)	
No	49 (60.5)	34 (54.0)	15 (83.3)	
Mother obese (BMI > 30)[a]				0.32
Yes	29 (39.7)	24 (42.9)	5 (29.4)	
No	44 (60.3)	32 (57.1)	12 (70.6)	
	Total (*N* = 81)	**Taster (*N* = 63)**	**Nontaster (*N* = 18)**	
	Mean (s.d.)	**Mean (s.d.)**	**Mean (s.d.)**	***P* value**
Child's age	4.21 (0.61)	4.23 (0.61)	4.16 (0.62)	0.67
Child's BMI *z*-score	0.77 (1.27)	0.99 (1.24)	0.03 (1.12)	0.004
Maternal BMI[b]	28.3 (6.9)	28.7 (6.8)	26.9 (7.1)	0.34
FNS score[c]	35.4 (11.4)	35.2 (11.3)	36.2 (12.1)	0.75
Nutritional Data				
% of kcal/day	1,252.9 (477.2)	1,257.3 (508.8)	1,237.4 (356.6)	0.88
% Fat	35.8 (3.7)	35.7 (3.7)	36.1 (3.8)	0.70
% Carbohydrate	50.2 (5.0)	50.0 (5.0)	50.5 (4.8)	0.76
% Protein	15.5 (1.9)	15.7 (2.0)	14.9 (1.8)	0.12
Grains				
% of kcal/ay	19.9 (4.8)	20.0 (4.8)	19.8 (5.0)	0.88
Servings/day	3.68 (2.05)	3.70 (2.14)	3.62 (1.74)	0.90
Fruits				
% of kcal/day	10.9 (5.3)	10.6 (5.5)	12.0 (4.6)	0.32
Servings/day	1.43 (0.67)	1.40 (0.69)	1.56 (0.60)	0.38
Vegetables				
% of kcal/day	5.8 (2.4)	5.7 (2.2)	5.9 (2.9)	0.78
Servings/day	0.93 (0.48)	0.96 (0.50)	0.85 (0.41)	0.40
Meats				
% of kcal/day	19.9 (5.7)	20.3 (5.8)	18.4 (5.4)	0.21
Servings/day	1.34 (0.63)	1.38 (0.68)	1.21 (0.39)	0.33
Dairy				
% of kcal/ day	22.8 (6.1)	23.1 (6.2)	21.7 (6.0)	0.39

Table 1 Continued on next Page

Table 1 Unadjusted bivariate comparisons of covariates by PROP taster status (*n* = 81) (Continued)

	Total (*N* = 81)	Taster (*N* = 63)	Nontaster (*N* = 18)	
	n (%)	*n* (%)	*n* (%)	*P* value
Servings/ day	1.68 (0.59)	1.70 (0.59)	1.63 (0.62)	0.64
% Sweets	11.7 (5.1)	11.4 (5.1)	12.8 (5.0)	0.34
% Sugars	21.3 (5.6)	20.9 (5.7)	22.6 (5.3)	0.27
Cholesterol (mg)	161.0 (55.8)	161.4 (53.3)	159.4 (64.8)	0.90
Saturated Fat (g)	19.2 (5.4)	19.0 (5.3)	19.7 (5.5)	0.62
Fiber (g)	8.8 (3.1)	8.7 (3.0)	9.0 (3.5)	0.74
Sugars (g)	65.8 (24.8)	64.7 (25.4)	69.4 (22.7)	0.48

[a]*n* = 73. [b]*n* = 72. [c]*n* = 78.

Table 2 Models predicting child's BMI *z*-score

	Model 1 (*N* = 72)		Model 2 (*N* = 72)		Model 3 (*N* = 72)		Model 4 (*N* = 70)		Model 5 (*N* = 72)	
	β (s.e.)	*P*	β (s.e.)	*P*	β (s.e.)	*P*	β (s.e.)	*P*	β (s.e.)	*P*
PROP taster	0.84 (0.32)	0.01	0.83 (0.32)	0.01	0.85 (0.32)	0.009	0.83 (0.32)	0.01	0.86 (0.32)	0.008
Maternal BMI	0.06 (0.02)	0.002	0.06 (0.02)	0.002	0.06 (0.02)	0.004	0.07 (0.02)	0.002	0.06 (0.02)	0.002
White race	—	—	−0.07 (0.27)	0.79	—	—	—	—	—	—
Female	—	—	—	—	0.26 (0.28)	0.35	—	—	—	—
FNS	—	—	—	—	—	—	0.009 (0.01)	0.44	—	—
% kcal from vegetables	—	—	—	—	—	—	—	—	0.05 (0.06)	0.39
P value, overall model	0.0002		0.0006		0.0004		0.0006		0.0004	
R^2 (%)	22.3		22.3		23.5		23.0		23.1	

Model 1: Most parsimonious model identified using Akaike Information Criteria from potential covariates PROP taster status, child's age, race, gender, maternal education, maternal BMI, and FNS score; *Model 2*: Model 1 with the inclusion of race; *Model 3*: Model 1 with the inclusion of gender; *Model 4*: Model 1 with the inclusion of FNS; *Model 5*: Model 1 with the inclusion of % kilocalories from vegetables.

DISCUSSION

Being more sensitive to the bitter taste of PROP was directly associated with a higher BMI *z*-score in this population of low-income preschoolers in whom overweight was relatively prevalent. The relationship was not altered by a number of potential confounders. Apart from PROP taster status, the other major contributor to children's BMI *z*-scores in our models was maternal BMI, which likely reflects both genetic and environmental factors. The association between PROP taster status and preschool-aged children's BMI is consistent with that identified by Keller and Tepper in preschool-aged girls (14). We did not detect significant differences in PROP taster status based on gender or race/ethnicity, though our relatively small sample size may have limited our ability to detect an effect. We had hypothesized that PROP tasters would be described by their mothers as significantly more food neophobic, and that a significantly smaller proportion of their daily caloric intake would be from vegetables, but neither of these was the case. Given that prior work by Keller *et al.* demonstrated relationships between PROP taster status and overweight only in girls, we explored the possibility that the patterns of nutritional intake may have varied on the basis of an interaction of PROP taster status and gender, but this was not the case.

There are several reasons that our findings may have paralleled only those in preschool-aged girls, and not boys, identified in prior work (14). The most obvious difference between the current sample and prior work is that the present sample is of significantly lower socioeconomic status and has a higher prevalence of childhood overweight. Lower socioeconomic status may unmask or even potentiate genetic predispositions to particular food preferences and eating behaviors in two broad ways: differences in parenting styles with regard to feeding, and differences in the larger food environment. Eating behavior characterized by high levels of restraint can mask the effect of PROP taster status on weight status among adult women (33). Given that lower income has been associated with less structured meals and less restrictive feeding practices (34,35), PROP taster status may more robustly predict weight status in low-income children when it is not modified as strongly by restrictive or controlling parental feeding practices. Lower income populations also have less access to fresh fruits and vegetables (36), more exposure to fast-food restaurants (37), and are more likely to purchase foods higher in energy density (i.e., high in fat and sugar, and fewer vegetables) for economic reasons (38). Given that PROP taster children, compared to nontaster children, have been shown to consume fewer vegetables (13), give lower hedonic ratings to broccoli (12) and spinach (22), have a higher preference for sweets (39), and consume a higher proportion of their diet from sugars (14), a low-income environment may particularly potentiate the effect of PROP taster status on children's weight status.

Despite the viability of the proposed framework in the context of prior literature, our results about dietary intake did not provide support for these hypotheses. Our results also significantly differed from prior work (14), in that we did not detect a lower proportion of daily calories from protein or meat or a greater proportion of daily calories from sugar and sweets among PROP tasters. Our inability to detect these relationships may have been due to limited power or limitations in the underlying constructs of the measures themselves. Our measure of vegetable intake did not allow us to separate green or cruciferous vegetables for analysis, and the variability in nutritional intake within our population of low-income children was relatively low, both of which may have limited our ability to detect an association. Future research may focus on the mechanism underlying the association between increased bitter sensitivity and higher BMI in low-income preschoolers.

There were several limitations to our study. Our study tested PROP taster status with methodology used by others (13) in children as young as 3.5-years-old. Of the 81 children in this study, 14 were between 3 and 3.5 years. Ideally, test–retest reliability in the younger children would have been performed. We did, however, repeat our analyses restricted to children >3.5 years ($n = 67$) and the results did not differ. Furthermore, Turnbull and Smith provided evidence that children as young as 3 years of age could communicate taste perceptions of PROP and preferences under test conditions (22). Although we modeled our methods after those of others in using facial expressions to inform classification of children as PROP tasters, Mennella *et al.* has found that at least in older children (aged 5–10 years), reliance on facial expression to classify taster status is questionable (39). Our experience in conducting this protocol suggested that facial expression in these young children was a valid indicator of tasting bitter, but this question requires further investigation. Nonetheless, the children's young age may have increased the chance that misclassification occurred on the basis of behavior measures of PROP taster status, and future studies may benefit from identification of PROP taster phenotype using genetic testing, as has been done by others with children recently (39). Finally, this study specifically sought to investigate the relationship between PROP taster status and children's dietary intake and weight status in children living at or below the federal poverty line. In 2005, 17.6% of US children lived in families with incomes in this category (40). The findings of this study may not be applicable to children of higher socioeconomic strata.

In conclusion, the findings support prior work by others (14) indicating that innate sensitivity to the bitter taste of PROP in preschoolers may be an important mediator of weight status. Obesity risk has a large heritable component and sensitivity to bitter taste may be one genetically conferred behavioral contributor. Understanding factors underlying the preference for and selection of foods may have important implications for improving dietary composition and reducing childhood obesity risk.

DISCLOSURE

The authors declared no conflict of interest.

REFERENCES

1. Ogden CL, Carroll MD, Curtin LR *et al.* Prevalence of overweight and obesity in the United States, 1999–2004. *JAMA* 2006;295:1549–1555.
2. Strauss RS, Pollack HA. Epidemic increase in childhood overweight. *JAMA* 2001;286:2845–2848.
3. Feese M, Franklin F, Murdock M *et al.* Prevalence of obesity in children in Alabama and Texas participating in social programs. *JAMA* 2003;289: 1780–1781.
4. Kim UK, Jorgenson E, Coon H *et al.* Positional cloning of the human quantitative trait locus underlying taste sensitivity to phenylthiocarbamide. *Science* 2003;299:1221–1225.
5. Guo SW, Reed DR. The genetics of phenylthiocarbamide perception. *Ann Hum Biol* 2001;28:111–142.
6. Tepper BJ, Nurse RJ. PROP taster status is related to the perception and preference for fat. *Ann NY Acad Sci* 1998;855:802–804.
7. Tepper BJ, Ullrich NV. Influence of genetic taste sensitivity to 6-*n*-propylthiouracil (PROP), dietary restraint and disinhibition on body mass index in middle-aged women. *Physiol Behav* 2002;75:305–312.
8. Dabrila GM, Bartoshuk LM, Duffy VB. Preliminary findings of genetic taste status association with fat intake and body mass index in adults. *J Am Diet Assoc* 1995;95:A64.
9. Lucchina L, Bartoshuk LM, Duffy VB, Marks LE, Ferris AM. 6-*n*-propylthiouracil perception affects nutritional status of independent-living older females. *Chem Senses* 1995;20:735.
10. Fischer R, Griffen F, Rockey M. Gustatory chemoreception in man: multidisciplinary aspects and perspectives. *Perspect Biol Med* 1966;4: 549–577.
11. Johnson FE, Hertzog KP, Malina RM. Phenylthiocarbamide taste sensitivity and its relationship to growth variation. *Am J Phys Anthropol* 1966;24: 253–255.
12. Keller KL, Steinmann L, Nurse RJ, Tepper BJ. Genetic taste sensitivity to 6-*n*-propylthiouracil influences food preference and reported intake in preschool children. *Appetite* 2002;38:3–12.
13. Bell KI, Tepper BJ. Short-term vegetable intake by young children classified by 6-*n*-propylthiouracil bitter-taste phenotype. *Am J Clin Nutr* 2006;84: 245–251.
14. Keller KL, Tepper BJ. Inherited taste sensitivity to 6-*n*-propylthiouracil in diet and body weight in children. *Obes Res* 2004;12:904–912.
15. Tepper BJ. 6-*n*-propylthiouracil: a genetic marker for taste, with implications for food preference and dietary habits. *Am J Hum Genet* 1998;63: 1271–1276.
16. Drewnowski A, Rock CL. The influence of genetic taste markers on food acceptance. *Am J Clin Nutr* 1995;62:506–511.
17. Fischer R, Griffin F, England S, Garn SM. Taste thresholds and food dislikes. *Nature* 1961;191:1328.
18. Glanville EV, Kaplan AR. Food preferences and sensitivity of taste for bitter compounds. *Nature* 1965;205:851–853.
19. Drewnowski A, Henderson SA, Hann CS, Berg WA, Ruffin MT. Genetic taste markers and preferences for fruit and vegetable of female breast care patients. *J Am Diet Assoc* 2000;100:191–197.
20. Dinehart ME, Hayes JE, Bartoshuk LM, Lanier SL, Duffy VB. Bitter taste markers explain variability in vegetable sweetness, bitterness, and intake. *Physiol Behav* 2006;87:304–313.
21. Tepper BJ, Keller KL, Ulrich NV. Genetic variation in taste and preferences for bitter and pungent foods. In: Hofman T, Ho C, Pickenhagen W (eds). *Challenges in Taste Chemistry and Biology*. American Chemical Society: Washington, D.C., 2003, pp 60–74.
22. Turnbull B, Matisoo-Smith E. Taste sensitivity to 6-*n*-propylthiouracil predicts acceptance of bitter-tasting spinach in 3–6-year-old children. *Am J Clin Nutr* 2002;76:1101–1105.
23. Cashdan E. A sensitive period for learning about food. *Hum Nat* 1994;5:279–291.
24. Rozin P. Development in the food domain. *Dev Psychol* 1990;26: 555–562.

25. Drewnowski A. Fat and sugar: an economic analysis. *J Nutrition* 2003;133:838S–840S.
26. 2006 Department of Health and Human Service Poverty Guidelines. *Fed Reg* 2006;71:3848–3849.
27. Steiner JE, Glaser D, Hawilo ME, Berridge KC. Comparative expression of hedonic impact: Affective reactions to taste by human infants and other primates. *Neurosci Biobehav Rev* 2001;1:53–74.
28. Kuczmarski RJ, Ogden CL, Grummer-Strawn LM, Flegal KM, Guo SS, Wei R. CDC Growth Charts. *Advance Data* 2000;314:1–28.
29. Pilner P. Development of measures of food neophobia in children. *Appetite* 1994;23:147–163.
30. Block Kids Questionnaire. Berkeley, CA: Block Dietary Systems, <http://www.nutritionquest.com/> Accessed 2 September 2006.
31. Block G, Woods M, Potosky A, Clifford C. Validation of a self-administered dietary history questionnaire using multiple diet records. *J Clin Epidemiol* 1990;43:1327–1335.
32. Block G, Murphy M, Roullet JB, Wakimoto P, Crawford PB, Block T. Pilot validation of a FFQ for children ages 8–10 years. Fourth International Conference on Dietary Assessment Methods, 2000, Tuscon, AZ, 2000.
33. Tepper BJ, Ulrich NV. Influence of genetic taste sensitivity to 6-*n*-propylthiouracil (PROP), dietary restraint, and disinhibition on body mass index in middle-aged women. *Physiol Behav* 2002;75:305–312.
34. Baughcum AE, Powers SW, Johnson SB, Chamberlin LA, Deeks CM, Jain A, Whitaker RC. Maternal feeding practices and beliefs and their relationships to overweight in early childhood. *J Dev Behav Pediatr* 2001;22:391–408.
35. Francis LA, Hofer SM, Birch LL. Predictors of maternal child-feeding style: maternal and child characteristics. *Appetite* 2001;37:231–243.
36. Zenk SN, Schulz AJ, Israel BA, James SA, Bao S, Wilson ML. Neighborhood racial composition, neighborhood poverty, and the spatial accessibility of supermarkets in metropolitain Detroit. *Am J Pub Health* 2005;95:660–667.
37. Redipath DD, Burns C, Garrard J, Mahoney M, Townsend M. An ecological study of the relationship between social and environmental determinants of obesity. *Health Place* 2002;8:141–145.
38. Drewnowski A, Specter SE. Poverty and obesity: the role of energy density and energy costs. *Am J Clin Nutr* 2004;79:6–16.
39. Mennella JA, Pepino Y, Reed DR. Genetic and environmental determinants of bitter and sweet preferences. *Pediatrics* 2005;115:e216–e222.
40. DeNavas-Walt C, Proctor BD, Lee CH. Income, poverty, and health insurance coverage in the United States: 2005, U.S. Census Bureau Current Population Reports, P60–231. U.S. Government Printing Office: Washington, D.C., 2006.