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A marker of growth differs between adolescents with high versus low sugar preference

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Abstract

Sweet preference is higher in childhood than adulthood but the mechanism for this developmental shift is not known. The objective of this study was to assess perceptual, physiological and eating habit differences between children preferring solutions high in sugar (high preference) and children preferring solutions low in sugar (low preference). We tested 143 children (11- to 15-years old) using sip and spit methodology to assess their hedonic profile, detection threshold, and perceived intensity of sucrose. Their plasma concentration of several hormones, a biomarker of bone-growth, body size, puberty stage, and dietary habits were measured. Eighty-eight children were classified as high preference and 53 were classified as low preference based on their hedonic ratings to a series of sucrose solutions. A marker of bone growth measured in urine and plasma leptin adjusted for body weight were significantly lower in the low preference group. Children with high and low preference patterns did not differ in sensory aspects of sucrose perception, nor did they differ in age, body mass index percentile, or dietary restraint. The change in sugar preference from high to low during adolescence appears to be associated with the cessation of growth.

Keywords

taste; sensory; psychophysics; development; puberty; caries

Introduction

Children are the population most at risk for over-consuming sugar. Both longitudinal and cross-sectional studies have shown a decrease in preference for intensely sweet substances from childhood to adulthood, with the sharpest decline observed during adolescence (1–5). This information on preference patterns is supported by information on consumption of desserts, candy, and sweet beverages, as well as total energy from sugar, which likewise decline from childhood to adulthood (6–11). The capacity of chronological age to determine sweet preference is striking; when children are compared with their own mothers, people with whom they share both genes and environment, they almost inevitably surpass them in liking for highly sweetened solutions, e.g., (12–14). Thus, it is not surprising that sweetness is among the most important features that determine what children are willing to eat (15).

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The reasons for an exaggerated sweet preference during childhood have not been determined. There are three general explanations, which fall into the categories of perception, physiology and cognition: in the perceptual realm, children may be less sensitive to certain tastes than are adults, e.g., (16,17), and therefore require a higher concentration of sweetness to get the same sensation. From a physiological perspective, the elevated sweet preference may reflect the caloric requirements to support a period of rapid growth, or it could be due to the hormonal changes associated with puberty. For example, puberty is associated with changes in secretion of insulin and leptin (18–21) both of which are known to decrease sweet taste preference (22, 23). It is also possible that cognitive factors might be responsible, either because adults are more concerned about weight or health than are children, and thus are less likely to admit to liking intensely sweet solutions, or it could be that children are impaired in their ability to perform the preference determination tasks, confusing intensity with pleasantness, e.g., (24). These possible explanations are not mutually exclusive, nor have any one of them been either convincingly confirmed or eliminated. Because this enhanced sweet preference by the young is also found in rodents, a biological rather than a psychological explanation may be more likely (25).

For the current investigation, we focused on two of the most dramatic physiological processes occurring during adolescence, sexual maturation and linear growth, and assessed whether these might differ between children with more adult-like versus child-like sweet preference patterns. Sexual maturation was assessed using two self-report measures, as well as through assessments of serum gonadal hormone concentrations. Linear growth was assessed using a measure of bone collagen resorption in urine. As children go through puberty, bone growth and bone turnover associated with that growth increase substantially (26,27). Breakdown products from bone collagen resorption during bone turnover may be detected in urine and have been found to correlate with growth in height during adolescence (26,28). Bone turnover markers in urine peak during the adolescent growth spurt and then decline substantially during late puberty (28–30). In healthy adults, urinary excretion of bone collagen degradation products is relatively low (29,31). Measurement of bone collagen degradation products in urine permits cross-sectional and short-term assessment of linear growth that would not otherwise be possible or accurate using standing height measures.

In the current investigation, we grouped children into high preference and low preference categories based on difference scores between their hedonic ratings of sucrose solutions varying in concentration from high to low. We then examined these groups for differences in perception (detection and intensity ratings of sucrose), hormone concentrations (leptin, insulin and gonadal hormones) and markers of growth and fatness, as well as cognitive/behavioral factors such as dietary restraint. In order to circumvent the confound of age and hormonal status, we took advantage of the fact that older children go through puberty at different time points within a window of chronological ages (32) and specifically asked whether puberty *per se* might contribute to the shift in sweet preference. We hypothesized that low preference children would be farther along in indicators of pubertal maturation (hormones and physical characteristics) than would high preference children.

Methods

Subjects and phone interview

Children or their parents phoned the study line in response to a metropolitan bus advertisement placed in the community. Oral permission for participation in the study was first obtained from the parent or guardian over the phone, followed by an initial screening to insure that children met age (11 to 15 years) and health criteria. These subjects stated they were healthy, specifically denying a history of diabetes or endocrine dysfunction, and denied that they took medications with a known effect on taste perception. Children and their parents were mailed the study

consent (parents) and assent forms (adolescents) to complete in advance of laboratory procedures. The screening and testing protocol was approved by the University of Washington Institutional Review Board. The final participants were 143 adolescents, 78 boys and 65 girls.

Physical Assessment and Lab Measures

Physical assessment and taste testing both took place in one testing session, after an over-night fast, between 8 and 11 AM. Prior to taste testing, approximately 5 ml of blood was drawn from the antecubital vein of one arm of the participant. Serum and plasma samples were extracted from whole blood and frozen for subsequent analysis. The participant's weight and height were measured (abco Health o Meter, Health o Meter, Inc., Bridgeview, Illinois), and an estimate of percentage body fat was obtained using a commercial impedance body fat scale (Body Composition Analyzer BF-350, Tanita, Tokyo, Japan). Each participant was given a urine collection container and instructed in how to obtain a midstream catch. Aliquots of urine were siphoned from the sample and frozen until subsequent analysis.

Taste Stimuli

Solutions were prepared with distilled water (Mountain Mist, Tacoma, WA). All sugar (C&H, Crockett, CA) solutions were made fresh every week. NaCl (Integra, Renton, WA) was prepared every three weeks. Solutions were refrigerated between test sessions and warmed to room temperature over night prior to use. Solutions were presented to participants two at a time (threshold assessment) or one at a time in 30 ml medicine cups, filled to the 10 ml mark. Subjects sipped each solution and then expectorated the solution into a sink. At least one minute elapsed between trials, during which subjects rinsed with distilled water. Subjects also rinsed with distilled water between cups when two cups were presented on a trial (threshold assessment).

Taste Testing

Taste testing commenced with sucrose threshold of detection assessment using the up-down, two-cup, forced-choice staircase procedure with five reversals, and the additional requirement that the tastant had to be correctly detected twice before decreasing sucrose concentration, while one miss resulted in an increase in concentration (33). For all taste tests, except as otherwise noted, subjects rinsed with distilled water between trials.

Following threshold assessment, subjects rated liking for and intensity of each of six concentrations of sucrose (0.056 M to 1.000 M in 0.25 log steps). Sucrose solutions were presented in three blocks, with solution order randomized within each block. The same blocked, random order of sucrose solutions was presented to all subjects. Subjects responded to how much they liked each sucrose solution on a five-point hedonic scale. The hedonic scale was labeled with numbers and with faces ranging in expression from frowning to smiling. Subjects were instructed that '1' was to be used to rate something they dislike intensely, '3' was for neither like nor dislike and '5' was something they liked intensely. The subjects looked at the labeled scale and responded verbally, rating each solution. These values were recorded by the investigator.

Subjects rated the intensity of each taste on a computerized version of Green's Labeled Magnitude Scale (LMS). The LMS is a visual analog scale labeled with "barely detectable", "weak", "moderate", "strong", "very strong", and "strongest imaginable" (34). Subjects were asked to compare the intensity of each taste to oral sensations of any kind and were given examples including the sweetness of cotton candy, biting into a raw lemon, the bitterness of celery, and biting into a chili pepper.

For the last taste task, participants were asked to taste and rank-order their preference for four solutions of orange Kool-Aid®, a culturally familiar, flavored beverage that differed in the

amounts of added sugar (10.0%, 14.4%, 20.8%, and 30.0% weight by volume). Re-sampling and swallowing of the solutions was permitted in this ranking task, although this behavior was not permitted for the other taste tests.

Self-Assessment of Puberty

After taste testing, children privately completed a self-report, line-drawing version of Tanner's Sexual Maturation Scale (35). This scale listed and illustrated five possible stages of puberty development. For girls, pubic hair and breast development were illustrated and rated separately. For boys, genital development and pubic hair were illustrated in the same pictures and rated simultaneously. Each child was asked to circle the picture that they think looks most like they do. All children were informed that they could leave the forms blank if they felt uncomfortable answering the questions. Completed forms were given to the researchers in an opaque envelope to prevent them from looking at the forms as they were being returned.

Children also completed a questionnaire based on the Pubertal Development Scale, PDS (36). The PDS contains five questions regarding physical changes that occur during puberty. Three questions (growth, body hair, and skin changes) were identical for girls and boys. Two additional questions were specific for boys (voice deepening, hair on face) and girls (breasts growing and menstruating). Responses to the five questions are each scored on a scale ranging from 1 (response consistent with a pre-pubertal stage of development) to 4 (response consistent with a post-pubertal stage of development) and then averaged to yield a summary score. The PDS has been demonstrated to have acceptable reliability and validity in adolescent samples (36,37).

Hormone Assays

For female subjects, serum samples were analyzed for estradiol and progesterone by the University of Washington Department of Laboratory Medicine (Seattle, WA) using solid phase chemiluminescence. Serum samples were analyzed for total testosterone by Quest Diagnostics (Seattle, WA) using immunoassay. Plasma samples were analyzed for leptin by the University of Washington Clinical Nutrition Research Unit using an Elisa test (Diagnostic Systems Laboratories, Inc., Webster, Texas). Leptin samples were run in duplicate and required to be within 10% (except if <2 ng/ml for which 15% was considered acceptable). Plasma insulin concentrations were measured by Steven Kahn's laboratory (Seattle Veteran's Affairs Hospital) using a modification of a double-antibody radioimmunoassay (38). CV% for insulin assays averaged 5.8%.

Bone Resorption Marker Assay

Following the procedures used by Bollen and colleagues (28,29), the bone resorption marker type I collagen cross-linked N-telopeptides (NTx) was measured in the urine samples by immunoassay using a commercially available kit (Osteomark®, Ostex International, Seattle, WA). For each urine sample, the bone collagen equivalent (BCE) of NTx immunoreactivity was normalized to creatinine. Creatinine concentration was assessed by spectrophotometry using a colorimetric assay (Sigma Diagnostics, St. Louis, MO, USA). Samples were run in triplicate and CV% averaged 14.6%. This marker was chosen because it is a reliable, valid and objective measure of the stage of bone growth in children and adolescents (28).

Eating Behaviors Questionnaire

Children and their parents were mailed the Dutch Eating Behaviors Questionnaire to complete in advance of laboratory procedures. The Dutch Eating Behaviors Questionnaire has 33 items that are answered on a 1 to 5 category scale, with 1 indicating the participant *never* does the item, and 5 indicating the participant does the item *very often* (39). For data analysis, responses

on the 10 items related to restrained eating, 13 items related to emotional eating, and 10 items related to externally-motivated eating were averaged separately to yield an average dietary restraint score, an average emotional eating score, and an average externally-motivated eating score for each subject.

Statistical Analysis

It has been common practice to categorize participants into sweet preference categories based on their patterns of hedonic ratings. Moskowitz and colleagues have described two different types of patterns of pleasantness ratings for sucrose solutions (40,41). Type I responders increase hedonic ratings up to a breaking point, but then sweeter solutions are rated as less pleasant (peak and fall). Type II responders show a rise in hedonic ratings with increasing concentration tested (up). The ratings of a Type II responder may asymptote, but they never fall, even at the highest concentration. Pangborn reported a third downward preference pattern in which increasing concentrations of sugar are inversely related to hedonic ratings (42). To capture these patterns and to be able to categorize subjects into low and high preference groups, we subtracted the average of the hedonic (liking) ratings of the two lowest concentrations of sucrose (0.056 M and 0.100 M) from the average of the hedonic ratings of the two highest sucrose concentrations (0.560 M and 1.000 M). 'High preference' was defined as having a positive difference score, whereas 'low preference' was defined as having a negative difference score.

BMI percentile was determined from birth date, date of testing, weight and height using a web-based calculator (<http://stokes.chop.edu/web/zscore/>). The calculator determines percentile relative to 2000 Center for Disease Control (CDC) growth charts.

Mann-Whitney U's were used to analyze differences in rank order given for each sugar level in Kool-Aid® solution between sugar preference groups (four separate analyses). MANOVA was used to analyze sucrose intensity data. Differences between the high preference and low preference groups in NTx, leptin, and insulin were assessed using separate ANCOVA's with sugar preference status and gender as between group factors, and body mass index percentile and age used as covariates in the analyses. Testosterone, estradiol and progesterone were each individually analyzed using ANCOVA with sugar preference status as a between group factor and age as a covariate in the analyses. A p-value of less than <0.05 was the criterion for group differences. Statistical calculations were conducted using Statistica 4.1 for the Macintosh (StatSoft, Inc., Tulsa, OK).

Results

Subjects

The average age of subjects was 13.5 (SE=1.2) years and the average body mass index percentile of subjects was 71.2 (SE=2.2). Forty percent of the subjects were over-weight or at risk for overweight relative to the year 2000 CDC growth charts. Of the 143 children (78 boys and 65 girls) tested in the study, 2 reported their ethnicity as Alaskan Native, 4 reported being American Indian, 14 reported being Asian/Pacific Islander, 31 reported being Black, Non-Hispanic, 11 reported being Hispanic, 8 indicated another ethnicity or declined to say, and the remaining 73 reported being White, Non-Hispanic. Due to technical errors or problems in data collection, a few data points are missing for some analyses, as individually noted below.

High/Low Preference Classification

Using the criterion described in the statistical analysis section, eighty-eight children were classified as high preference (48 male, 40 female) and 53 (28 male, 25 female) were classified

as low preference. Two male children could not be classified because the difference between their hedonic rating of the high and low sucrose concentrations was zero. Figure 1 (top) depicts mean hedonic ratings for each of the six sucrose concentrations by sugar preference group, high or low. As expected based on our selection criteria, high preference and low preference groups significantly differed in hedonic rating of sucrose solutions at every concentration tested [$F(1, 139) = 75.0$, $p < 0.0000001$, Newman-Keuls, p 's < 0.05]. To demonstrate the range of responses, Figure 2 depicts patterns of hedonic ratings in each group as previously described by Moskowitz or Pangborn (up, down, peak) and the few subjects that did not fit these previously described patterns.

Ranking Task

In the ranking task, high preference children ranked 30% sucrose in Kool-Aid® (the most sugar-concentrated solution) as best of four (median rank), whereas low preference children ranked 30% sucrose in Kool-Aid® as worst of four [see Table 1, $U(88, 52) = 1135$, $p < 0.000001$]. Due to a technician error, Kool-Aid® solution ranking was not recorded for one subject.

Taste Acuity Measures

High preference and low preference groups did not differ in their ability to detect sucrose in water [$t(139) = 0.39$, $p = 0.70$]. In both groups, the mean (geometric) detection threshold for sucrose was 0.004 M.

Low preference children rated the perceived intensity of sucrose marginally higher than did high preference children [Figure 1, $F(1, 138) = 4.8$, $p < 0.03$]. Post-hoc analyses indicated this difference was significant for three of the six sucrose solutions tested (0.056 M, 0.1 M, and 0.32 M; Neuman-Keuls, p 's < 0.05).

Anthropomorphic Measures and Ethnicity

High preference and low preference groups did not significantly differ in age (13.4 years vs. 13.6 years), body weight (134 lbs vs. 131 lbs), height (63.6 inches vs. 62.8 inches), percent body fat (25.0% vs. 25.0%), or body mass index corrected for age and gender (BMI percentile, 68.7 vs. 74.9), all p -values > 0.05 , Table 2. The sugar preference groups contained the same proportion of Black subjects: 22% in the high preference group, and 23% for the low preference group, $p > 0.05$. BMI percentile was not obtained for one child and percent body fat was not obtained for four children.

Puberty Measures and Gonadal Hormones

High preference and low preference groups did not differ in self-reported stage of puberty or in PDS summary scores (Table 3). For males, serum testosterone concentration was also similar between high preference and low preference groups (Table 4). Gonadal hormone concentrations tended to be higher in females with low preference than in those with high preference, but these trends did not reach statistical significance [Table 4, Estradiol, $F(59) = 3.87$, $p = 0.053$; Progesterone, $F(60) = 1.92$, $p = 0.14$]. Supporting the validity of the self-report measures, in males serum testosterone concentrations correlated with self-reported puberty stage ($r = 0.77$, $p < 0.0001$) and PDS summary scores ($r = 0.75$, $p < 0.0001$). Hormone concentrations by self-reported puberty stage are presented in Table 5. Two children (one male and one female) turned in blank PDS forms. Four female children failed to respond to the menstruation question on the PDS. These six children were excluded from analyses involving the PDS. Six children turned in blank puberty stage self-assessment questionnaires and were excluded from puberty stage analyses.

Hormones Involved in Regulation of Food Intake

Plasma leptin concentrations were significantly higher in the high preference group than in the low preference group, when BMI percentile and age were used as covariates in the analyses [$F(1,129) = 5.64, p < 0.05$, Table 4]. Leptin levels were also significantly higher in females than in males [$F(1,129) = 14.9, p < 0.001$, Table 4]. There was no significant difference in plasma insulin concentrations between sugar preference groups or genders (Table 4). Leptin concentrations were not obtained for 5 children and insulin concentrations were not obtained for 19 children.

Bone Resorption Measure

One hundred thirty-nine children were included in NTx analyses for indication of bone resorption during growth. BMI percentile and age were used as covariates in these analyses. NTx levels were significantly higher in the high sugar preference group compared with the low preference group [$F(1,133) = 4.79, p < 0.05$, Table 4]. NTx levels were also higher in males than in females [$F(1,133) = 8.89, p < 0.01$, Table 4].

Eating Behaviors Questionnaire

Dietary restraint, emotional eating, and externally-driven eating scores did not differ between the high and low preference groups (Table 6). Three children did not complete the Dutch Eating Behavior Questionnaire.

Discussion

Children like highly sweetened food and drinks more than do adults, but the underlying mechanism for this developmental shift is not understood. We found support for the involvement of one physiological explanation, which is that linear growth (independent of puberty) is associated with sugar preference in childhood, and we also ruled out some of the other explanations. Growth rate was assessed from the urine concentration of a metabolite produced during bone turn-over (NTx) (28). We assessed preference using a sip and spit methodology, combined with a five-point hedonic scale. We attempted to control details known to influence variability in each of these measures, such as time of day and time since last meal. However, physiological measures were collected on each child only once. Variability in the NTx measure, and possibly the hedonic measure, could have been reduced by averaging across multiple assessments taken on different days. Nevertheless, these data support a previous suggestion that hormonal and biochemical changes controlling growth (those which are common to both sexes) are a likely explanation of sugar preference in youth (2). Furthermore liking for sweets during periods of high growth is reminiscent of the short-term changes in sugar liking that occur in response to short-term food deprivation (43). This elegant link between taste preferences and biological need may leave modern children especially vulnerable to the long-term consequences of overeating and caries in the advent of an abundant sugar supply. However if we accept sugar liking as a natural concomitant to growth in childhood, then it brings into question the assumption that this propensity is invariably unhealthy and undesirable among this age group.

High sugar preference participants had higher plasma concentrations of leptin adjusted for body weight percentile than did low preference participants. At Tanner Stage 2, girls and boys have similar leptin levels, while at Tanner stage 3, levels in boys begin to decline and levels in girls begin to increase (21). Given that sugar preference consistently decreases in both sexes late in puberty, while leptin levels diverge, it seems unlikely that leptin is mediating the change in sugar preference. Changes in leptin levels correlate with other events during puberty associated with growth, such as changes in muscle mass and body fat (21), it thus seems more parsimonious that growth mediates the change in preference than does leptin itself.

Other explanations for the developmental shift in sugar preference were not strongly supported. For instance, perceptual differences are not a likely explanation for child-like and adult-like patterns of sugar preference because in this study, subjects who had high sugar preference or low sugar preference did not differ in the ability to recognize sucrose at low concentrations, a result consistent with a similar study (44). Although the children with low preference found some concentrations of sucrose to be slightly more intense than did those who had high preference, this effect was small.

An appealing explanation for the sugar preference shift during adolescence is that it is caused in part by the hormonal changes that accompany puberty. This hypothesis was worth exploring in detail for three reasons: first, men have a higher sugar preference (on average) than do women, e.g., (45), and second, the hormonal fluctuations of adult women are popularly thought to trigger sugar cravings, and third, the time of puberty corresponds to the time of the shift in sugar preference. These points implicate sex hormones as a contributor to sugar preference. However, contrary to this expectation, high preference and low preference groups did not differ by self-reported pubertal stage. This lack of association is not likely to be due to insensitive testing methods because the self-report methods (used here) correlate with physician assessments (37,46,47). As an extra measure of validation, the self-reported measures agreed with the maturation stage suggested by the laboratory assays of testosterone (reported here) and NTx, reported elsewhere (48). Mean testosterone values for each stage were generally found to be in agreement with total testosterone values expected for that stage (49). The exception to this expected relationship was that the four male children self-reporting as Stage I had a mean value of 26 ng/dL total testosterone, which exceeded the expected value of 5 ng/dL for that stage. This indicates that these four children may have under-estimated their developmental stage. Mean estradiol concentrations for each self-reported stage were consistent with values observed in normal adolescents (50). There was a tendency for high preference girls to have lower concentrations of estradiol and progesterone, so this idea that sex hormones affect sugar liking in girls cannot be completely discounted. However, the observation is complicated by the fact that this study made no attempt to control for menstrual cycle phase in girls. (Indeed, differing points in the menstrual cycle likely explains lower estradiol levels in Stage 5 females compared with Stage 4 females.) It is therefore difficult to separate the effects of maturational stage from menstrual phase on estradiol and progesterone concentrations. However for boys, it is clear that high preference and low preference groups did not differ in plasma testosterone or puberty stage.

Besides the physical changes associated with adolescence, there are psychological changes. As children develop ---when body shape and size change dramatically--- there is an increased emphasis on dieting and personal appearance. One aspect of this concern might be to change the willingness of an adolescent to either consciously or unconsciously admit to a liking for a very sweet solution, which might be viewed as greedy, lacking in willpower, or socially undesirable in some way. To understand how beliefs about dieting might affect sugar preference, we administered tests of restraint, emotional eating and externality (the tendency to eat in response to cues) to the study participants. There was a range of scores on these measures, but these personality features did not differ for high and low preference groups. Specifically, there was no indication that adolescents with a low preference were more restrained in their eating habits than those with a high preference. This result indicates that the changes in sugar preference are not due to the onset of weight concern as children reach sexual maturity, or that children are learning to give socially desirable responses about their personal preferences.

Evaluating sugar preference in the laboratory is straightforward, but given the other pressures that determine human food intake, it may not be reasonable to expect this laboratory-based measure to be highly predictive of real-world food intake. In adults, who may be at more liberty

to eat what they like, sugar preference and habitual food intake is correlated, but the relationship is loose (51,52). The applicability of sucrose preference tests have been shown in other studies to extend to other simple sugars (53), to familiar beverages, and may affect real-world food choices of children, at least in some circumstances, e.g., (14,54). In our study, ratings of simple sugar solutions did generalize to the liking for a culturally-familiar, sweet beverage with a complex flavor (Kool-Aid®).

Some of the sensory ratings that the adolescents were asked to make, such as hedonic and intensity assessments are based on sophisticated concepts. Although this study population contained older children, who are more advanced and more able to think in abstract terms, they are not yet like the adult populations used to originally validate these measures. In particular, the labeled magnitude scale used to describe the intensity of sucrose might have a different meaning to children who have had less of a lifetime to judge whether a particular taste is the 'strongest imaginable'. Some of these scaling considerations for intensity ratings in special populations have been described (55). We believe that these scales for intensity rating were appropriate because previous studies report data from children younger than those studied here, aged 5 to 11 years old (56–58). Compared with intensity ratings, hedonic ratings may be more straightforward for children because whether they like something, food, drink or otherwise, is a common question posed to them. For the hedonic measures, the values obtained from the scales are convincing because two different measures of the same construct converged, i.e., ratings of sugar-water and ranking of a sweet beverage.

One aspect of these results is surprising because it is at variance with the observations of others, which is that there were no race differences. Like age, race has a consistent effect with Americans of European descent (White or Caucasian) often having a lower sugar preference than Americans of African descent (Black) (1,12,13,59,60), and these effects have been observed in most or all studies, and found by different investigators using different methods. Why this race effect was not seen in the data collected here is not known. This is most likely a result of low power to detect such a race effect in this study due to the small sample size in each racial category. However, it could be that sugar preference is strongly influenced by habitual food intake that differs between cultures, and these cultural differences are less marked in some cities and regions than others. Studies of human infants have suggested that early dietary habits influence sugar preference (61) and it is possible that there is less difference among these types of practices by race among these subjects. The majority of participants in this study were recruited from advertisements in metropolitan buses, which may have ensured greater cultural, neighborhood, and income similarity among racial groups than is typically observed in such studies. How race affects sugar preference is worthy of closer study.

One question not addressed in this experiment is the extent to which a reduced liking for highly concentrated sugar solutions might generalize to other taste qualities such as sour or salty. A similar shift in preference for high concentrations of salt and sour substances is seen at about the same time period as that for sweet (1,62). In addition to the child-like pattern of preference for sugar, salt and perhaps sour, there is a child-like pattern to dislike bitter. Children are remarkably resourceful at avoiding this taste quality in food and drinks, especially vegetables, but there may be biological reasons for this seemingly unhealthy behavior. For instance bitter-disliking in children could be a developmental defense against accidental poisoning from plant-food. This focus on sweet drinks and foods is in some measure due to the nutrition and health problems of excess sugar consumption, e.g., dental caries, but the shifts in sugar preference could be part of a tendency that applies equally well to other taste qualities. This is a research area in need of further exploration.

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Figure 1.

Average liking ratings of ascending sucrose solutions using a five-point hedonic scale by high and low sugar preference groups of adolescents (top), average ratings of ascending sucrose concentrations using the labeled scale developed for intensity scaling by high and low sugar preference groups of adolescents (bottom). Standard errors are smaller than the symbols.

Figure 2. Patterns of sweet preference in adolescent human subjects within the high (top) and low (bottom) preference groups. The patterns are characterized as 'up', 'peak' and 'down' with a few subjects who failed to fall into previously described patterns ('other').

Table 1

Median and Mode Rank Order of Sucrose-sweetened Koolaid® Solutions Divided According to Adolescents' Sugar Preference Group

	HIGH Median Rank	HIGH Mode Rank	LOW Median Rank	LOW Mode Rank
30% sucrose **	1	1	4	4
20.8% sucrose	2	2	2	2
14.4% sucrose **	3	3	2	1
10% sucrose **	4	4	3	3

Numbers indicate solution rank order from most (1) to least (4) preferred.

** Indicates a significant difference in rank between high and low sugar preference groups for that solution, $p < 0.001$.

Table 2
 Characteristics of Adolescents Categorized as High Sugar Preference or Low Sugar Preference

Measure	HIGH	Male		HIGH	Female	
		LOW			LOW	
Number of subjects	48	28		40	25	
Age (years)	13.45 ± 0.20	13.04 ± 0.29		13.43 ± 0.22	13.77 ± 0.32	
% Black	19%	25%		25%	20%	
Body Weight (kg)	61.5 ± 3.1	61.5 ± 3.4		60.3 ± 3.6	57.5 ± 2.4	
Height (m)	1.63 ± 0.02	1.62 ± 0.02		1.59 ± 0.01	1.57 ± 0.02	
Body Mass Index	22.7 ± 0.9	23.3 ± 1.0		23.4 ± 1.2	23.2 ± 0.9	
Body Mass Index %	68 ± 4	75 ± 4		70 ± 4	74 ± 5	
% Body Fat	21 ± 2	21 ± 2		30 ± 2	30 ± 2	

Notes: Values are means ± SE. There were no significant differences between high and low sugar preference groups in subject characteristics, either separately by sex, or combining across sexes. Body Mass Index percentile is relative to year 2000 Center for Disease Control tables, and was determined from birth date, date of testing, weight and height using a web-based calculator (<http://stokes.chop.edu/web/zscore/>).

Table 3
 Puberty Measures for Adolescents Categorized as High Sugar Preference or Low Sugar Preference

Measure	Male		Female	
	HIGH (n)	LOW (n)	HIGH (n)	LOW (n)
Pubertal Development Scale (1 to 4 scale)	2.50 ± 0.09 (47)	2.38 ± 0.12 (28)	2.88 ± 0.13 (35)	2.99 ± 0.15 (25)
Puberty Stage (1 to 5 scale)	3.48 ± 0.18 (46)	3.50 ± 0.22 (26)	3.41 ± 0.16 (39)	3.79 ± 0.23 (24)
Puberty Stage (breast)	-	-	3.60 ± 0.15 (38)	3.92 ± 0.18 (24)

Notes: Values are means ± SE (n). There were no significant differences between high and low sugar preference groups in puberty measures, either separately by sex, or combining across sexes.

Table 4
Metabolic Measures for Adolescents Categorized as High Sugar Preference or Low Sugar Preference

Measure	Male		Female	
	HIGH (n)	LOW (n)	HIGH (n)	LOW (n)
Testosterone (ng/dl)	287 ± 35 (47)	302 ± 50 (26)	-	-
Estradiol (pg/ml)	-	-	36 ± 3 (38)	48 ± 7 (24)
Progesterone (ng/ml)	-	-	0.7 ± 0.1 (38)	1.2 ± 0.4 (24)
Insulin (pM)	112 ± 15 (41)	76 ± 9 (21)	118 ± 19 (36)	108 ± 17 (24)
Leptin (ng/ml) ^{*†}	18.8 ± 3 (48)	7.7 ± 2 (26)	32.4 ± 6 (37)	24.6 ± 4 (24)
NTx (nmol BCE/mmol creatinine) ^{*†}	242 ± 26 (48)	175 ± 15 (28)	157 ± 23 (38)	123 ± 17 (25)

Notes: Values are means adjusted for covariates ± SE (n). Testosterone, estradiol and progesterone were measured from serum, insulin and leptin from plasma, and NTx from urine.

* Indicates a significant difference between high and low preference groups when adjusting for BMI percentile and age.

[†] Indicates a significant difference between males and females when adjusting for BMI percentile and age.

Table 5
Gonadal Hormone Concentrations for Adolescents by Self-Reported Puberty Stage

Puberty Stage	Testosterone in Males (n)	(SE)	Estradiol in females (n)	(SE)
I	26.0 (4)	(10.3)	20.6 (5)	(0.60)
II	78.1 (9)	(28.9)	28.0 (3)	(5.29)
III	141.2 (17)	(35.2)	39.1 (14)	(4.25)
IV	396.3 (25)	(32.1)	47.3 (29)	(5.34)
V	577.4 (16)	(43.0)	27.4 (9)	(4.66)

Table 6
Eating Behaviors for Adolescents Categorized as High or Low Sugar Preference

	HIGH	(SE)	LOW	(SE)
Restrained	1.72	(0.08)	1.87	(0.12)
Emotional	1.84	(0.09)	1.90	(0.12)
External	3.03	(0.07)	2.88	(0.09)

Higher values are associated with more extreme thoughts and behaviors, i.e., higher reported restraint, more externally-driven eating. The high sugar preference group did not differ from the low sugar preference group, $p>0.05$.