Current Research in Food Science 5 (2022) 2204–2210

Contents lists available at ScienceDirect

Current Research in Food Science

journal homepage: www.sciencedirect.com/journal/current-research-in-food-science

Umami detection threshold among children of different ethnicities and its correlation with various indices of obesity and blood pressure

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ARTICLE INFO

Handling Editor: Dr. Yeonhwa Park

Keywords:
Children
Ethnicity
Glutamate
Obesity
Taste threshold
Umami

ABSTRACT

Sensitivity to savory taste has been linked to high consumption of savory foods and increased risks of obesity and hypertension. However, there are limited studies that investigate whether obesity indices are correlated with the differences in umami taste perception, particularly in children. This study aimed to investigate the umami detection threshold among children of different ethnicities and the threshold's correlation with obesity indices and blood pressure. A total of 140 subjects were recruited and consisted of a nearly equal distribution of children from three main ethnicities (37.2% Malays, 31.4% Chinese, 31.4% Indians). Umami detection threshold was measured using the two-alternative, forced-choice staircase procedure. Body weight, height, waist circumference and blood pressure of children were measured. Body composition was assessed using bioelectrical impedance analysis (BIA). Mean umami detection threshold was 1.22 ± 1.04 mM and there were no observable differences attributable to the subjects' ethnicities. Body fat percentage was negatively correlated ($r = -0.171$, $p < 0.05$), while lean body mass percentage was positively correlated ($r = 0.171$, $p < 0.05$) with umami detection threshold. These findings revealed that umami taste perception correlated with children's body composition, but not other anthropometric indicators and blood pressure. Future studies should explore the correlation between umami taste perception and children's total dietary intake.

1. Introduction

Sensory perception varies significantly among individuals, affecting food preferences and selection and even nutritional status in the long term (de Macedo et al., 2016; Naish and Harris, 2012; Overberg et al., 2012). Generally, the taste system can distinguish five main sensory qualities (sweet, sour, salty, bitter and umami) (Barragán and Coltell, 2018), with each sensory quality indicating a different nutritional or physiological need. Furthermore, taste sensitivity may influence eating behavior, dietary intake and the likelihood of dietary-related chronic diseases (Puputti et al., 2019; Tan and Tucker, 2019; Veček et al., 2020).

Saltiness and umami are the taste qualities that provide savory flavor sensation (Overberg et al., 2012). A European study has reported that when asked to describe verbally the taste of monosodium glutamate (MSG), a large percentage of subjects from Finland, Germany and Italy used the term "salty" (Iannilli et al., 2020). A functional magnetic resonance imaging (fMRI) study reported that the activation of salty and umami taste is similar and may be processed within common neural areas (Han et al., 2018). This may be due partly to the existence of similar sodium components in monosodium glutamate (Na-glutamate) and salt (Na-chloride). Excessive intake of salt can contribute to elevated blood pressure and may cause hypertension (Raj et al., 2016), whereas the impact of MSG intake on hypertension remains unclear. In East and Southeast Asian countries the dietary intake of MSG was higher than those reported in Western diet. For instance, the MSG intake was reported to be 1.5–3.0 g/day in Taiwan, 1.1–1.6 g/day in Japan and 1.6–2.3 g/day in South Korea (Lee and Lee 1986; Maga and Yamaguchi 1983). For frequent consumer, the MSG intake can be up to 4.0 g/day (Beyreuher et al., 2007). In South Asia, many ready-made foods sold at street-side restaurants or dhaba contains MSG (Banerjee et al., 2021). The increased demand for MSG in Asian countries could be due to rapid urbanization and industrialization especially in the food processing

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https://doi.org/10.1016/j.crfs.2022.11.006
Received 2 September 2022; Received in revised form 2 November 2022; Accepted 3 November 2022
Available online 4 November 2022

industry (Kazmi et al., 2017). A recent double-blind, randomized study reported that the umami taste quality can potentially replace sodium without sacrificing palatability (Hayabuchi et al., 2020).

While the variation in perception of savoriness between obese and normal weight subjects has been investigated, the findings are contradictory and inconclusive. Some studies observed that subjects who are obese have a lower perception for salty taste (Donaldson et al., 2009) and tend to have more difficulties in identifying different taste qualities (Overberg et al., 2012). Other studies have indicated that obese adults have lower sensitivity and higher preference for salty (Donaldson et al., 2009) and umami tastes (Pepino et al., 2010), respectively. On the other hand, a recent study has found children become more sensitive to salty taste and less taste sensitive for umami with the increasing of age (Jilani et al., 2022). Umami taste can be found naturally in different foods; however, a strong stimulus of umami taste in our diet is MSG (Noel et al., 2018). Taste preferences of umami may be subject to an individual's taste sensitivity, which is the ability to taste a stimulus at its lowest concentration and can be measured using detection threshold. Donaldson and colleagues reported no difference in the preference of MSG in different BMI groups (Donaldson et al., 2009). Nevertheless, obese children tend to consume more savory snacks than normal weight children (Maffeis et al., 2008). On the other hand, a study among adults in Sri Lanka did not observe any significant association between underweight and sensitivity to umami (Fuchida et al., 2013).

In recent decades, concern about childhood obesity has grown as it tracks strongly into adulthood and increases the risk of such non-communicable, chronic diseases as diabetes and hypertension (Craigie et al., 2011; Piernas et al., 2016; Simbolon et al., 2019). In Malaysia, approximately one-third of children or adolescents aged 6–17 years have been classified as overweight or obese (Institute for Public Health, 2019). In addition, severe obesity in children has also been associated with lower cognitive abilities, which have lifelong consequences (Poh et al., 2019). Childhood is a crucial stage for developing dietary behavior in which exposure to taste stimulus is essential. Differences in the dietary habits of children from different ethnic backgrounds have been observed (Chong et al., 2016). Meanwhile, taste perception may vary with geographical locations (Baharuddin and Sharifudin, 2015). Although several works have studied the detection threshold of umami tastes in children, many of these studies had been conducted in Western countries (Bobowski and Mennella, 2015; Donaldson et al., 2009). Our study conducted in Malaysia reported that MSG had no effect on the appetite and subsequent energy intake in children of different ethnicities (Lim et al., 2021). However, it is important to understand whether children of different ethnic backgrounds perceive umami taste differently as genetic differences in taste receptors can give rise to individual taste differences (Kim and Drayna, 2005; Rawal et al., 2013; Wu et al., 2021) and affects children's food choices and nutritional status. In view of the increasing prevalence of obesity as a global health threat, any additional perspective that sheds light on obesity's underlying factors would be beneficial. If the perception of umami taste and indices of obesity share a common link, sensory perception of savory taste can provide new insights into our understanding of childhood obesity, which could be crucial for targeted obesity prevention programs.

To date, studies on savory taste among children are scarce, especially in Malaysia, a multi-ethnic country. A recent study observed that Malaysian Chinese children have a significantly higher salt detection threshold, compared to Malay and Indian children (Dora et al., 2020), and that this threshold has no relationship with blood pressure. Since MSG is also a sodium-containing taste stimulus, it is worthwhile to explore further whether umami taste sensitivity differs among children from different ethnicities by using a validated methodology. Hence, this study aims to investigate the umami detection threshold among Malay, Chinese and Indian primary school-aged children and to determine its correlation with various obesity indices and blood pressure.

2. Materials and methods

2.1. Study design

This cross-sectional study was conducted in Kuala Lumpur and its metropolitan suburbs in Malaysia. A total of 169 subjects aged 9–11 years of both sexes, from the three main ethnicities, namely Malays, Chinese and Indians, were recruited from five primary schools, which comprised National schools, National-type Chinese schools, and National-type Tamil schools. Only 140 subjects (82.4%) completed the entire procedure. Two-alternative, forced choice (2-AFC) staircase procedure was used to determine the umami detection threshold in children. Children were requested not to drink or eat any food and to drink only plain water starting from 22:00 h the night before the test day. Anthropometric, body composition and blood pressure measurements were carried out on the morning of the test day.

A minimum sample size of 40 was required to obtain a power of 95% and $\alpha = 0.01$ (Ennis and Jesionka, 2011). Thus, to compare the differences of umami detection threshold among the three main ethnicities, at least 120 subjects were needed. Children with diabetes, heart disease, asthma, autism, attention deficit hyperactivity disorder (ADHD), food intolerance or allergies or have a negative reaction after consuming monosodium glutamate (MSG) were excluded from this study. The present study was conducted in accordance with the guidelines set out in the Declaration of Helsinki and was approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia (Ref No. UKM PPI/111/8/JEP-2017-594). Written informed consent was obtained from the parents or guardian of the children prior to participation in the study and verbal assent was obtained from each child before data collection.

2.2. Anthropometric measurements

Body weight was measured with the participant wearing light indoor clothing, without shoes, to the nearest 0.1 kg, using a calibrated digital scale (SECA Model 813, Hamburg, Germany). Height was measured with the participant barefoot, to the nearest 0.1 cm, using a stadiometer (SECA Model 213, Hamburg, Germany). BMI was calculated by dividing the measured weight (kg) by the square of height (m^2). Z-score for BMI-for-age (BAZ) was then determined using WHO AnthroPlus Version 1.0.3 software (WHO, Geneva, Switzerland).

Waist circumference was measured with a Lufkin tape (Model W606PM, Apex Tool Group, United States) to the nearest 0.1 cm. Subjects were asked to stand still with feet together with shirt lifted above the waistline in order to measured directly over the skin of subject. Lufkin tape was placed around the subject, in horizontal line (on the midway of the last rib and top of iliac crest) using cross hand technique. Measurement was taken at the end of normal expiration, without the tape compressing against the skin. For hip circumference, subjects were requested to put their feet together and the gluteal muscle relaxed before the measurement. The level of greatest posterior perpendicular to the long axis of trunk with standing position of subjects was measured by using a Lufkin tape (Model W606PM, Apex Tool Group, United States) to the nearest 0.1 cm.

2.3. Body composition measurement

The children's body composition was measured using bioelectrical impedance technique with a BodyStat 1500 MDD analyzer (Bodystat Ltd, UK). Subjects were requested to take off their shoes, socks, watch or any metal jewelry, and then lie comfortably in a supine position, with both arms and limbs abducted without touching the body, for about 5 min to ensure that fluid levels have stabilized in the body before the measurement. For the subject's right-hand position, disposable electrodes were placed behind the knuckle of the middle finger and on the wrist next to the ulna head, while for the subject's right foot position, electrodes were placed at the middle of the dorsal surface, proximally to the metatarsal-phalangeal joints and between medial and lateral malleoli at the ankle, respectively. An alcohol swab was used to clean the skin surface prior to attaching the electrodes. Crocodile clips connected to the BodyStat analyzer were clipped to the connective ends of electrodes to complete the analysis. Readings of body composition (fat mass and lean body mass) were derived from the measured impedance and extended algorithms of the analyzer, after entering the information of subject's age, sex, weight, height, activity level, waist and hip circumferences.

2.4. Blood pressure measurement

Blood pressure was measured by Omron digital sphygmomanometer model HEM-907 (Omron, Japan), with the right arm of the children on the table and situated at heart-level, while the children were sitting on a chair. Appropriately-sized blood pressure cuffs, either 17–22 cm (Omron HEM-CS19) or 22–32 cm (Omron HEM-CR24), were used, based on the children's arm circumference. All measurements were taken twice and there was a 5-min interval between each reading. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) values were recorded as the average of the two measurements of each reading.

2.5. Measurement of umami detection threshold

MSG concentrations ranging from 0.056 mM to 1 M were used to assess umami detection threshold by using 2AFC staircase procedure adopted from Bobowski and Mennella (2015). Children were requested to rinse their mouth twice with water before the trial started. Pairs of 5 ml solutions were provided; one solution was distilled water and the other was the MSG taste stimulus. The solutions were randomized in order across subjects (Pepino et al., 2010). Each test session was initiated using 1.0 mM of MSG solution for all subjects, which is similar to the study conducted by Bobowski and Mennella (2015). Based on the order presented, the children were requested to taste the first solution, swish the solution in their mouth for 5 s, and then spit it out. After tasting both solutions within a pair, the children were requested to point out which solution had a taste. The children then rinsed their mouths with distilled water twice and waited 20 s before moving onto the next sample.

When the subject successfully identified the MSG solution from a blank solution on two consecutive trials, a lower concentration of MSG solution was provided. However, if the subject failed to distinguish the MSG solution from a blank solution, a higher concentration of MSG solution was provided. During the trial, a reversal was deemed to have occurred when there was an incorrect response followed by a correct response or vice versa. The same procedure was then repeated until four reversals were obtained, as shown in Fig. 1. The detection threshold for MSG was calculated using the geometric mean of the four reversals recorded.

2.6. Statistical analysis

All data was analyzed using SPSS version 22.0 (IBM Corp., United States). Analytical data were presented as mean ± standard deviation (SD). Non-parametric tests were used due to the skewed distribution of data. Mann-Whitney *U* test was performed to determine the difference of anthropometric measurements, body composition and MSG detection threshold between the sexes, while Kruskal-Wallis test was used to examine the differences in the measurements among the three main ethnicities, namely Malays, Chinese and Indians. Spearman correlation was used to examine the relationship between MSG detection threshold with blood pressure, BMI-for-age z-score, waist circumference, body fat percentage and lean body mass percentage. P-values below 0.05 were regarded as significant.

MSG concentration (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
1000												
562												
316												
178												
100												
56												
32												
18												
10												
5.6												
3.2			+	+		+	+					
1.8		-			-			-				
1.0	-											
0.56												
0.32												
0.18												
0.10												
0.056												

Fig. 1. Sample of testing grid with four reversals.

3. Results

Table 1 provides the children's characteristics. Some 64.3% of the subjects were girls and 35.7% boys. There were almost equal numbers of children (37.2% Malays, 31.4% Chinese and 31.4% Indians) from each of the three major ethnic groups in Malaysia. More than one-third (36.4%) of the children in the current study were categorized as either overweight or obese (OW/OB), whereas the others (63.6%) were considered non-overweight or non-obese (non-OW/OB), according to the WHO 2007 BMI-for-age z-scores (WHO 2007).

Table 2 shows the children's anthropometric characteristics, body composition and blood pressure measurements. The children's mean age was significantly different among ethnicities; with Malays being youngest, followed by Chinese and Indians. Similarly, the Indian children in our study were significantly taller and heavier when compared to Malay children ($p < 0.05$). For blood pressure measurements, the average SBP and DBP of children were 106.1 ± 10.8 mmHg and 64.0 ± 8.3 mmHg, respectively. No significant differences were noted in BMI, BAZ, waist

Table 1
Socio-demographic descriptive data and BMI category of children (n = 140).

Characteristics	n (%)
Sex	
Male	50 (35.7)
Female	90 (64.3)
Ethnicity	
Malay	52 (37.2)
Chinese	44 (31.4)
Indian	44 (31.4)
[a]**BMI categories**	
Non-overweight/obese (Non OW/OB)	89 (63.6)
Overweight/obese (OW/OB)	51 (36.4)

[a] BMI categories were done according to BMI-for-age z-scores (WHO 2007).

Table 2
Anthropometry, body composition and blood pressure measurement of children (mean ± SD).

Variables	All (n = 140)	Malays (n = 52)	Chinese (n = 44)	Indian (n = 44)	p-value (p value)
Age (years)	10.0 ± 1.0	9.5 ± 0.8[a]	10.2 ± 1.0[b]	10.6 ± 0.9[b]	<0.001*
Height (cm)	138.2 ± 9.3	134.8 ± 8.8[a]	138.8 ± 9.2[a,b]	142.0 ± 8.3[b]	<0.001*
Weight (kg)	34.8 ± 12.0	31.9 ± 10.0[a]	36.6 ± 12.1[b]	36.6 ± 12.4[b]	0.017*
BMI (kg/m^2)	17.9 ± 4.5	17.3 ± 3.9	18.6 ± 4.5	17.9 ± 4.6	0.185
BMI-for-age (SD)	0.4 ± 2.8	−0.1 ± 2.6	1.0 ± 2.7	0.4 ± 2.8	0.128
Waist Circumference (cm)	62.4 ± 12.7	60.1 ± 11.4	63.6 ± 12.2	63.9 ± 13.4	0.085
Body fat (%)	27.3 ± 9.4	27.4 ± 10.7	25.4 ± 9.1	29.1 ± 7.2	0.131
Lean body mass (%)	72.7 ± 9.4	72.6 ± 10.7	74.6 ± 9.1	70.9 ± 7.7	0.131
SBP (mmHg) PRESSPREpressure (mmHg)	106.1 ± 10.7	104.5 ± 10.7	107.8 ± 10.1	106.5 ± 10.6	0.224
DBP (mmHg)	64.2 ± 8.4	63.4 ± 8.0	64.5 ± 8.6	64.6 ± 8.8	0.630

1Based on BMI-for-age z-score: Severely thin and thin (z-score < −2SD); Normal (-2SD ≤ z-score≤+1SD); Overweight (+1SD < z-score ≤+2SD) and obese (z-score >+2SD) (WHO 2007).
2SBP: Systolic blood pressure; DBP: Diastolic blood pressure.
*Kruskal-Wallis test showed significant difference between ethnicity at p<0.05 based on pairwise comparison.
[a] Mean values not sharing the same superscript letter indicate significant difference between ethnics groups based on pairwise comparison.
[b] Mean values not sharing the same superscript letter indicate significant difference between ethnics groups based on pairwise comparison.

circumference and body composition measurements among children from the three major ethnic groups in Malaysia.

The mean umami detection threshold of children was 1.22 ± 1.04 mM (Table 3). Boys had a higher umami threshold (1.52 ± 1.39 mM) compared to girls (1.06 ± 0.74 mM) but the difference was not significant ($p = 0.054$). For the comparison among three ethnicities, Malay children had the highest umami threshold, followed by Chinese and Indian children. However, no significant difference in umami detection threshold was found among the three ethnicities. It was observed that OW/OB children had a similar threshold (1.23 ± 0.96 mM) with non-OW/OB children (1.23 ± 1.11 mM).

Table 4 shows the correlation of various obesity indices and blood pressure with umami detection threshold. It was found that the percentage of the children's body fat correlated negatively with the MSG detection threshold ($r = -0.171$, $p = 0.047$). In contrast, the percentage of lean body mass was observed to correlate positively with the MSG detection threshold ($r = 0.171$, $p = 0.047$). No significant correlations were observed between BMI-for-age z-scores, waist circumference, SBP and DBP with MSG taste threshold among children.

Table 4
Spearman correlation model of relationship between various obesity indices and blood pressure with MSG taste detection threshold in children (n = 140).

Variables	Correlation	
	R	p-value
BMI-for-age z-score	−0.031	0.712
Body fat (%)	−0.171	0.047*
Lean body mass (%)	0.171	0.047*
Waist Circumference (cm)	−0.099	0.247
SBP (mmHg)	−0.045	0.602
DBP (mmHg)	−0.044	0.609

r refers to the correlation coefficient.
* Significant difference was found at $p < 0.05$.
SBP: Systolic blood pressure; DBP: Diastolic blood pressure.

4. Discussion

The present cross-sectional study examined the umami detection threshold of children from different ethnic backgrounds and the threshold's association with various indices of obesity and blood pressure. A higher detection threshold indicates that the children would need a higher umami concentration to differentiate between umami taste and water. Our results showed no variation in umami taste perception among Malaysian primary school children of different ethnic backgrounds. Out of the six indices studied, namely, BMI-for-age z-score, body fat %, lean body mass %, waist circumference, SBP and DBP, no correlations were found with MSG threshold, except for the percentages of body fat and lean body mass for body composition. A neuroimaging study has shown that brain responses to taste stimuli may vary in obese individuals compared to individuals of normal weight (Liu et al., 2019). In addition, based on the findings of fMRI, the blood-oxygen-level-dependent activation response in regions related to food motivation, such as the cerebellum, precuneus, and fusiform gyrus decreased after the consumption of MSG broth (Liu et al., 2019). This further confirm the importance of the umami taste on food intake.

However, the current findings observed no correlation between MSG taste detection thresholds with weight status and blood pressure, which is consistent with previous literature (Bobowski and Mennella, 2015). In terms of body composition, a previous study reported that the taste thresholds (sweet, sour, salty and bitter) negatively correlated with visceral fat where a lower score was observed in the taste thresholds of obese adult females (Fernandez-Garcia et al., 2017). Similarly, another

Table 3
Umami detection threshold of children (Mean ± SD).

Variables	n	MSG Threshold (mM)	p-value
Overall	140	1.22 ± 1.04	
Sex[a]			0.054
Boys	50	1.52 ± 1.39	
Girls	90	1.06 ± 0.74	
Ethnicity[b]			0.759
Malay	52	1.29 ± 1.27	
Chinese	44	1.24 ± 0.85	
Indian	44	1.16 ± 0.98	
BMI category			0.812
Non-overweight/obese (non OW/OB)	89	1.23 ± 1.11	
Overweight/obese (OW/OB)	51	1.23 ± 0.96	

[a] Comparison between sexes and BMI category were made with Mann-Whitney test.
[b] Comparison between ethnicity were made with Kruskal-Wallis test.

study reported that obese subjects have a lower recognition threshold of sweet and salty tastes, which in turn suggests that obese individuals have higher taste sensitivity (Hardikar et al., 2017). However, the umami taste threshold was not measured in these two studies. As observed in our study, OW/OB children have a similar threshold with non-OW/OB children. This may be partially due to the unequal subject distribution in each BMI category in the present study. A similar number of normal weight (n = 47) and overweight/obese (n = 50) children were recruited in the previous study (Bobowski and Mennella, 2015). Therefore, to clarify whether the weight status (obese or non-obese) of individuals influences taste perception, a similar number of normal weight and obese subjects needs to be recruited in future studies.

No gender differences in umami taste perception were detected in a study conducted among Caucasian adults and elderly based on total taste scoring for five different concentrations of tastant (Barragán and Coltell, 2018). However, another study that used the 2-AFC methodology similar to the one employed in the present study, indicated that taste detection threshold of young adults was influenced by gender (Hong et al., 2005). The different methodologies used to determine taste detection threshold likely contributed to the discrepancy of the results. Our study showed that the difference in umami taste detection thresholds between genders was at the limit of statistical significance ($p = 0.054$). It has been suggested that taste perception is associated with the density of taste buds (Khan et al., 2019). Women tend to have more taste buds and fungiform papillae than men due in part to differences in hormones, dietary habits, alcohol consumption and smoking behavior (Prutkin et al., 2000; Yackinous and Guinard, 2002).

The present finding was consistent with Overberg et al. (2012), where no variations were observed in the taste sensitivity of the five basic tastes of children and adolescents from German, Turkish and other ethnic backgrounds (Overberg et al., 2012). However, several studies have indicated that taste perceptions can be affected by culture and ethnicity (Baharuddin and Sharifudin, 2015; Dora et al., 2020; Williams et al., 2016). In Asia, there are few taste perception studies that compare the umami taste perception of different ethnic groups, especially among children. In contrast to our study, a recent Singapore study reported that Indian adults have higher umami recognition threshold compared to Chinese adults, which suggests that Singaporean Indians have a lower sensitivity for umami taste (Leong et al., 2018). However, instead of using a detection threshold, this study used the recognition threshold to determine umami taste perception among their subjects (Leong et al., 2018). Hence, the results of the study from Singapore should be interpreted with caution in relation to our study, as readings of taste threshold vary depending on the method used.

Taste thresholds may change over time as they are influenced by such environmental factors as dietary habits and taste exposure (Vennerød et al., 2018; Navarro-Allende et al., 2008). A recent study in Korea revealed the umami recognition threshold of elderly subjects was higher when compared to young adults (Vennerød et al., 2018). In addition, Barragán and Coltell (2018) and Overberg et al. (2012) have indicated that taste sensitivity may increase from childhood until adulthood and then decline from adulthood to elderly. Since the subjects of the present study are children, future studies should examine the umami detection threshold of different populations, including adolescents, adults and elderly of different ethnicities, in order to have in-depth understanding of variations of umami taste perception among individuals of various age and ethnic backgrounds. Furthermore, the seasonings used in different cuisines may contribute to variations in taste threshold (Leong et al., 2018). For instance, soy sauce, which is commonly used in Chinese cuisine, is rich in glutamate and is thus likely to influence umami taste sensitivity in frequent consumers (Leong et al., 2018). However, the relationship between consuming high umami food frequently with taste sensitivity requires further clarification as dietary records were not available in our study.

Moreover, genetic variations in taste receptor type 1 member 1 (TAS1R1) and taste receptor type 1 member 3 (TAS1R3), the umami taste receptors, may directly influence the umami taste sensitivity (Nelson et al., 2002; Wu et al., 2021; Zhang et al., 2019). A U.S. study associated the difference in umami taste perception with variations in the TAS1R3 gene (Chen et al., 2009). Another study observed a difference in the genetic polymorphism of TAS1R1 and TAS1R3 genes among Korean populations, where the coding of A372T in TAS1R1 and C75R in TAS1R3 genes were commonly found in Koreans (Bae et al., 2010). Although the influence of ethnicity in umami detection threshold was not significant, it is important to further investigate the genetic polymorphism among Malaysians of different ethnicities that may affect the sensitivity to glutamate among different ethnic populations.

This study investigates the umami detection threshold in children and compares the threshold among children from three different ethnicities which can be considered as novel research in Malaysia. In addition, the 2-AFC staircase procedure used in the present study is a valid method to determine the detection threshold among children (Mennella et al., 2011). However, it should be noted that the complexity of the food matrix may play a role in the perception of umami. The detection threshold for MSG can vary between pure aqueous solutions and different food samples (such as soups, sauces, or pasta) as the threshold is partly determined by the food texture or appearance. Future research is needed to follow up and investigate the detection thresholds of MSG in different foods to better understand the MSG thresholds in children. In addition, a larger number of subjects from different age groups should be recruited in future studies so that more meaningful comparisons can be made. Although the present study was designed as a cross-sectional study and a causal relationship of umami threshold with obesity could not be determined, the findings can still be considered as foundational research and a stepping stone for future studies. On the other hand, the present study was conducted only in Kuala Lumpur Metropolitan, Malaysia. Hence, the outcomes may not be generalizable to all children living in different regions of Malaysia, as geographic difference is also a known determinant of dietary habits and taste perception. Future studies should recruit an equal number of subjects in each BMI category to provide better understanding of the relationship between nutritional status and taste sensitivity.

5. Conclusion

The current study showed that the mean MSG detection threshold of Malaysian children was 1.22 ± 1.04 mM. No differences attributable to gender or ethnic background were observed among the children. The study also observed that umami taste perception was correlated only with children's body composition, but not any other anthropometric indicators or blood pressure, which provides a new horizon into our current understanding of childhood obesity. Healthcare professionals or food manufacturers may consider the current finding about the umami taste threshold in menu planning or when designing low-sodium and appetizing food products for children without altering their palatability. It is worthwhile to further examine the relationship between the children's umami taste threshold and their preference for umami taste in future studies. This is critical when designing targeted intervention programs as taste perception is known to influence food intake.

Funding

This study was supported by International Glutamate Technical Committee (IGTC) (UKM Project Code NN-2017-093). IGTC was not involved in the design or the outcome of the study.

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and was approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia (Ref No. UKM PPI/111/8/JEP-2017-594).

Informed consent statement

Written informed consent was obtained from the parents or guardian of the children prior to participation in the study and verbal assent was obtained from each child before data collection.

CRediT authorship contribution statement

Sim Yee Lim: Formal analysis, Data curation, Writing – original draft. **Dora Rosmawati:** Formal analysis, Data curation, Writing – review & editing. **Noor Hafizah Yatiman:** Writing – review & editing. **Jyh Eiin Wong:** Writing – review & editing. **Hasnah Haron:** Conceptualization, Writing – review & editing. **Bee Koon Poh:** Conceptualization, Writing – review & editing, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Prof Dr Poh Bee Koon reports financial support was provided by International Glutamate Technical Committee (IGTC).

Data availability

Data will be made available on request.

Acknowledgement

The authors thank all children involved for their participation and cooperation and to their parents for their consent and support during the course of this study. We are also grateful to the school principals, teachers and administrators for their cooperation and assistance, and to the Ministry of Education for permission to conduct the study in selected schools.

References

Bae, J.W., Lee, H.J., Oh, S.K., Kim, S.Y., Kim, U.K., 2010. Genetic variation of umami taste genes in Koreans. Genes Genomics 32, 111–113. https://doi.org/10.1007/s13258-009-0889-5.

Baharuddin, A.R., Sharifudin, M.S., 2015. The impact of geographical location on taste sensitivity and preference. Int. Food Res. J. 22 (2), 731–738.

Banerjee, A., Mukherjee, S., Maji, B.K., 2021. Worldwide flavor enhancer monosodium glutamate combined with high lipid diet provokes metabolic alterations and systemic anomalies: an overview. Toxicol Rep 8, 938–961. https://doi.org/10.1016/j.toxrep.2021.04.009.

Barragán, R., Coltell, O., 2018. Bitter, sweet, salty, sour and umami taste perception decreases with age: sex-specific analysis, modulation by genetic variants and taste-preference associations in 18 to 80 year-old subjects. Nutrients 10 (10), 1539. https://doi.org/10.3390/nu10101539.

Beyreuher, K., Biesalski, H.K., Fernstrom, J.D., Grimm, P., Hammes, W.P., Heinemann, U., Kempski, O., Stehle, P., Steinhart, H., Walker, R., 2007. Consensus meeting: monosodium glutamate - an update. Eur. J. Clin. Nutr. 61 (3), 304–313. https://doi.org/10.1038/sj.ejcn.1602526.

Bobowski, N.K., Mennella, J.A., 2015. Disruption in the relationship between blood pressure and salty taste thresholds among overweight and obese children. J. Acad. Nutr. Diet. 115 (8), 1272–1282. https://doi.org/10.1016/j.jand.2015.02.017.

Chen, Q.Y., Alarcon, S., Tharp, A., Ahmed, O.M., Estrella, N.L., Greene, T.A., Rucker, J., Breslin, P.A., 2009. Perceptual variation in umami taste and polymorphisms in TAS1R taste receptor genes. Am. J. Clin. Nutr. 90 (3), 770s–779s. https://doi.org/10.3945/ajcn.2009.27462N.

Chong, K.H., Wu, S.K., Noor Hafizah, Y., Bragt, M.C., Poh, B.K., 2016. Eating habits of Malaysian children: findings of the South east asian nutrition surveys (SEANUTS). Asia Pac. J. Publ. Health 28 (5 Suppl. l), 59s–73s. https://doi.org/10.1177/1010539516654260.

Craigie, A.M., Lake, A.A., Kelly, S.A., Adamson, A.J., Mathers, J.C., 2011. Tracking of obesity-related behaviours from childhood to adulthood: a systematic review. Maturitas 70 (3), 266–284. https://doi.org/10.1016/j.maturitas.2011.08.005.

de Macedo, I.C., de Freitas, J.S., da Silva Torres, I.L., 2016. The influence of palatable diets in reward system Activation: a mini review. Adv. Pharmacol. Pharm. Sci. 2016, 7238679. https://doi.org/10.1155/2016/7238679.

Donaldson, L.F., Bennett, L., Baic, S., Melichar, J.K., 2009. Taste and weight: is there a link? Am. J. Clin. Nutr. 90 (3), 800s–803s. https://doi.org/10.3945/ajcn.2009.27462Q.

Dora, R., Lim, S.Y., Haron, H., Wong, J.E., Yatiman, N.H., Poh, B.K., 2020. Salty taste threshold among children of different ethnicities. J. Sensory Stud. 36 (1), e12623 https://doi.org/10.1111/joss.12623.

Ennis, J.M., Jesionka, V., 2011. The power of sensory discrimination methods revisited. J. Sensory Stud. 26, 371–382. https://doi.org/10.1111/j.1745-459X.2011.00353.x.

Fernandez-Garcia, J.C., Alcaide, J., Santiago-Fernandez, C., Roca-Rodriguez, M.M., Aguera, Z., Banos, R., Botella, C., De La Torre, R., Fernandez-Real, J.M., Fruhbeck, G., Gomez-Ambrosi, J., Jimenez-Murcia, S., Menchon, J.M., Casanueva, F. F., Fernandez-Aranda, F., Tinahones, F.J., Garrido-Sanchez, L., 2017. An increase in visceral fat is associated with a decrease in the taste and olfactory capacity. PLoS One 12 (2), e0171204. https://doi.org/10.1371/journal.pone.0171204.

Fuchida, S., Yamamoto, T., Takiguchi, T., Kandaudahewa, G., Yuyama, N., Hirata, Y., 2013. Association between underweight and taste sensitivity in middle- to old-aged nursing home residents in Sri Lanka: a cross-sectional study. J. Oral Rehabil. 40 (11), 854–863. https://doi.org/10.1111/joor.12099.

Han, P., Mohebbi, M., Unrath, M., Hummel, C., Hummel, T., 2018. Different neural processing of umami and salty taste determined by umami identification ability independent of repeated umami exposure. Neuroscience 383, 74–83. https://doi.org/10.1016/j.neuroscience.2018.05.004.

Hardikar, S., Hochenberger, R., Villringer, A., Ohla, K., 2017. Higher sensitivity to sweet and salty taste in obese compared to lean individuals. Appetite 111, 158–165. https://doi.org/10.1016/j.appet.2016.12.017.

Hayabuchi, H., Morita, R., Ohta, M., Nanri, A., Matsumoto, H., Fujitani, S., Yoshida, S., Ito, S., Sakima, A., Takase, H., Kusaka, M., Tsuchihashi, T., 2020. Validation of preferred salt concentration in soup based on a randomized blinded experiment in multiple regions in Japan-influence of umami (L-glutamate) on saltiness and palatability of low-salt solutions. Hypertens. Res. 43 (6), 525–533. https://doi.org/10.1038/s41440-020-0397-1.

Hong, J.H., Chung, J.W., Kim, Y.K., Chung, S.C., Lee, S.W., Kho, H.S., 2005. The relationship between PTC taster status and taste thresholds in young adults. Oral Surg Oral Med Oral Pathol Oral Radiol 99 (6), 711–715. https://doi.org/10.1016/j.tripleo.2004.08.004.

Iannilli, E., Knaapila, A., Cecchini, M.P., Hummel, T., 2020. Dataset of verbal evaluation of umami taste in Europe. Data Brief 28, 105102. https://doi.org/10.1016/j.dib.2019.105102.

Institute for Public Health (IPH), 2019. National health and morbidity survey (NHMS) non-communicable diseases, healthcare demand, and health literacy—key findings. http://www.iku.gov.my/images/IKU/Document/REPORT/NHMS2019/Report_NHMS2019-NCD_v2.pdf. Retrieved on 29 March 2021.

Jilani, H., Intemann, T., Buchecker, K., Charalambos, H., Gianfagna, F., De Henauw, S., Lauria, F., Molnar, D., Moreno, L.A., Lissner, L., Pala, V., Siani, A., Veidebaum, T., Ahrens, W., Hebestreit, A., IDEFICS consortium, 2022. Correlates of bitter, sweet, salty and umami taste sensitivity in European children: role of sex, age and weight status - the IDEFICS study. Appetite 175, 106088. https://doi.org/10.1016/j.appet.2022.106088.

Kazmi, Z., Fatima, I., Perveen, S., Malik, S.S., 2017. Monosodium glutamate: review on clinical reports. Int. J. Food Prop. 20 (Suppl. 2), 1807–1815. https://doi.org/10.1080/10942912.2017.1295260.

Khan, A.M., Ali, S., Jameela, R.V., Muhamood, M., Haqh, M.F., 2019. Impact of fungiform papillae count on taste perception and different methods of taste assessment and their clinical applications: a comprehensive review. Sultan Qaboos Univ. Med. J. 19 (3), e184–e191. https://doi.org/10.18295/squmj.2019.19.03.003.

Kim, U.K., Drayna, D., 2005. Genetics of individual differences in bitter taste perception: lessons from the PTC gene. Clin. Genet. 67 (4), 275–280. https://doi.org/10.1111/j.1399-0004.2004.00361.x.

Lee, E.H., Lee, D.I., 1986. A study on intake level of monosodium glutamate in Korea. J Environ Health Sci 12 (2), 75–85.

Leong, C.S., Forde, C.G., Tey, S.L., Henry, C.J., 2018. Taste perception and diet in people of Chinese ancestry. Asia Pac. J. Clin. Nutr. 27 (2), 478–486. https://doi.org/10.6133/apjcn.052017.08.

Lim, S.Y., Dora, R., Yatiman, N.H., Wong, J.E., Haron, H., Poh, B.K., 2021. No effect of monosodium glutamate on subjective appetite and subsequent energy intake in children of different ethnicities. Appetite 167, 105629. https://doi.org/10.1016/j.appet.2021.105629.

Liu, C.K., Joseph, P.V., Feldman, D.E., Kroll, D.S., Burns, J.A., Manza, P., Volkow, N.D., Wang, G.J., 2019. Brain imaging of taste perception in obesity: a review. Curr. Nutr. Rep. 8 (2), 108–119. https://doi.org/10.1007/s13668-019-0269-y.

Maffeis, C., Grezzani, A., Perrone, L., Del Giudice, E.M., Saggese, G., Tatò, L., 2008. Could the savory taste of snacks be a further risk factor for overweight in children? J. Pediatr. Gastroenterol. Nutr. 46 (4), 429–437. https://doi.org/10.1097/MPG.0b013e318163b850.

Maga, J.A., Yamaguchi, S., 1983. Flavor potentiators. Crit. Rev. Food Sci. Nutr. 18, 231–312. https://doi.org/10.1080/10408398309527364.

Mennella, J.A., Lukasewycz, L.D., Griffith, J.W., Beauchamp, G.K., 2011. Evaluation of the Monell forced-choice, paired-comparison tracking procedure for determining sweet taste preferences across the lifespan. Chem. Senses 36 (4), 345–355. https://doi.org/10.1093/chemse/bjq134.

Naish, K.R., Harris, G., 2012. Food intake is influenced by sensory sensitivity. PLoS One 7 (8), e43622. https://doi.org/10.1371/journal.pone.0043622.

Navarro-Allende, A., Khataan, N., El-Sohemy, A., 2008. Impact of genetic and environmental determinants of taste with food preferences in older adults. J. Nutr. Elder. 27 (3–4), 267–276. https://doi.org/10.1080/01639360802261920.

Nelson, G., Chandrashekar, J., Hoon, M.A., Feng, L., Zhao, G., Ryba, N.J., Zuker, C.S., 2002. An amino-acid taste receptor. Nature 416 (6877), 199–202. https://doi.org/10.1038/nature726.

Noel, C.A., Finlayson, G., Dando, R., 2018. Prolonged exposure to monosodium glutamate in healthy young adults decreases perceived umami taste and diminishes appetite for savory foods. J. Nutr. 148 (6), 980–988. https://doi.org/10.1093/jn/nxy055.

Overberg, J., Hummel, T., Krude, H., Wiegand, S., 2012. Differences in taste sensitivity between obese and non-obese children and adolescents. Arch. Dis. Child. 97 (12), 1048–1052. https://doi.org/10.1136/archdischild-2011-301189.

Pepino, M.Y., Finkbeiner, S., Beauchamp, G.K., Mennella, J.A., 2010. Obese women have lower monosodium glutamate taste sensitivity and prefer higher concentrations than do normal-weight women. Obesity 18 (5), 959–965. https://doi.org/10.1038/oby.2009.493.

Piernas, C., Wang, D., Du, S., Zhang, B., Wang, Z., Su, C., Popkin, B.M., 2016. Obesity, non-communicable disease (NCD) risk factors and dietary factors among Chinese school-aged children. Asia Pac. J. Clin. Nutr. 25 (4), 826–840. https://doi.org/10.6133/apjcn.092015.37.

Poh, B.K., Lee, S.T., Yeo, G.S., Tang, K.C., Noor Afifah, A.R., Siti Hanisa, A., Parikh, P., Wong, J.E., Ng, A.L.O., 2019. Low socioeconomic status and severe obesity are linked to poor cognitive performance in Malaysian children. BMC Publ. Health 19 (Suppl. 4), 541. https://doi.org/10.1186/s12889-019-6856-4.

Prutkin, J., Fisher, E.M., Etter, L., Fast, K., Gardner, E., Lucchina, L.A., Snyder, D.J., Tie, K., Weiffenbach, J., Bartoshuk, L.M., 2000. Genetic variation and inferences about perceived taste intensity in mice and men. Physiol. Behav. 69 (1–2), 161–173. https://doi.org/10.1016/s0031-9384(00)00199-2.

Puputti, S., Hoppu, U., Sandell, M., 2019. Taste sensitivity is associated with food consumption behavior but not with recalled pleasantness. Foods 8 (10), 444. https://doi.org/10.3390/foods8100444.

Raj, S.E., Tan, L.M., Adyani, M.R., 2016. Dietary salt intake: history, assessment, and benefit in hypertensive treatment. Asian J. Pharmaceut. Clin. Res. 9 (2), 39–42. https://doi.org/10.22159/ajpcr.2016.v9s2.13483.

Rawal, S., Hayes, J.E., Wallace, M.R., Bartoshuk, L.M., Duffy, V.B., 2013. Do polymorphisms in the TAS1R1 gene contribute to broader differences in human taste intensity? Chem. Senses 38 (8), 719–728. https://doi.org/10.1093/chemse/bjt040.

Simbolon, D., Yorita, E., Talib, R., 2019. Consequences of overweight and obesity in adolescents against the risk of hypertension in adulthood. Kesmas. Nat. Pub. Health J. 14 (1), 28–36. https://doi.org/10.21109/kesmas.v14i1.2723.

Tan, S.Y., Tucker, R.M., 2019. Sweet taste as a predictor of dietary intake: a systematic review. Nutrients 11 (1), 94. https://doi.org/10.3390/nu11010094.

Veček, N.N., Mucalo, L., Dragun, R., Miličević, T., 2020. The association between salt taste perception, mediterranean diet and metabolic syndrome: a cross-sectional study. Nutrients 12 (4), 1164. https://doi.org/10.3390/nu12041164.

Vennerød, F.F.F., Nicklaus, S., Lien, N., Almli, V.L., 2018. The development of basic taste sensitivity and preferences in children. Appetite 127, 130–137. https://doi.org/10.1016/j.appet.2018.04.027.

WHO, 2007. Growth Reference Data for 5-19 Years. World Health Organization, Geneva.

Williams, J.A., Bartoshuk, L.M., Fillingim, R.B., Dotson, C.D., 2016. Exploring ethnic differences in taste perception. Chem. Senses 41 (5), 449–456. https://doi.org/10.1093/chemse/bjw021.

Wu, B., Eldeghaidy, S., Ayed, C., Fisk, I.D., Hewson, L., Liu, Y., 2021. Mechanisms of umami taste perception: from molecular level to brain imaging. Crit. Rev. Food Sci. Nutr. 1–10. https://doi.org/10.1080/10408398.2021.1909532.

Yackinous, C.A., Guinard, J.X., 2002. Relation between PROP (6-n-propylthiouracil) taster status, taste anatomy and dietary intake measures for young men and women. Appetite 38 (3), 201–209. https://doi.org/10.1006/appe.2001.0481.

Zhang, J., Sun-Waterhouse, D., Su, G., Zhao, M., 2019. New insight into umami receptor, umami/umami-enhancing peptides and their derivatives: a review. Trends Food Sci. Technol. 88, 429–438. https://doi.org/10.1016/j.tifs.2019.04.008.