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Correlates of bitter, sweet, salty and umami taste sensitivity in European children: Role of sex, age and weight status - the IDEFICS Study

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Conflict of interest

All the authors declare that they have no conflict of interest.

Abstract

We aimed to describe differences in taste sensitivity in children according to age across 7- to 11-year-old children from eight European countries. We further compared taste sensitivity between boys vs. girls and under-/normal weight vs. overweight/obese children. Within the European multicentre IDEFICS (Identification and prevention of dietary and lifestyle-induced health effects in children and infants) study, 1,938 school children participated in sweet, bitter, salty and umami detection threshold tests between 2007 and 2010, using the paired comparison staircase method. The lowest concentration at which the child was able to detect a difference to water was determined as taste detection threshold as a proxy of taste sensitivity. Mean taste thresholds were calculated stratified for sex, age groups, weight groups and country. BMI was calculated using measured height and weight; socio-demographic information was collected using questionnaires. Ordinal logistic regressions were conducted to investigate the association between sex, weight status (as categorical exposure variable) and age (as continuous exposure variable) and the taste sensitivity for the four taste modalities (as outcome), separately. Older children were more taste sensitive for sweet and salty and less taste sensitive for umami and bitter than younger children. Girls were more sensitive to sweet taste than boys. Overweight or obese children were less sensitive to sweet and salty taste compared to normal weight children This was the first study comparing taste sensitivity by measuring taste thresholds in children across different European countries. We conclude that taste thresholds are associated with weight status, children become more sensitive to sweet and salty tastes with increasing age, and girls might be more sensitive to sweet than boys.

1. Introduction

Overweight and obesity among children continue to be a major public health concern in Europe and worldwide. About 22 million children in Europe are overweight or obese (Watson, 2008). One factor that influences an unfavourable weight development is diet. Sensory taste perception is assumed to play a substantial role in food choice, especially in childhood, when other aspects such as healthiness and prices of foods are not yet considered (Birch, 1979, 1998).

One dimension that contributes to sensory taste perception is taste sensitivity. Sensory taste sensitivity can be measured through the assessment of taste thresholds where the lowest concentration of a taste modality that can be detected is considered as detection threshold. Sensory taste sensitivity differs substantially between individuals and changes during the developmental stages of infancy and childhood (Anliker, Bartoshuk, Ferris, & Hooks, 1991). Although infants and children have up to five times more taste buds than adults, they do not seem to be more taste sensitive, probably because the innervation of taste papillae in infants is not yet fully developed and functional (Plattig, 1984). Nevertheless, studies on taste thresholds in children, show inconsistent results. Whereas Anliker et al. observed that children aged 5 to 6 years and adults have similar bitter taste thresholds when determining the PROP taster status (Anliker et al., 1991), other studies showed that children and infants have higher taste thresholds; Glanville, Kaplan and Fischer showed this by measuring detection thresholds for bitter with different tastants like PROP and quinine sulphate (Glanville, Kaplan, & Fischer, 1964; James, Laing, & Oram, 1997) or lower recognition thresholds for bitter taste than adults (Whissell-Buechy, 1990). James et al. measured detection thresholds for sweet (using sucrose), salty (using sodium chloride) sour (using citric acid) and bitter (using caffeine) and reported that 8-9 year old boys had higher thresholds for sweet, bitter and salty tastes than adults and higher sweet and salty thresholds than girls, while girls' taste thresholds were similar to those of adults (James et al., 1997). The results of James et al. indicate that there might also be sex differences with regard to taste sensitivity during childhood. Overberg at al. reported that older children showed a higher overall taste sensitivity (sweet, salty, sour, bitter and umami) than younger children assessing taste sensitivity using taste strips with different concentrations of sucrose (for sweet), citric acid (for sour), sodium chloride (for salty), monosodium glutamate (for umami) and quinine hydrochloride (for bitter) (Overberg, Hummel, Krude, & Wiegand, 2012). In contrast, Vennerød et al. found in a longitudinal study that children between 4 to 6 years became less sweet sensitive, more sour and salty sensitive and remained stable with regard to bitter and umami sensitivity when measuring detection thresholds with different concentrations of sucrose (for sweet), citric acid (for sour), monosodium glutamate (for umami) and quinine hydrochloride dehydrate (for bitter) (Vennerod, Nicklaus, Lien, & Almli, 2018).

Results of studies investigating associations between taste sensitivity and weight status are also contradictory. Overberg et al. found that children and adolescents with obesity had higher salty, umami and bitter thresholds than children and adolescents without obesity. In contrast, another study compared taste sensitivity of 39 adolescents with obesity versus 48 adolescents without obesity and found that those with obesity were more sensitive for sweet and salty taste (Pasquet, Frelut, Simmen, Hladik, & Monneuse, 2007). Further results on the other hand showed no associations between salty taste sensitivity in 421 adolescents (Kirsten & Wagner, 2014) nor in 72 children and adolescents (Alexy et al., 2010) and Fernández-Aranda et al. did not find any association between taste perception of any taste modality and extreme weight/eating conditions in adults (Fernandez-Aranda et al., 2016).

As it seems most likely that children, due to the development of taste sensitivity during childhood and adolescence, have different taste thresholds than adults, results of studies with an adult population may not be applicable in children. Besides age and sex, which may influence individual taste thresholds, taste sensitivity itself may be associated with overweight and obesity as described above.

In general, the inconsistent observations of former studies may possibly result from investigating different age groups and usage of different methodologies to assess taste sensitivity. Further, the mentioned studies that investigated weight status differed in their sample size, ranging from 72 to 421. This could be another reason for inconsistent results.

For the first time the present study describes taste sensitivity by measuring taste detection thresholds for sweet, bitter, umami and salty taste in 1,938 boys and girls using a standardised study protocol across 8 European countries. Further, this study analysed the hypotheses that sex, age and weight status are associated with sweet, salty, bitter and umami taste thresholds.

2. Methods

2.1 Study design and participants

The study sample group is a sub-sample of the IDEFICS (Identification and prevention of dietary and lifestyle-induced health effects in children and infants) study, a prospective European multicentre cohort study whose aim was to investigate the aetiology of lifestyle- and nutrition- related disorders such as childhood overweight and obesity. The overall aim and design of the IDEFICS study has been described previously (Ahrens et al., 2011). Between September 2007 and May 2008, a baseline survey (T0) was conducted in 16 228 children from 8 European countries (Belgium, Cyprus, Estonia, Germany, Hungary, Italy, Spain and Sweden) aged 2 to 9.9 years. Two years later, between September 2009 and May 2010, a follow up (T1) examination was conducted. Between T0 and T1, interventions to improve health behaviour took place in one region in each country, with one other region in each country serving as a control region. A sub-sample of children from the age of 6 years onwards was asked to participate in the sensory perception module which consisted of taste threshold as well as taste preference tests. Application of inclusion criteria (see below) resulted in a final study sample for this cross-sectional analysis of 1,938 children aged between 7 and 11 years old that participated in sweet, salty, bitter and umami threshold tests either at T0 or T1.

All centres obtained ethical approval from their local institutional review board (e.g. Ethics Committee, University Hospital, Gent, Belgium; Cyprus National Bioethics Committee, Nicosia, Cyprus; Tallinn Medical Research Ethics Committee, Tallinn, Estonia; Ethics Committee of the University of Bremen, Bremen, Germany; Egeszsegugyi Tudomanyos Tanacs, Pecs, Hungary; Comitato Etico dell'Azienda Sanitaria Locale di Avellino, Italy; Regionala Etikprovningsnamnden i Göteborg, Gothenburg, Sweden; Comite Etico de Investigacion Clınica de Aragon, Zaragoza, Spain). Parents gave their written informed consent and children were first informed orally, after which they gave their oral consent to participate in our study.

2.2 Anthropometric measurements

Children's weight and height were measured in an overnight fasting state using a Tanita BC 420 SMA scale (TANITA, Tokyo, Japan) for weight measurement and a SECA 225 Stadiometer (SECA GmbH & KG, Hamburg, Germany) for height measurement. BMI was calculated and converted to age- and sex-specific z-scores (Cole & Lobstein, 2012). Children were classified into underweight/normal weight and overweight/obese (weight status) using age- and sex-specific cut-offs published by Cole and Lobstein. The cut-offs for overweight were for boys the 90.5th and for girls the 89.3rd percentile curve (Cole & Lobstein, 2012).

2.3 Taste threshold tests

For the taste threshold test, a paired comparison staircase taste threshold test to assess the sweet, salty, umami and bitter detection threshold was arranged as a board game as described by Knof et al. (Knof et al., 2011). In brief, 5 watery solutions (see Table 1) prepared with distilled water, with ascending concentrations of sucrose (8.8-46.7 mmol/l, sweet), sodium chloride (3.4-27.4 mmol/l, salty), monosodium glutamate (0.6-9.5 mmol/l, umami) or caffeine (0.26-1.3 mmol/l, bitter) were presented to the participant in 20 ml cups at room temperature. To prepare the solutions, sucrose from Applichem GmbH, Darmstadt, Germany was used for sweet, sodium chloride from Applichem GmbH, Darmstadt, Germany for salty, caffeine from Carl Roth GmbH & Co. KG, Karlsruhe, Germany for bitter and sodium glutamate from Merck KGaA, Darmstadt, Germany for umami. Cups were placed at the bottom of the game board and the child compared each solution against pure distilled water. The observer asked the child if there was any difference between the two tastes. The child indicated if yes or no by placing the cup on the respective field on the game board. If the child was unsure, he/she was allowed to try a second sip of the test solution. Thus, the child was only asked to indicate if it tasted something and not which taste they perceived. After the decision was made, the child was not allowed to try again. The first concentration at which the participant could taste a difference to water was recorded as detection threshold. If the child did not taste a difference to water at any concentration, ‘no taste threshold’ was assigned for the respective taste modality. After each taste modality, participants recovered for 2 minutes, during which they neutralised their palate with distilled water, and the field staff prepared the next test sequence. According to the examination protocol, the children should not have eaten for at least an hour before the examinations, but should not be hungry either. Adherence to this stipulation was ensured through the fact that the children participated in another examination module of the IDEFICS study prior to the first lesson in the morning. As the children had to be in fasting status for this examination, they received something to drink and eat afterwards. They then joined their classes from where they were taken individually to the sensory taste perception tests. These were solely conducted during the morning hours, in the school setting. The order of presentation of tested taste modalities was fixed as follows: sweet, salty, bitter and umami.

The concentrations were chosen based on the DIN (German Institute for Standardisation, www.DIN.de) 10959, which defines concentrations of test samples and procedures for adults. It works with ten aqueous solutions with increasing concentrations of the corresponding test substance. For our purpose the test design had to be adapted to the physical and psychological development of children. First, the number of test solutions was reduced to five. Furthermore, an additional cup of distilled water was provided to the child to compare the test solutions with a neutral taste. Between the different taste modalities children rinsed their mouth with water and waited for two minutes before they moved on to the next taste modality. The adapted concentrations and procedures were adjusted after being pre-tested in all survey centres (Suling et al., 2011). During the development of the taste threshold tests 40 children were selected randomly to be included into the test-retest procedure. This subsampled consisted of 22 boys and 18 girls aged between 5 and 7 years. The test-retest analysis of the taste threshold tests revealed a kappa coefficient of 0.81 (sweet), 0.75 (salty), 0.68 (bitter) and 0.77 (umami) (Knof et al., 2011). Thus, the analysis of test-retest results show a strength of agreement that is rated to be “almost perfect” for sweet and “substantial” for the detection of salty, bitter, and umami (Landis & Koch, 1977). The results of the test re-test procedure in the sub-sample were assumed to be applicable to the full sample. We conducted extensive pre-tests and found the test procedures to be only suitable for children from the age of 6 years onwards but not for pre-schoolers (Suling et al., 2011). Schoolchildren were in general able to understand the task and to deliver meaningful results. Therefore, the minimum age was set to 6 years for the actual taste threshold tests. Thus, the test procedure was developed in a way that was easy to understand for children from the ages of 6 years (Suling et al., 2011). Training for the implementation of the standardised testing protocol was organised centrally for all 8 countries and testing materials were prepared centrally and then shipped to the survey centres. On the day of testing the survey centres only needed to prepare the solutions with distilled water according to standard operation procedure (SOP). The adherence to the testing protocol was monitored via site visits to ensure a maximum degree of standardisation.

2.4 Taste sensitivity

For our study taste sensitivity was determined measuring taste thresholds. Taste thresholds were measured as described above resulting in five categories of taste sensitivity. Having the lowest taste threshold means being very sensitive to the specific taste modality. Having the highest taste threshold in contrast means being very insensitive to the specific taste modality.

The five taste threshold levels were used as categorical variables for each taste modality in the statistical analysis as the main outcome and can be found in table 2.

2.5 Statistical analyses

Mean taste thresholds (mmol/l) and corresponding standard deviations (SDs) were calculated by age, sex and country. For the calculation of mean taste thresholds (mmol/l) the category 'no threshold' was excluded.

Ordinal logistic regressions were conducted to investigate the associations between sex (as dichotomous exposure), weight status (as dichotomous exposure), age (as continuous exposure) and taste sensitivity for the four taste modalities (as outcome), separately. The outcome variable therefore had 6 categories ranging from 'threshold 1' to 'threshold 5' and 'no threshold'. The odds ratios (ORs) associated with one level lower taste threshold (i.e. being one threshold level more sensitive) for girls, overweight/obese children and children being one year older and the corresponding 95% CI were calculated. To prevent for confounding by sex, country, residing in control or intervention region and weight status, the ordinal logistic regression analyses were repeated with adjustment for these variables in multivariate model. To exemplify the age trend, raw and adjusted ORs were also calculated for an increase in age of three years.

Furthermore, the k-means algorithm (Hartigan & Wong, 1979) was applied to the standardised taste threshold variables (i.e. z-scores) to identify clusters of children with similar taste patterns. In this popular data-driven cluster approach (Lo Siou, Yasui, Csizmadi, McGregor, & Robson, 2011) the within-cluster variance is minimized and children are partitioned into k distinct clusters, in which each child is assigned to the cluster with the closest cluster mean, i.e., with respect to the standardized taste threshold children in the same cluster are close to each other and far apart from children in the other clusters. Standardisation is intended to prevent the k-means algorithm from weighting the variables differently due to different variances. To decide on the appropriate number of clusters the so-called elbow method was used taking into account the explained variances of all two- to eight -cluster solutions. The five-cluster solution was favoured which explained 56 % of variance. The different clusters are explained in detail in the results section and can be found in tables 5 and 6. A multinomial logistic regression model was used to analyse the association between the derived clusters as dependent variable and the demographic variables (sex, weight status and age) as independent variables.

All analyses were carried out with SAS, version 9.3 (Statistical Analysis System, SAS Institute Inc., Cary, USA).

3. Results

The study population included children between 7 and 11 years. In total, 466 children were 7 years old, 444 were 8 years old, 328 were 9 years old, 498 children were 10 years old and 202 were 11 years old. On average the children were 8.2 (SD 1.3) years old and the proportion of girls and boys was evenly balanced. In total, 25.1% of the children were overweight or had obesity. Children were most likely from Belgium (18.1%) and less likely from Sweden and Germany (8.4% each). For the full sample, the mean BMI z-score was 0.5 (SD 1.2) **(Table 1)**. Mean (SD) taste thresholds of the full sample were 0.7 (0.3) mmol caffeine/l for bitter, 18.7 (8.9) mmol sucrose/l for sweet, 10.7 (6.1) mmol sodium chloride/l for salty and 2.9 (2.3) mmol monosodium glutamate/l for umami.

Table 1: Characteristics of the study sample (total number and percentages or mean and standard deviation (SD)) given by sex groups

	Boys	**Girls**	**Total**
	N (%)	**N (%)**	**N (%)**
	970 (50.1)	968 (49.9)	1938 (100.0)
Country			
Belgium	174 (17.9)	176 (18.2)	350 (18.1)
Cyprus	157 (16.2)	136 (14.1)	293 (15.1)
Estonia	102 (10.5)	116 (12.0)	218 (11.3)
Germany	66 (6.8)	96 (9.9)	162 (8.4)
Hungary	122 (12.6)	124 (12.8)	236 (12.2)
Italy	144 (14.9)	126 (13.0)	270 (13.9)
Spain	125 (12.9)	111 (11.5)	246 (12.7)
Sweden	80 (8.3)	83 (8.6)	163 (8.4)
Weight status[1]			
Under-/ normal weight	732 (75.5)	719 (74.3)	1451 (74.9)
Overweight/Obese	238 (24.5)	249 (25.7)	487 (25.1)
	Mean (SD)	**Mean (SD)**	**Mean (SD)**
BMI z-score[2]	0.5 (1.2)	0.5 (1.2)	0.5 (1.2)
Age (years)	8.2 (1.3)	8.2 (1.3)	8.2 (1.3)

[1]: Defined by Cole and Lobstein (Cole & Lobstein, 2012)
[2]: BMI z-scores according to Cole and Lobstein (Cole & Lobstein, 2012)

Table 2 shows the concentrations of the different test solutions used. The concentration ranges have been described in the methods section. Further, the table shows the distribution of children assigned to the different taste thresholds. About 2/3 of the children belonged to the first or second sweet taste threshold whereas for bitter the children were more equally distributed across all taste thresholds including ‘no threshold’. For salty, 2/3 of the children belonged to the second or third taste threshold and for umami, most of the children belonged to the first, second or third threshold.

Table 2 Concentrations of test solutions and distribution of participants assigned to the different taste thresholds.

	1 (mmol/l) n (%)	2 (mmol/l) n (%)	3 (mmol/l) n (%)	4 (mmol/l) n (%)	5 (mmol/l) n (%)	No Threshold n (%)
Sucrose (sweet)	8.76	17.53	26.29	35.06	46.74	
	520 (26.8)	821 (42.4)	350 (18.1)	123 (6.4)	53 (2.7)	71 (3.7)
Caffeine (bitter)	0.26	0.51	0.77	1.03	1.29	
	340 (17.5)	372 (19.2)	313 (16.2)	220 (11.4)	196 (10.1)	497 (25.6)
Sodiumchloride (salty)	3.42	6.85	13.68	20.51	27.35	
	318 (16.4)	673 (34.7)	622 (32.1)	205 (10.6)	64 (3.3)	56 (2.9)
Monosodiumglutamate	0.59	1.77	3.55	7.10	8.87	
(umami)	441 (22.8)	615 (31.7)	483 (24.9)	248 (12.8)	58 (3.0)	93 (4.8)

Table 3 shows further descriptive results. It shows the mean taste thresholds of children that were included in our sample according to different groups (sex, weight status, country and age). In our study sample higher sweet sensitivity was observed for girls than for boys. Further, boys needed a slightly higher concentration of salt in water to detect a taste. Overweight children/children with obesity of our sample were less sensitive to the salty taste than under-/normal weight children and needed also a slightly higher sugar concentration in water to detect a taste. For bitter and umami taste sensitivity there was no difference between under-/normal weight children and overweight children/children with obesity. Further details of the country, sex, weight and age group comparisons are presented in table 3.

Table 3: Means and standard deviations of concentrations to measure taste sensitivity for sex-groups, weight status, countries and age-groups

	Sweet threshold (mmol sucrose/l)	Salty threshold (mmol sodium chloride/l)	Umami threshold (mmol monosodium glutamate/l)	Bitter threshold (mmol caffeine/l)
Sex of the child				
Boys	19.25 (9.43)	10.96 (6.21)	2.86 (2.30)	0.70 (0.35)
Girls	18.16 (8.22)	10.45 (5.96)	2.94 (2.32)	0.70 (0.35)
Weight status				
Under-/ normal weight	18.49 (8.53)	10.51 (6.02)	2.92 (2.32)	0.70 (0.35)
Overweight/obese	19.33 (9.75)	11.28 (6.28)	2.85 (2.29)	0.69 (0.34)
Country				
Belgium	19.61 (8.06)	12.09 (5.57)	3.21 (2.33)	0.80 (0.35)
Cyprus	23.87 (11.01)	12.21 (7.17)	3.42 (2.43)	0.66 (0.23)
Estonia	15.61 (6.23)	8.94 (4.75)	2.27 (1.83)	0.78 (0.35)
Germany	19.35 (9.07)	10.50 (5.48)	3.56(2.30)	0.74 (0.33)
Hungary	16.31 (7.13)	10.80 (7.20)	1.96(1.85)	0.54 (0.30)
Italy	17.62 (9.21)	11.33 (6.29)	3.26 (2.51)	0.73 (0.34)
Spain	17.06 (7.29)	9.21 (5.08)	2.72 (2.33)	0.63 (0.35)
Sweden	18.85 (8.65)	8.67 (4.91)	2.59 (2.20)	0.78 (0.36)
Age				
7 years	19.58 (9.66)	11.33 (6.29)	3.26 (2.56)	0.68 (0.35)
8 years	19.52 (9.50)	11.99 (6.90)	2.81 (2.23)	0.68 (0.34)

9 years	17.76 (8.52)	10.01 (5.96)	2.66 (2.13)	0.64 (0.35)
10 years	17.57 (7.34)	9.66 (5.06)	2.87 (2.25)	0.74 (0.34)
11 years	19.34 (9.21)	10.19 (5.72)	2.77 (2.25)	0.77 (0.36)

The results of the unadjusted ordinal logistic regression analysis revealed the following. Odds ratios for the sex comparison - not statistically significant - showed that girls were more sensitive to sweet and salty tastes than boys. (OR (95 % CI): 1.17 (0.99; 1.38) and 1.16 (0.99; 1.36), respectively). Statistically not significant odds ratios for overweight/obese children compared to under-/normal weight children showed that overweight/obese children were less taste sensitive towards sweet and salty (OR (95 % CI): 0.88 (0.73; 1.06) and 0.80 (0.66; 0.96), respectively). Older children were more sensitive for sweet and salty: Per year of age increase, the statistically significant ORs (95 % CI) for a one level higher sensitivity for sweet and salty were 1.12 (1.06; 1.20) and 1.18 (1.11; 1.26), respectively. Older children were less sensitive for umami and bitter: Per year of age increase, the OR (95 % CI) for a one level lower sensitivity for bitter and umami were 0.95 (0.89; 1.01) and 0.90 (0.84; 0.96), respectively. Here the CIs indicated that the difference for bitter was not and for umami was statistically significant. After adjustment the ORs changed slightly (Table 4). Overweight and obese children were more sensitive to bitter than underweight and normal weight children after adjustment.

Table 4: Odds ratios for being more sensitive for sex, age and weight status

	Sweet		Salty		Bitter		Umami	
	OR[1] 95% CI	OR[2] 95% CI	OR[1] 95% CI	OR[2] 95% CI	OR[1] 95% CI	OR[2] 95% CI	OR[1] 95% CI	OR[2] 95% CI
Boys	Reference		Reference		Reference		Reference	
Girls	1.17 0.99;1.38	1.16 0.98;1.36	1.16 0.99;1.36	1.16 0.99;1.37	0.96 0.82;1.26	0.95 0.81;1.11	0.94 0.80;1.11	0.93 0.79;1.09
Under-/normal weight	Reference		Reference		Reference		Reference	
Overweight/obese	0.88 0.73;1.06	0.83 0.69;1.01	0.80 0.66;0.96	0.77 0.64;0.93	1.13 0.94;1.35	1.20 1.01;1.45	1.03 0.86;1.24	1.04 0.86;1.25
Age+1[3]	1.12 1.06;1.20	1.16 1.09;1.23	1.18 1.11;1.26	1.22 1.15;1.30	0.95 0.89;1.01	0.98 0.93;1.05	0.90 0.84;0.96	0.88 0.83;0.94
Age+3[4]	1.43 1.18;1.72	1.55 1.28;1.88	1.66 1.38;1.99	1.83 1.52;2.20	0.85 0.71;1.02	0.95 0.79;1.15	0.73 0.61;0.88	0.68 0.57;0.83

[1]: Unadjusted odds ratios
[2]: Odds ratios from the full model including sex, country, residing in control or intervention region, age and weight status as independent variables
[3]: Odds ratio to have a one level higher taste sensitivity for an increase in age of one year
[4]: Odds ratio to have a one level higher taste sensitivity for an increase in age of three years

Based on standardised taste sensitivity data five taste patterns were derived and the following labels were assigned: “Salty and bitter sensitive” (N=166), “Mild taste insensitive” (N=173), “Taste insensitive” (N=148), “Taste sensitive” (N=679) and “Mild taste sensitive”

(N=360). Table 5 represents the means and standard deviations of the taste threshold z-scores for each taste pattern.

Table 5: Means and standard deviation (SD) of the taste threshold z-scores for each taste pattern

Taste pattern (N[1])	Sweet taste z-score Mean (SD)	Salty taste z-score Mean (SD)	Umami taste z-score Mean (SD)	Bitter taste z-score Mean (SD)
Salty and bitter sensitive (166)	0.30 (0.74)	-0.55 (0.55)	0.84 (0.91)	-0.67 (0.60)
Mild taste insensitive (173)	1.57 (0.89)	0.64 (1.04)	-0.13 (0.58)	0.65 (0.85)
Taste insensitive for all taste modalities (148)	0.46 (1.09)	0.87 (1.04)	1.77 (0.65)	0.95 (0.89)
Taste sensitive for all taste modalities (679)	-0.49 (0.62)	-0.84 (0.27)	-0.58 (0.44)	-0.20 (0.96)
Mild taste sensitive (360)	-0.38 (0.60)	0.75 (0.58)	-0.45 (0.46)	-0.05 (0.89)

[1]: Since children with 'No taste threshold' were excluded the sample size is reduced.

The five clusters included children (1) who were salty and bitter sensitive but not sweet and umami sensitive, (2) who were insensitive for sweet, salty and bitter but mild sensitive for umami, (3) who were insensitive for all taste modalities, (4) who were taste sensitive for all taste modalities and (5) who were rather sensitive for all taste modalities except for the salty taste.

The results of the multinomial logistic regression analysis can be found in Table 6. Older children had a lower chance to belong to the salty and bitter sensitive, mild taste insensitive, taste insensitive or mild taste sensitive pattern compared to the taste sensitive pattern (OR: 0.83-0.94). In relation to under-/ normal weight children, overweight/obese children were more likely to belong to the salty and bitter sensitive, mild taste insensitive, taste insensitive or mild taste sensitive pattern compared to the taste sensitive pattern (OR: 1.34-1.94). Girls had a higher probability than boys to be assigned to the salty and bitter sensitive patterns (OR: 1.38) but were (slightly) less likely to belong to the mild taste insensitive, taste insensitive or mild taste sensitive compared to the taste sensitive pattern (OR: 0.75-0.98).

Table 6: Odds ratios for belonging to the taste patterns for sex, age, and weight status compared to the reference category 'Taste sensitive for all taste modalities[1]

	Salty and bitter sensitive	Mild taste insensitive	Taste insensitive for all modalities	Mild taste sensitive for all modalities
		Odds Ratio[1] (95% - Confidence interval)		
Boys	Reference	Reference	Reference	Reference

Girls	1.38 (0.98; 1.94)	0.75 (0.53; 1.05)	0.98 (0.69; 1.40)	0.85 (0.65; 1.09)
Non-overweight/non-obese	Reference	Reference	Reference	Reference
Overweight/obese	1.34 (0.90; 1.98)	1.94 (1.35; 2.80)	1.40 (0.93; 2.11)	1.76 (1.32; 2.35)
Age	0.88 (0.77; 1.00)	0.94 (0.83; 1.06)	0.83 (0.72; 0.95)	0.93 (0.85; 1.03)

[1]: Odds ratios from the model including sex, age and weight status as independent variables

4. Discussion

4.1 Main results and previous studies

To our knowledge this is the first study that investigated sweet, salty, bitter and umami taste sensitivity in a population-based sample of primary school children from different European countries, following a standardised study protocol. In a previous study of this cohort (Lanfer et al., 2012), we observed that preferences for sweetened over non-sweetened juice were associated with overweight and obesity in both girls and boys. The current study provides complementary data on taste sensitivity for sweet as well as 3 additional taste modalities that were not included in the previous preference test, namely bitter, salty and umami. Our analysis revealed that umami and bitter sensitivity did not differ between boys and girls aged 7 to 11 years. Taste sensitivity for sweet and salty differed; girls may have a slightly higher sweet and salty taste sensitivity than boys. In line with our results, two studies observed higher sweet but not higher salty taste sensitivity in girls compared to boys (Bobowski & Mennella, 2015; Joseph, Reed, & Mennella, 2016). Our results support the recent results, that 11 year old girls have a higher sweet taste sensitivity than boys (Ervina, Berget, & V, 2020), whereas in this population also the bitter sensitivity was higher in girls compared to boys, different than in IDEFICS. An Italian study in contrast did not find any sex differences regarding sweet, bitter, salty and sour taste sensitivity between boys and girls between 5 and 12 years of age (Italian Study Group on taste et al., 2012). Also, in very young children between 3 and 6 years, no sex differences in sweet and bitter sensitivity were found (Visser, Kroeze, Kamps, & Bijleveld, 2000). Another study in adults observed that women were more bitter-sensitive than men (Bartoshuk, Duffy, & Miller, 1994; Hyde & Feller, 1981) while a Mexican study found that women were more sensitive to sweet taste than men (Martinez-Cordero, Malacara-Hernandez, & Martinez-Cordero, 2015). It seems likely that sex differences in taste sensitivity in early childhood are too small to be detectable. However, as taste sensitivity matures until adolescence, it might develop faster in teenage girls than in teenage boys due to the earlier onset of puberty in girls.

Overweight or obese children were less sweet and salty sensitive and more bitter sensitive. Additionally, the cluster analysis revealed that overweight children/children with obesity were more likely to belong to any less taste sensitive pattern (e.g. mild taste insensitive and mild taste sensitive) compared to the taste sensitive pattern than under-/ normal weight. A possible explanation for this finding is that children with lower sweet and salty taste sensitivity might consume more foods high in sugar or salt because they perceive these tastes as less intense and may need more sugar and salt to experience the same sweet and salty sensations. Many sugar- or salt rich foods are considered to be highly processed and energy dense, such as snack foods. Their augmented consumption may thus contribute to the development of overweight and obesity if the physiological status of the child does not demand the supply of increased nutritional energy. Bitter foods in contrast often belong to the more favourable food groups like many vegetables. Therefore, if overweight and obese children are more sensitive to the bitter taste they might avoid these healthy food or tend to consume them combined with sweet/fatty (energy dense foods) to mask the bitter taste. As stated above this is a possible explanation for our results. The association between taste sensitivity, perceived suprathreshold intensity and actual food intake is still not yet fully understood and needs to be investigated in future studies. A better understanding will also help to explain the association between taste sensitivity and weight status. Previous research did not find any differences neither between overweight/obese and normal weight children regarding salty and umami taste sensitivity (Bobowski & Mennella, 2015) nor between sensitivity for the salty taste and body composition (Kirsten & Wagner, 2014). As mentioned before previous studies differed in methods used as well as ages and numbers of children included. This may have led to contradicting results. Until the development of our study (2006), no studies had been detected (based on a literature research) describing associations between sour taste and obesity in children. With respect to the demanding examination protocol for this young age group, sour taste was therefore not included in our investigation. Nevertheless, it would be of interest for future studies to investigate also sour taste. Sauer et al. discovered that obese adolescents had a poorer ability to identify sour taste (Sauer et al., 2017). Further, our results show that taste sensitivity in younger children was lower for sweet and salty than in older children and that older children were less likely to belong to the less taste sensitive taste pattern. In accordance with our findings, Visser et al. found that children between 3 and 6 years of age seem to become more sweet sensitive with age (Visser et al., 2000). A recent study also found that children were less sweet sensitive than adolescence and adolescence in turn less sweet sensitive than adults (Petty, Salame, Mennella, & Pepino, 2020). This may happen because of physiological changes during the development of the taste apparatus and the fact that the innervation of taste papillae is not yet fully developed and functional (Correa, Hutchinson, Laing, & Jinks, 2013). For bitter, it may even be reverse; younger children may be more bitter sensitive than older children. The observed age trend of sweet and bitter sensitivity may be evolutionary meaningful. Sweet sensitivity may be lowered during early childhood to ensure sufficient energy intake, and bitter sensitivity in contrast is possibly elevated to ensure the detection of possible toxins (Drewnowski, 2000; Ventura & Mennella, 2011). Additionally, bitter taste perception may change across the lifespan due to repeated exposure to bitter tasting foods. Thus, the bitter taste sensitivity may not only decrease due to evolutionary reasons but also as a result of learning and adaptation processes. With regards to bitter sensitivity we observed that ¼ of the children indicated to have no threshold. This might appear very high considering that children have an innate aversion towards bitter (Steiner, 1979). This might be due to the concentration range of caffeine that we used in our study. James et al. for example used much higher concentrations of caffeine when testing children than we used (James et al., 1997). Our highest concentration was 0.00139 mol/l vs. 0.01277 mol/l in study of James et al.. The concentration range we used was based on the DIN norm and comparable to other studies (Ervina et al., 2021).

We observed higher sweet taste thresholds (18.7 mmol/l) compared to previous investigations in children (girls: 7.2 mmol/l, boys: 17.0 mmol/l ((James et al., 1997) and girls and boys: 12.0 mmol/l (Joseph et al., 2016)). We also observed higher salty taste thresholds (10.7 mmol/l) compared to previous investigations in children (girls: 2.7 mmol/l, boys: 6.1 mmol/l ((James et al., 1997) and girls and boys: 3.6 mmol/l (Bobowski & Mennella, 2015)). Caffeine thresholds for children reported in previous studies were higher (girls: 1.1 mol/l, boys: 2.0 mol/l (James et al., 1997)) than observed in the present study (girls and boys: 0.70 mmol/l), while those reported for monosodium glutamate were similar to our results (2.4 mmol/l vs. 2.9 mmol/l (Bobowski & Mennella, 2015)). The use of different methodologies in the studies mentioned could have led to the contrasting results. The methods could have led to diverse responses due to their specific cognitive demands. Other studies used Propylthiouracil (PROP) to assess the bitter perception. We used caffeine instead of PROP, as PROP was classified as potentially carcinogenic (National Toxicology Program; Organisation, 2001) and was therefore ethically not safe to use in children.

4.2 Strengths and limitations

There are some limitations to our study that need to be discussed. Compared to previous studies that assessed taste sensitivity in children (Italian Study Group on taste et al., 2012; Joseph et al., 2016; Kirsten & Wagner, 2014; Visser et al., 2000), we used a smaller number of test-solutions per taste modality. Generally, the studies referenced here performed training sessions with participating children before conducting the actual test series, thus children were familiar with the test procedures once data collection for the different taste modalities started. Due to our cross-cultural and large-scale study design we chose a simpler study protocol but assured a standardised procedure across all countries and centres. To minimise measurement errors due to the lack of practice and to limited cognitive abilities of study participants, we measured only detection thresholds instead of identification thresholds for the basic tastes. Furthermore, the order of presentation of all tested taste modalities was fixed and not randomised. This may have led to the positional bias due to the tendency to answer depending on the order of presentation. Umami was tested in the last position because during test development we observed that the umami taste remains on the taste buds for a long time and would thus affect subsequent taste experiments. Again, a further reason was to facilitate the test procedure for all survey centres in order to ensure a standardised test protocol and to minimise the error-proneness. However, in Table 2 it can be seen that the taste sensitivity levels are distributed over the different concentration levels we tested. This implies that there was no general tendency to choose always the first or the last sample in our study population.

Due to the cross-sectional design of our study we cannot draw any conclusions about the temporality of the associations between sweet and salty taste sensitivity and weight status. Therefore, further longitudinal analyses are needed to further explain this association.

Beside these limitations our study has several strengths, one of them being that we were able to investigate taste sensitivity of isolated taste modalities. In real foods, umami taste is often accompanied by salty or fatty tastes in foods that are often energy-dense. Umami is however also characteristic for foods low in energy, e.g. tomatoes. Therefore, the physiological regulation of umami sensitivity might work differently than for salty or fatty as our results indicate. Our method to assess detection thresholds was adapted from the DIN 10959. Our cross-cultural standardised study design resulted in a large sample of children from the general population. Substantial differences in taste sensitivity could be seen between countries. These differences might be culturally determined. National diets may pose a particular exposure to their population and may shape taste sensitivity over the long term. Genetic differences across Europe may also explain part of this phenotypic variability. Previous studies in different countries showed inconsistent results and are not comparable due to different substrates or study designs (Bobowski & Mennella, 2015; Italian Study Group on taste et al., 2012; Joseph et al., 2016; Overberg et al., 2012). Our study was able to show that taste sensitivity indeed varied substantially between children from different countries.

5. Conclusion

This is the first study to compare taste sensitivity in children across different European countries. We conclude that taste sensitivity might be associated with weight status and overweight/obese children are often less taste sensitive to sweet and salt than under- and normal weight children. Further, taste sensitivity might increase due to maturation in children as they get older. We observed large differences in taste sensitivity between children from different countries, which can possibly be explained by cultural and/or genetic influences. Further research is needed to explore the impact of cultural factors on taste perception. Cultural traditions and taboos, food preparation and storage aspects and parenting styles, as well as beliefs may play a role. Also the physiological mechanisms occurring during maturation in childhood that may influence children's taste perception need to be investigated.

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Author's contribution

HJ: Writing - Original Draft, Data Curation, Formal analysis; TI: Formal analysis, Writing - Review & Editing; KB: Conceptualization, Methodology, Writing - Review & Editing; HC: Investigation; FG: Conceptualization, Writing - Review & Editing; SDH: Conceptualization, Investigation, Writing - Review & Editing; FL: Conceptualization, Writing - Review & Editing; DM: Conceptualization, Investigation, Writing - Review & Editing; LAM: Conceptualization, Investigation, Writing - Review & Editing; LL: Conceptualization, Methodology, Investigation, Writing - Review & Editing; VP: Methodology, Writing - Review & Editing; AS: Conceptualization, Project administration, Writing - Review & Editing; TV: Investigation, Writing - Review & Editing; WA: Conceptualization, Methodology, Writing - Review & Editing, Supervision, Project administration, Funding acquisition; AH: Methodology, Investigation, Writing - Review & Editing, Supervision. All authors have approved the final article.

Data Availability

Due to the sensitive nature of data collected, ethical restrictions prohibit the authors from making the minimal data set publicly available. Each cohort centre received approval of the corresponding local Ethical Commission and participants did not provide consent for data sharing. Additionally, all co-authors are members of the IDEFICS consortium who have access to the full dataset that is stored on a secured central data server (CDS) that is hosted by the coordinating centre. Data can only be accessed by registered scientists who are authorised to access the data with an individual account and an individual password. Statistical analyses are done on the CDS. It is strictly forbidden to copy or download any data from the CDS. Data are available on request and all requests need approval by the study's Steering Committee. Interested researchers can contact the IDEFICS consortium (http://www.ideficsstudy.eu) or the study co-ordinator (Ahrens@leibniz-bips.de) to request data access. All requests for accessing data of the IDEFICS/I.Family cohort are discussed on a case-by-case basis by the Steering Committee. For this, interested parties are asked to provide details (e.g. for testing reproducibility of results) on the purpose of their request.

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6. References

Ahrens, W., Bammann, K., Siani, A., Buchecker, K., De Henauw, S., Iacoviello, L., . . . Consortium, I. (2011). The IDEFICS cohort: design, characteristics and participation in the baseline survey. *International Journal of Obesity (2005), 35 Suppl 1*, S3-15. doi:10.1038/ijo.2011.30

Alexy, U., Schaefer, A., Sailer, O., Busch-Stockfisch, M., Reinehr, T., Kunert, J., & Kersting, M. (2010). Sensory preferences and discrimination ability of children before and after an obesity intervention. *Int J Pediatr Obes, 5*(1), 116-119. doi:10.3109/17477160903111755

Anliker, J. A., Bartoshuk, L., Ferris, A. M., & Hooks, L. D. (1991). Children's food preferences and genetic sensitivity to the bitter taste of 6-n-propylthiouracil (PROP). *Am J Clin Nutr, 54*(2), 316-320.

Bartoshuk, L. M., Duffy, V. B., & Miller, I. J. (1994). PTC/PROP tasting: anatomy, psychophysics, and sex effects. *Physiology and Behavior, 56*(6), 1165-1171.

Birch, L. L. (1979). Preschool children's food preferences and consumption patterns. *Journal of Nutrition Education, 11*(4), 189-192. doi:10.1016/S0022-3182(79)80025-4

Birch, L. L. (1998). Psychological influences on the childhood diet. *J Nutr, 128*(2 Suppl), 407S-410S.

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. doi:10.1016/j.jand.2015.02.017

Cole, T. J., & Lobstein, T. (2012). Extended international (IOTF) body mass index cut-offs for thinness, overweight and obesity. *Pediatr Obes, 7*(4), 284-294. doi:10.1111/j.2047-6310.2012.00064.x

Correa, M., Hutchinson, I., Laing, D. G., & Jinks, A. L. (2013). Changes in fungiform papillae density during development in humans. *Chemical Senses, 38*(6), 519-527. doi:10.1093/chemse/bjt022

Drewnowski, A. (2000). Sensory control of energy density at different life stages. *Proc Nutr Soc, 59*(2), 239-244. doi:S0029665100000264 [pii]

Ervina, E., Almli, V. L., Berget, I., Spinelli, S., Sick, J., & Dinnella, C. (2021). Does Responsiveness to Basic Tastes Influence Preadolescents' Food Liking? Investigating Taste Responsiveness Segment on Bitter-Sour-Sweet and Salty-Umami Model Food Samples. *Nutrients, 13*(8). doi:10.3390/nu13082721

Ervina, E., Berget, I., & V, L. A. (2020). Investigating the Relationships between Basic Tastes Sensitivities, Fattiness Sensitivity, and Food Liking in 11-Year-Old Children. *Foods, 9*(9). doi:10.3390/foods9091315

Fernandez-Aranda, F., Aguera, Z., Fernandez-Garcia, J. C., Garrido-Sanchez, L., Alcaide-Torres, J., Tinahones, F. J., . . . Casanueva, F. F. (2016). Smell-taste dysfunctions in extreme weight/eating conditions: analysis of hormonal and psychological interactions. *Endocrine, 51*(2), 256-267. doi:10.1007/s12020-015-0684-9

Glanville, E. V., Kaplan, A. R., & Fischer, R. (1964). Age, Sex, and Taste Sensitivity. *Journal of Gerontology, 19*, 474-478.

Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A K-Means Clustering Algorithm. *Journal of the Royal Statistical Society. Series C (Applied Statistics), 28*(1), 100-108. doi:10.2307/2346830

Hyde, R. J., & Feller, R. P. (1981). Age and sex effects on taste of sucrose, NaCl, citric acid and caffeine. *Neurobiology of Aging, 2*(4), 315-318.

Italian Study Group on taste, d., Majorana, A., Campus, G., Anedda, S., Piana, G., Bossu, M., . . . Polimeni, A. (2012). Development and validation of a taste sensitivity test in a group of healthy children. *European Journal of Paediatric Dentistry, 13*(2), 147-150.

James, C. E., Laing, D. G., & Oram, N. (1997). A comparison of the ability of 8-9-year-old children and adults to detect taste stimuli. *Physiol Behav, 62*(1), 193-197.

Joseph, P. V., Reed, D. R., & Mennella, J. A. (2016). Individual Differences Among Children in Sucrose Detection Thresholds: Relationship With Age, Gender, and Bitter Taste Genotype. *Nurs Res, 65*(1), 3-12. doi:10.1097/NNR.0000000000000138

Kirsten, V. R., & Wagner, M. B. (2014). Salt taste sensitivity thresholds in adolescents: are there any relationships with body composition and blood pressure levels? *Appetite, 81*, 89-92. doi:10.1016/j.appet.2014.06.001

Knof, K., Lanfer, A., Bildstein, M. O., Buchecker, K., Hilz, H., & Consortium, I. (2011). Development of a method to measure sensory perception in children at the European level. *International Journal of Obesity (2005), 35 Suppl 1*, S131-136. doi:10.1038/ijo.2011.45

Landis, J. R., & Koch, G. G. (1977). The Measurement of Observer Agreement for Categorial Data. *Biometrics, 33*(1), 159-174.

Lanfer, A., Knof, K., Barba, G., Veidebaum, T., Papoutsou, S., de Henauw, S., . . . Lissner, L. (2012). Taste preferences in association with dietary habits and weight status in European children: results from the IDEFICS study. *Int J Obes (Lond), 36*(1), 27-34. doi:ijo2011164 [pii]
10.1038/ijo.2011.164

Lo Siou, G., Yasui, Y., Csizmadi, I., McGregor, S. E., & Robson, P. J. (2011). Exploring statistical approaches to diminish subjectivity of cluster analysis to derive dietary patterns: The Tomorrow Project. *Am J Epidemiol, 173*(8), 956-967. doi:10.1093/aje/kwq458

Martinez-Cordero, E., Malacara-Hernandez, J. M., & Martinez-Cordero, C. (2015). Taste perception in normal and overweight Mexican adults. *Appetite, 89*, 192-195. doi:10.1016/j.appet.2015.02.015

National Toxicology Program, (2016). Report on Carcinogens, Fiftteenth Edition
Propylthiouracil. Retrieved from https://ntp.niehs.nih.gov/ntp/roc/content/profiles/propylthiouracil.pdf

World Health Organisation, (2001). PROPYLTHIOURACIL. Retrieved from http://monographs.iarc.fr/ENG/Monographs/vol79/mono79-8.pdf

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. doi:10.1136/archdischild-2011-301189

Pasquet, P., Frelut, M. L., Simmen, B., Hladik, C. M., & Monneuse, M. O. (2007). Taste perception in massively obese and in non-obese adolescents. *International Journal of Pediatric Obesity, 2*(4), 242-248. doi:10.1080/17477160701440521

Petty, S., Salame, C., Mennella, J. A., & Pepino, M. Y. (2020). Relationship between Sucrose Taste Detection Thresholds and Preferences in Children, Adolescents, and Adults. *Nutrients, 12*(7). doi:10.3390/nu12071918

Plattig, K. H. (1984). The sense of taste. In J. R. Piggot (Ed.), *Sensory analysis of foods* (pp. 1-22). New York: Elsevier Science Publishing Company.

Sauer, H., Ohla, K., Dammann, D., Teufel, M., Zipfel, S., Enck, P., & Mack, I. (2017). Changes in Gustatory Function and Taste Preference Following Weight Loss. *J Pediatr, 182*, 120-126. doi:10.1016/j.jpeds.2016.11.055

Steiner, J. E. (1979). Human facial expressions in response to taste and smell stimulation. *Adv Child Dev Behav, 13*, 257-295. doi:10.1016/s0065-2407(08)60349-3

Suling, M., Hebestreit, A., Peplies, J., Bammann, K., Nappo, A., Eiben, G., . . . Consortium, I. (2011). Design and results of the pretest of the IDEFICS study. *Int J Obes (Lond), 35 Suppl 1*, S30-44. doi:10.1038/ijo.2011.33

Vennerod, 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. doi:10.1016/j.appet.2018.04.027

Ventura, A. K., & Mennella, J. A. (2011). Innate and learned preferences for sweet taste during childhood. *Curr Opin Clin Nutr Metab Care, 14*(4), 379-384. doi:10.1097/MCO.0b013e328346df65

Visser, J., Kroeze, J. H., Kamps, W. A., & Bijleveld, C. M. (2000). Testing taste sensitivity and aversion in very young children: development of a procedure. *Appetite, 34*(2), 169-176. doi:10.1006/appe.1999.0306

Watson, R. (2008). EU parliament backs 30 minutes' exercise a day for all children to tackle obesity. *BMJ, 337*, a1892.

Whissell-Buechy, D. (1990). Effects of age and sex on taste sensitivity to phenylthiocarbamide (PTC) in the Berkeley Guidance sample. *Chemical Senses, 15*(1), 39-57.