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Disruption in the relationship between blood pressure and salty taste thresholds among overweight and obese children

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Abstract

Background—Prevalence of high blood pressure (BP) among American children has increased over the past two decades, due in part to increasing rates of obesity and excessive dietary salt intake.

Objective—We tested the hypotheses that the relationships among BP, salty taste sensitivity, and salt intake differ between normal-weight and overweight/obese children.

Design—In an observational study, sodium chloride (NaCl) and monosodium glutamate (MSG) taste detection thresholds were measured using the Monell two-alternative, forced-choice, paired-comparison tracking method. Weight and BP were measured, and salt intake was determined by 24-hour dietary recall.

Participants/Setting—Eight- to 14-year-olds (N=97; 52% overweight or obese) from the Philadelphia area completed anthropometrics and BP measurements; 97% completed one or both thresholds. Seventy-six percent provided valid dietary recall data. Testing was completed between December 2011 and August 2012.

Main outcome measures—NaCl and MSG detection thresholds, BP, and dietary salt intake.

Statistical analyses—Outcome measures were compared between normal-weight and overweight/obese children with t-tests. Relationships among outcome measures within groups were examined with Pearson correlations, and multiple regression analysis was used to examine the relationship between BP and thresholds, controlling for age, BMI-Z score, and dietary salt intake.

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Conflict of Interest Disclosure

The authors have no conflicts of interest to declare.

Results—Salt and MSG thresholds were positively correlated (r(71)=0.30, p=0.01) and did not differ between body-weight groups (p>0.20). Controlling for age, BMI-Z score, and salt intake, systolic BP was associated with NaCl thresholds among normal-weight children (p=0.01), but not among overweight/obese children. All children consumed excess salt (>8 g/day). Grain and meat products were the primary source of dietary sodium.

Conclusions—The apparent disruption in the relationship between salty taste response and BP among overweight/obese children suggests the relationship may be influenced by body weight. Further research is warranted to explore this relationship as a potential measure to prevent development of hypertension.

Keywords

Salty taste; blood pressure; obesity; children; taste sensitivity

Introduction

Characterizing an association between taste perception and blood pressure is an ongoing area of research, based on the premise that taste function may be reflective of physiological processes elsewhere in the body, and as such, serve as a marker for an individual's health status[1]. Because of the well-established link between high dietary salt intake and blood pressure[2], salty taste has long been an area of focus in examining differences between hypertensives and normotensives in terms of hedonic appeal of salt[3–5], perceived salty taste intensity[6,7], and sensitivity to salty taste[5,8–14], as any differences between these groups may allow for diagnosing or managing hypertension[7,15]. To date, findings from research of this nature have been largely equivocal.

No definitive association between blood pressure and either salt preference[3–5] or perceived salty taste intensity[6,7] has been published thus far. Examinations of the link between blood pressure and salty taste sensitivity, measured via detection thresholds (defined as the lowest concentration of a stimulus needed by a subject to detect its presence relative to water[16]) or recognition thresholds (defined as the lowest concentration of a stimulus correctly identified by name by a subject based on its characteristic taste[16]), have produced mixed results. Systolic blood pressure (SBP) was positively correlated with salty taste recognition thresholds among normal- and underweight 10- to 17-year-old Nigerian children[9], and was positively correlated with salty taste detection thresholds among normal-weight but not obese Spanish children (age was not reported)[8]. No relationship between blood pressure and salty taste detection thresholds was found among 11- to 16-year-old American children who ranged from normal weight to obese[3]. Among adults, hypertensives had higher recognition thresholds than normotensives in several studies[6,10–12], and in one study had higher detection thresholds[13]. Others found no difference in detection thresholds between adults with and without hypertension[11], and in two studies, found no difference in either detection or recognition thresholds between these groups[5,14].

Our understanding of potential shared mechanisms underlying salty taste sensitivity and blood pressure thus far may be limited by several confounding factors across studies including differences in subject age, body weight, and dietary salt intake; as well as wide variation in methodologies used to measure taste sensitivity. In light of 1) an increased prevalence of high blood pressure among pediatric populations over the last two decades[17,18], and 2) a known association between weight, dietary salt intake, and blood pressure[18,19], we examined the relationship between blood pressure and salty taste detection thresholds among normal-weight versus overweight and obese children using a rigorous validated methodology[20], and we explored whether differences in dietary salt intake influenced this relationship. To determine whether findings were specific to salty taste sensitivity, detection thresholds were also measured for monosodium glutamate (MSG), because of demonstrated differences in MSG taste sensitivity between obese and nonobese women[21], and because MSG is also a sodium-containing taste stimulus. If blood pressure and salty taste sensitivity share a common link, taste measures could provide new insight into our current understanding of the development of high blood pressure in children.

Materials and Methods

Participants

Mothers of 8- to 14-year old healthy children were recruited for a “taste study” from local advertisements in the Philadelphia area and from a list of past subjects who asked to be notified of future studies at the Monell Chemical Senses Center. Children with allergies were excluded from participation. All procedures were approved by the Office of Regulatory Affairs at the University of Pennsylvania. Written informed consent was obtained from each mother, and written informed assent from each child.

Procedures

Testing took place in a private, comfortable room specifically designed for sensory testing that was illuminated with red light to mask any visual differences among samples. Subjects consumed no food or drink other than water for at least one hour before the task and acclimated to the testing room and to the researcher for approximately 15 minutes. Prior to testing, all children were trained to become familiar with the method and to assess whether they understood the detection threshold task (modified from pediatric assessment of sucrose preference) [20]. Children were presented with a pair of plastic medicine cups: one containing distilled water and the other containing either 0.056 mM or 0.018 M sucrose solution. Children were asked to taste both solutions in the order presented and to point to the solution that had a taste (Figure 1a). This method eliminated the need for a verbal response and is effective for assessing both taste and olfaction in children. The two pairs (water vs. 0.056 mM and water vs. 0.018 M sucrose) provided the children with the experience of tasting a pair of solutions in which they could not detect a difference and a pair in which the difference between solutions was easily discernible, both of which are conditions encountered during threshold testing. Training was repeated with children who did not understand the task after one training session.

Taste Detection Thresholds

Detection thresholds for NaCl and MSG in solution were measured separately and in randomized order via a two-alternative forced choice staircase procedure developed at the Monell Center and later adapted for use among pediatric populations [20]. As shown in Figure

1b, solutions used for testing ranged in concentration from 0.056 mM to 1 M for both NaCl and MSG. Solutions for both stimuli were made through a $10^{.025}$-fold serial dilution of a 1.0 M solution to make a series of 18 concentrations. Solutions were randomized for order across subjects [22]. For the first trial and each subsequent trial, subjects were presented with pairs of solutions; within each pair, one solution was distilled water and the other the taste stimulus. Subjects were instructed to taste the first solution presented within a pair, swish the solution in their mouth for 5 seconds, and expectorate. Subjects tasted the second solution within a pair using the same protocol, rinsing their mouth with water once between solutions within a pair and twice between successive pairs. After tasting both solutions within a pair, subjects were asked to point to the solution that had a taste, as in the training task. The concentration of the tastant in the solution presented in the subsequent pair was increased after a single incorrect response and decreased after two consecutive correct responses. A reversal occurred when the concentration sequence changed direction (i.e., an incorrect response followed by a correct response or vice versa). A tracking grid (Figure 1b) was used to record subjects' responses. The testing procedure was terminated after four reversals occurred, provided the following criteria were met, to ensure a stable measure of the detection threshold: (1) there were no more than two dilution steps between two consecutive reversals, and (2) the reversals did not form an ascending pattern such that positive and negative reversals were achieved at successively higher concentrations[23]. A subject's threshold for a tastant was calculated as the mean of the log values of the last four reversals. Threshold testing for each child always began at step 12 (Figure 1b), a stimulus concentration that ensured an adequate number of steps on either side of the starting point to determine an accurate threshold. Though only a narrow section of the testing grid was required to test the subject illustrated in Figure 1b, some children tasted stimuli over a wider range of concentrations before their threshold was determined.

Anthropometry, Biometrics, and Blood Pressure

Children were weighed (kilograms; model 439 physical scale; Detecto Scale Company) and measured for height (centimeters) wearing light clothing and no shoes. Body mass index (BMI, kg/m^2) was determined, and age- and sex-specific BMI z-scores were calculated using EpiInfo 3.5 (www.cdc.gov/epiinfo). Participants were placed into one of four BMI categories according to Centers for Disease Control and Prevention pediatric growth charts [24]. None of the children were underweight. For analyses, participants were categorized as either overweight/obese or normal weight. Total body water, fat-free mass, and body fat were estimated by bioelectrical impedance analysis using the Quantum X instrument (RJL Systems)[25,26], and waist-to-hip ratio was determined using measurements for abdominal and hip circumferences[27]. Blood pressure was measured using an appropriately sized automated cuff based on arm circumference (Dinamap, GE Medical Systems) while children were seated with feet flat on the floor. Values were recorded for SBP and diastolic blood pressure (DBP) twice and recorded as the average of the two measurements for each reading. Children were required to rest for 1 minute before and between measurements. Blood pressure category was determined according to the National High Blood Pressure Education Program guidelines for classifying hypertension among children and adolescents [28]. Those with normal blood pressure had SBP or DBP below the 90th percentile; those with prehypertension had SBP or DBP between the 90th and 95th percentile or blood pressure that exceeded 120/80 mm Hg; and those with hypertension had SBP or DBP greater than the 95th percentile.

Demographics and Dietary Habits

Demographic data were collected by interview, and dietary intake data were collected and analyzed using the Automated Self-Administered 24-Hour Recall system (ASA24), a web-based validated methodology developed by the National Cancer Institute[29] that allows for calorie, nutrient, and food group estimates of overall intake. On each testing day, mothers and children sat side by side as the mother reported 24-hour dietary recall for her child to a researcher familiar with ASA24, who entered data into the program on their behalf. Children were asked to report on snacks or foods eaten outside the home (e.g., school)[30]. After a subject reports a specific food or beverage, ASA24 provides visual depiction of the item in an appropriate dish, which allows subjects to accurately estimate portion sizes. From the data collected, we focused specifically on reported daily sodium intake (mg Na/day) and caloric intake (kcal/day).

To determine the sources of sodium in children's diets, individual food items were grouped into the following categories according to their Food and Nutrient Database for Dietary Studies codes [31]: milk and milk products; meat, poultry, and fish; eggs; dry beans, peas, legumes, nuts, and seeds; grain products; fruits; vegetables; fats, oils, and salad dressings; and sugars, sweets, and beverages (see also NHANES for similar analysis of dietary recall data grouped by the same categories[32]). Because grain products have been cited as the largest overall contributor to sodium intake among children[32,33], this group was further broken down into its eight subgroups: yeast breads and rolls; quick breads; cakes, cookies, pies, and pastries; crackers and salty snacks; pancakes, waffles, and French toast; pastas, cooked cereals, and rice; cereals, not cooked; and grain mixtures. The relative percentage of sodium consumption from a specific food group was determined as the sum of sodium consumption within that specific food group divided by the sum of sodium consumption from all food groups. The relative proportion of sodium consumption from a specific grain subgroup was determined as the sum of all sodium within that subgroup divided by the sum of sodium consumption from all grain products subgroups. The Goldberg cutoff was applied to eliminate low-energy reporters prior to analysis of reported dietary intake data [34].

Data Analysis

NaCl and MSG detection thresholds were normalized by logarithmic transformation to approximate a normal distribution prior to analysis. Independent t-tests were performed to compare primary outcome measures (NaCl and MSG detection thresholds, anthropometric measures, blood pressure, including distribution of normotensive, pre-hypertensive, and hypertensive children, and reported dietary salt intake) between normal weight and overweight/obese children; and dependent t-tests were used to compare thresholds within each weight group. Distribution of blood pressure categories were also examined by sex with independent t-tests. Pearson correlation coefficients were used to assess relationships between NaCl and MSG detection thresholds with SBP, DBP, anthropometric measures, and reported dietary salt intake, within each weight group (normal weight and overweight/

obese). Correlations are reported in Results as the correlation coefficient (r) with degrees of freedom.

In line with study hypotheses, regression analyses were used to test for associations between salty taste thresholds and blood pressure, controlling for reported dietary salt intake, age, and BMI-Z score. Regression analyses were conducted for all children as one group, for normal weight children, and for overweight/obese children. Identical analyses were used to test MSG taste thresholds. All analyses were conducted with Statistica (version 12, 2013, StatSoft Inc.); and criterion for statistical significance was $p < 0.05$.

Results

Subject Characteristics, Completion of Tasks, and Reported Dietary Intake

As shown in Table 1, the study population consisted of 97 children (53 girls, 44 boys) whose race/ethnicity, family income, and education levels reflected the diversity of the city of Philadelphia [35]. None of the children refused to participate and the majority (96.9%) of children completed both MSG and NaCl thresholds (75.3%) or one of the thresholds (21.6%). Only 3% of children did not complete either. Reasons for completing only one or neither of the thresholds included noncompliance with protocol, or the child was too tired, hungry, or distracted to continue testing.

Approximately half of children were overweight or obese, and 30% were classified as pre-hypertensive or hypertensive (Table 1). There were no differences in distribution of blood pressure categories by weight (p=0.66), nor by sex (p=0.71). Normal-weight and overweight/obese children were well matched for age, sex, and ethnicity. As expected, overweight/obese children had a higher mean BMI z-score, waist circumference, percent body fat, waist-to-height ratio (a measure of central obesity), and mean SBP compared with normal-weight children.

As shown in Table 1, most children completed dietary recall tasks. About one-fifth were identified as low-energy reporters after the Goldberg cutoff was applied and thus were excluded from analyses of dietary records/reported sodium intake (overweight and obese children were no more likely to underreport than normal weight children (p=0.40). However, findings remained the same when analyses were conducted including low-energy reporters. Of the 73 children that completed and provided dietary recall data that satisfied the Goldberg cutoff, all reported excessive sodium intake that failed to meet the recommended 1,500 mg per day from the 2010 Dietary Guidelines[36].

Overweight/obese children consumed more sodium than normal-weight children and tended to consume more calories (Table 1). For both normal-weight and overweight/obese children, grain products were the largest relative contributor to reported sodium intake (Figure 2), though meat, poultry, and fish were a significant contributor to reported sodium intake among overweight/obese children as well (specifically, hot dogs, sausages, and ham). Within the grain products group, grain mixtures were the largest relative contributor to reported sodium intake; this subgroup includes pasta and rice mixed dishes, pizza, tacos and nachos, and pasta/grain-based soups.

Taste Thresholds, Blood Pressure, Body Weight, and Reported Dietary Salt Intake

Thresholds for NaCl, and MSG were positively related to each other (r (71) = 0.30; p=0.01, where r = 0.30 is the correlation coefficient and 71 is the degrees of freedom). Thresholds for either tastant did not differ between normal-weight and overweight/obese children (Table 2) and were not related to BMI z-scores, waist circumference, waist-to-height ratio, reported dietary salt intake, or blood pressure in either group. SBP was positively correlated with salty taste detection thresholds among normal-weight children (Figure 3a) but not among overweight/obese children (Figure 3b); this relationship was not evident for MSG thresholds for either group (Figure 3c,d).

Of the covariates used in multiple regression analyses (SBP, DBP, reported dietary salt intake, BMI-Z score, and age), only SBP was significantly correlated with salty taste thresholds, and only among normal weight children; there were no significant relationships between variables when analyses were completed on all children as one group or on overweight/obese children, nor were there any relationships with MSG taste thresholds for any of the groups. A model including all covariates accounted for 25% of the variance in salty taste thresholds among normal weight children, F (5, 32) = 2.7, p = 0.01, $R^2 = 0.25$, 90% CI [0.0003, 0.002].

Discussion

In light of the growing concern regarding high dietary salt intake and increased prevalence of high blood pressure among pediatric populations, we examined the relationship of salty taste sensitivity with blood pressure, body weight, and reported dietary salt intake in a racially diverse population of 8- to 14-year-old children from the Philadelphia area. We found a positive correlation between salty taste thresholds and SBP among normal-weight children but not among overweight and obese children, a relationship that did not extend to MSG thresholds. Thresholds for both tastants were within the range previously reported for both adults [22,37] and children [8]; however, there was no difference in either MSG or NaCl thresholds between normal-weight and overweight/obese children, as has been reported in adults [22,38]. The lack of a relationship between detection thresholds and obesity among children warrants future exploration of whether alterations in taste sensitivity are a consequence of years of obesity.

A relationship between salty taste sensitivity and SBP has been observed previously in children. Salty taste detection thresholds were positively correlated with SBP among non-obese but not among obese Spanish children[8]. Among normal- and underweight Nigerian children, salty taste recognition thresholds were positively correlated with SBP (overweight and obese children were not included in the study); in addition, no relationship between SBP and thresholds for sucrose, urea, or hydrochloric acid was observed, indicating the relationship was specific to salty taste [9]. To our knowledge, no adult studies have examined the relationship among salty taste sensitivity, SBP, and body weight—all studies to date have instead examined differences in salty taste sensitivity between normotensive and hypertensive subjects[6,12,13]. Future research is needed to investigate whether the observed relationship between blood pressure and taste sensitivity for salt is also evident in normal weight adults.

Several explanations, not mutually exclusive, may explain the association between blood pressure and salt sensitivity among normal-weight but not obese/overweight children. First, the observed differences may be due to differences between the groups in the ability to measure detection thresholds. This seems unlikely, however, as there were no differences in ability to comprehend or complete the task. Furthermore, only children who completed the task were included in the final analyses, and the findings were specific to NaCl and did not extend to MSG thresholds.

Second, salty taste detection thresholds may not be related with SBP among overweight/obese children because of their relatively higher blood pressures compared with normal-weight children; that is, the relationship may not have been observed due to a ‘ceiling effect’. On average, the SBP of overweight/obese children in our study was significantly higher than that of normal weight children. In addition, the overall range of SBPs among overweight/obese children (100 – 144 mm Hg) was more similar to the range of SBPs one might expect to see among healthy, prehypertensive, and stage 1 hypertensive adults collectively (<120 – 159 mm Hg), than it was to the normal weight children in the present study (77 – 130 mm Hg). Perhaps this similarity in blood pressures between overweight/obese children and adults explains why a positive association between SBP and salty taste thresholds has not been observed in either group. Examining whether a reduction in blood pressure of overweight/obese children shifts this relationship, could be an interesting area for future research.

Third, the differences in the relationship between SBP and taste thresholds between the two groups may be due to dietary intake. Overweight/obese children had higher reported dietary salt intake and higher caloric intake than did the normal-weight children. Though this difference in dietary intake did not directly explain the lack of a relationship between blood pressure and taste detection for salt, a previous study reported a positive relationship between salty taste preferences and dietary salt intake (mg/day) among children[39]. Greater liking of salt may have led to higher salt intake among overweight/obese children, serving as a contributing factor to heightened blood pressure[40], which, in turn, may have influenced the relationship between SBP and salty taste sensitivity. Whether high-sodium diets mediate the lack of a relationship between blood pressure and taste sensitivity among obese children is an important area for future research.

The present study highlights three important findings. First, blood pressure is positively associated with salty taste sensitivity among normal weight children. The method for measuring detection thresholds detailed herein addresses the cognitive limitations of children by eliminating the need for a verbal response and has previously been validated[20] for assessing both taste and olfaction in children[41,42]. Second, that the observed relationship did not follow a simple pattern of higher salty taste detection thresholds with higher reported dietary salt intake, suggests overweight and obesity and high blood pressure may have as of yet unresolved consequences on taste. Obese children have a 3-fold higher risk for developing hypertension than non-obese children, regardless of race, ethnicity, and sex[43]. Weight loss among obese children has repeatedly been shown through observational and interventional studies to result in a drop in blood pressure[44–47]; assessing the impact of weight loss and reduced blood pressure on salty taste thresholds of overweight and obese children could be an important area for future research, as this has yet to be explored. Third, results from 24-hour dietary recall indicate that children in the present study, regardless of body weight, are consuming salt at levels well in excess of recommendations[36,48], and that grain and meat products serve as primary sources of sodium. Should salty taste detection thresholds and blood pressure share a common link, the high rate of pediatric obesity and the current food environment rife with readily available sodium-rich foods[49] could be limiting our ability to fully understand the relationship between these variables, underscoring the need for a continued focus on reducing both rates of pediatric obesity and excessive salt intake. Further elucidation of the discussed relationship could be useful for identifying and directing dietary guidance of children susceptible to developing high blood pressure.

Limitations

While the methods described herein were easy for children to comprehend and complete, as expected, not all children completed both thresholds often because they were hungry or could not sustain attention. Nevertheless, it is important for future research on children (as well as adults) to monitor and report failures and noncompliance as part of the research protocol. Although the sample size used for the present study was sufficient for an exploration of the relationship between salty taste sensitivity and blood pressure by body weight, a larger sample would allow for stratification of subjects by race, ethnicity, and sex to account for how these variables might interact to influence sodium intake and blood pressure, particularly since these variables have been shown to be important factors when assessing blood pressure of children[50]. Although mothers confirmed dietary intake at home, children reported on dietary intake during periods when they were away from home (e.g., school). Because children of this age group are prone to reporting error[51], this can be viewed as a limitation. We note, however, that the average daily dietary sodium intake (~3,800 mg) collected from mothers and children via ASA24 in the present study was similar to NHANES data from a national sample of children (~3,300 mg) [52]. Future studies would benefit from multiple 24-hour dietary recalls on both weekdays and weekends and from other geographic areas.

Conclusions

In light of the apparent disruption in the relationship between salty taste detection thresholds and blood pressure among overweight and obese children, future research is warranted to further elucidate this relationship, including whether changes in taste perception precede or follow weight gain and heightened blood pressure, and whether variables such as race, sex, and parental income and education have any influence on the observed relationship. Continued investigation in this area has potential to add valuable insight to our current understanding of the associations among taste sensitivity, dietary intake, and health.

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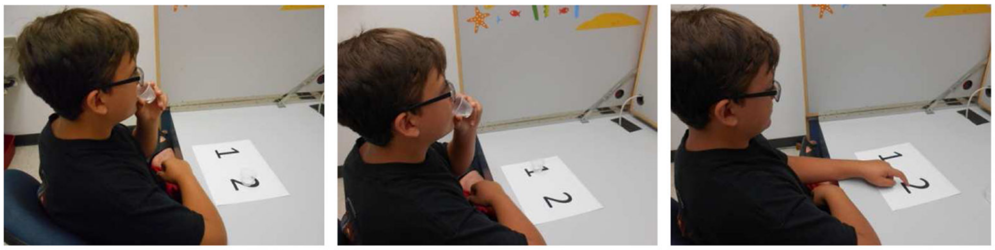
a) Child conducting detection threshold task



Child tastes contents of cup 1. Child tastes contents of cup 2. Child points to cup with a taste.

b) Sample testing grid

Step	Stimulus concentration (MSG or NaCl, mM)	Pair											
		1	2	3	4	5	6	7	8	9	10	11	12
		Order of presentation											
		2	2	2	2	1	1	2	1	1	2	2	1
Step 0	1000												
Step 1	562												
Step 2	316												
Step 3	178												
Step 4	100												
Step 5	56												
Step 6	32												
Step 7	18												
Step 8	10												
Step 9	5.6					+	+		+	+			
Step 10	3.2			+	-			-			+	-	
Step 11	1.8		-										
Step 12*	1.0*	-											
Step 13	0.56												
Step 14	0.32												
Step 15	0.18												
Step 16	0.10												
Step 17	0.056												

*indicates starting step/concentration. Solutions for both stimuli were made through a $10^{.025}$-fold serial dilution of a 1.0 M (1000 mM) solution to make a series of 18 concentrations.

Figure 1.

a) A 10-year-old subject performing the paired-comparison threshold tracking method. b) Tracking grid used to determine detection. For order of presentation of pairs, 1 signifies water and 2 signifies the tastant solution (either MSG or NaCl) is presented first within that particular pair. Whether a subject correctly (+) or incorrectly (−) identified the solution with a taste was recorded. Testing continued until four reversals in performance were achieved (circles with arrows). (Parental consent was provided for use of the photograph.)

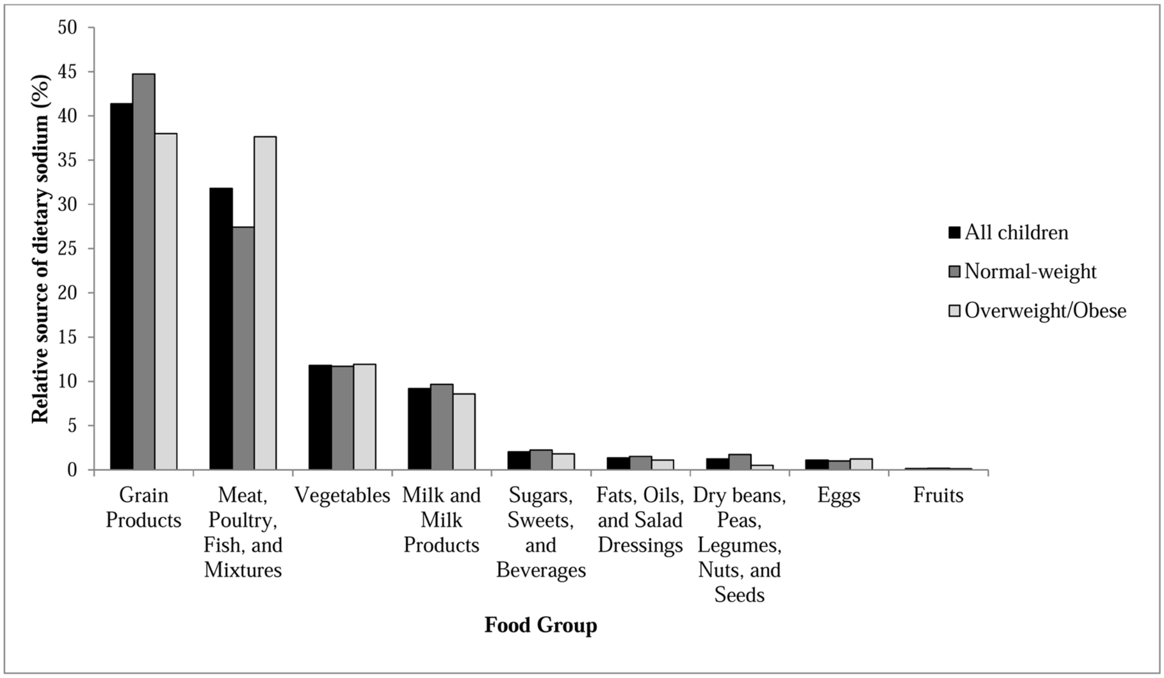
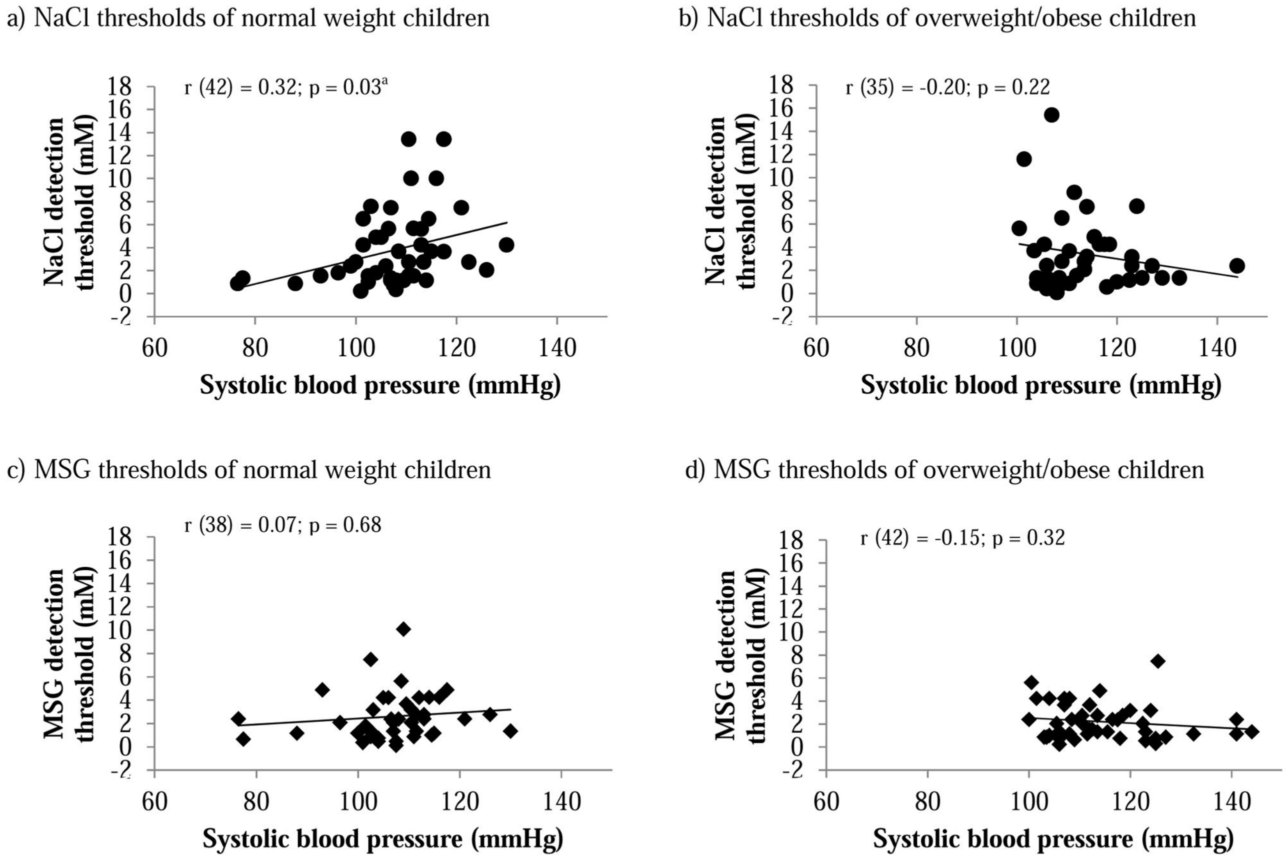


Figure 2.

Relative sources of dietary sodium among all children, normal-weight children, and overweight/obese children.



[a]r=0.32 is the correlation coefficient and 42 is the degrees of freedom. p-values from correlations are unadjusted.

Figure 3.

Association between NaCl (a, b) and MSG (c, d) detection thresholds and systolic blood pressure (SBP) among normal-weight (a, c) and overweight/obese children (b, d) as determined with Pearson correlations.

Table 1

Characteristics of a cohort of 97 pediatric subjects recruited to complete NaCl and MSG taste detection thresholds.

Characteristic	Pediatric subjects			p-Value[a]
	All children (N=97)	**Normal weight (N=47)**	**Overweight/obese (N=50)**	
Age, years [mean (SEM)]	10.5 (0.2)	10.4 (0.3)	10.7 (0.3)	0.40
Race [% (n)]				0.12
Black	51.5 (50)	48.9 (23)	54.0 (27)	
White	16.5 (16)	25.5 (12)	8 (4)	
Asian	2.1 (2)	2.1 (1)	2 (1)	
Other	29.9 (29)	23.4 (11)	36 (18)	
Ethnicity [% (*n*)]				0.62
Hispanic/Latino	12.4 (12)	10.6 (5)	14.0 (7)	
Female [% (*n*)]	54.6 (53)	59.6 (28)	50 (25)	0.34
BMI [mean (SEM)]	21.4 (0.6)	17.4 (0.3)	25.1 (0.8)	<0.01
BMI z-score [mean (SEM)]	0.94 (0.1)	0.04 (0.1)	1.8 (0.1)	<0.01
Waist circumference [cm; mean (SEM)]	72.8 (1.5)	63.4 (0.8)	81.6 (2.1)	<0.01
Waist-to-height ratio [cm/kg; mean (SEM)]	0.49 (0.01)	0.44 (0.005)	0.55 (0.01)	<0.01
Percent body fat [mean (SEM)]	33.5 (1.2)	24.2 (0.9)	42.3 (1.1)	<0.01
Systolic blood pressure [mmHg; mean (SEM)]	111.4 (1.1)	107.8 (1.3)	114.8 (1.5)	<0.01
Diastolic blood pressure [mmHg; mean (SEM)]	66.0 (0.6)	65.9 (0.9)	66.0 (0.8)	0.97
Blood pressure category [% (*n*)] [b]				0.35
Normal	70.1 (68)	74.5 (35)	66.0 (33)	
Prehypertensive	10.3 (10)	8.5 (4)	12.0 (6)	
Hypertensive	19.6 (19)	17.0 (8)	22.0 (11)	
Valid dietary recall [% (*n*)]	74.0 (73)	76.6 (36)	74.0 (37)	0.97
Dietary intake [mean (SEM); range)][c]				
Energy intake, kcal/day	2260.9 (91.4) (1168.0 – 4540.5)	2090.9 (108.9) (1168.0 – 3979.8)	2426.2 (142.2) (1338.8 – 4540.5)	0.07
Sodium, mg/day	3820.9 (176.0) (1702.5 – 8001.5)	3432.0 (241.4) (1702.5 – 8001.5)	4199.2 (242.9) (1947.3 – 7254.6)	0.03
Sodium density[d]	1697.9 (45.4) 638.6 – 2762.6	1637.9 (69.0) 638.6 – 2640.9	1756.3 (58.8) 1123.6 – 2762.6	0.19
Sodium mg/kg body weight	93.0 (6.0) 35.3 – 352.1	103.9 (10.3) 37.7 – 352.1	82.5 (5.9) 35.3 – 183.9	0.07
Completion of task [% (*n*)]				0.16
Completed both MSG and NaCl thresholds	75.3 (73)	80.9 (38)	70.0 (35)	
Completed threshold for either MSG or NaCl	21.6 (21)	17.0 (8)	26.0 (13)	
Did not complete either MSG or NaCl threshold	3.1 (3)	2.1 (1)	4.0 (2)	
Socioeconomic Characteristics[e]				

Characteristic	Pediatric subjects			p-Value[a]
	All children (N=97)	Normal weight (N=47)	Overweight/obese (N=50)	
Family income, % (*n*)				0.09
<$15,000	21.6 (21)	10.6 (5)	32.0 (16)	
$15,000–35,000	41.2 (40)	46.8 (22)	36.0 (18)	
$35,000–75,000	25.8 (25)	29.8 (14)	22.0 (11)	
>$75,000	11.3 (11)	12.8 (6)	10.0 (5)	
Highest level of education [mother; % (*n*)]				0.10
Grade school	4.1 (4)	6.4 (3)	2.0 (1)	
High school	45.4 (44)	38.3 (18)	52.0 (26)	
Trade school	9.3 (9)	12.8 (6)	6.0 (3)	
College	37.1 (36)	34.0 (16)	40.0 (20)	
Graduate school	4.1 (4)	8.5 (4)	0.0 (0)	

[a] Unadjusted p-values were generated from independent t-tests comparing the means of normal weight and overweight/obese children.

[b] Blood pressure categories were determined according to the National High Blood Pressure Education Program guidelines for classifying hypertension among children[28].

[c] Intake data are from one testing day and were collected using the Automated Self-Administered 24-Hour Recall, beta version (2009)[29]. Data included in the table are excluding underreporters eliminated with the Goldberg cutoff.

[d] Sodium density is calculated as (total mg sodium consumed/total kcal consumed) × 1000.

[e] Reported by mother.

Table 2

MSG and NaCl taste detection thresholds in a cohort of 97 pediatric normal-weight and overweight/obese subjects [mean ± SEM (*n*)].

Measure	All children	Normal weight	Overweight/obese	p-Value[a]
MSG threshold (mM)	2.4 ± 0.2 (84)	2.2 ± 0.2 (40)	2.7 ± 0.1 (44)	0.23
NaCl threshold (mM)	3.6 ± 0.3 (83)	3.7 ± 0.3 (44)	3.4 ± 0.3 (39)	0.75
p-Value[b]	0.003	0.03	0.04	

[a]Comparisons between normal weight and overweight/obese groups were made with independent t-tests. p-values are unadjusted.

[b]Comparisons between MSG and NaCl thresholds within each group were made with dependent t-tests. p-values are unadjusted.