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ORIGINAL ARTICLE

Factors explaining individual differences in taste sensitivity and taste modality recognition among Finnish adults

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Abstract

The objective of this study was to investigate the factors affecting interindividual variation in the sense of taste among Finnish adults. Two components of taste function were examined with five established taste modalities: taste sensitivity and capability to identify taste modalities. The potential explanatory factors for taste function included gender, age, BMI, and smoking. In total, 205 volunteers participated in the study at the sensory evaluation laboratory of Functional Foods Forum. Older age (>50 years) and male gender predicted a less sensitive sense of taste in general. For umami sensitivity, high BMI along with older age predicted lower sensitivity. Additionally, taste recognition and sensitivity were related in bitter and umami tastes. Older age was also associated with a poorer capability in taste recognition. Sour–bitter, umami–salty, and salty–umami were the most frequent taste confusions.

Practical applications

These results showed individual differences in taste perception among adult. This study can help to understand diversity in personal eating practices and food choices, which can be utilized in personal nutritional guidance and well-being applications. We suggest that umami should be included in studies concerning taste function. There is high variation in umami perception and as umami may increase food palatability, it can be an important element in improving diet especially among elderly people. In sensory research, panelists' interindividual variation in taste perception can be wide and should be acknowledged by careful design of studies.

1 | INTRODUCTION

Eating is an essential part of an individual's well-being and daily-life practices. The more palatable a food is, the more likely it will be eaten. Thus, food quality perceived with our senses is an essential factor contributing to our nutrition and health. Therefore, it is important to investigate what type of sensory worlds individuals live in.

Humans perceive at least five taste modalities according to current knowledge: sweet, salty, sour, bitter, and umami. In the oral cavity, taste stimuli are detected by taste receptor cells organized in taste buds of gustatory papillae. When the receptor cells interact with taste molecules, signals are transmitted to the brain via cranial nerves (Bachmanov & Beauchamp, 2007). Interindividual variations in taste perception may be due to physiological differences in the gustatory system, cognitive processing of taste signals in the brain, genetics, or environmental influence. The most variation seemingly occurs in bitter and umami perception (Knaapila et al., 2012; Lugaz, Pillias, & Faurion, 2002; Puputti, Aisala, Hoppu, & Sandell, 2018). Additionally, among the general population, accuracy in recognizing taste qualities as sweet, salty, sour, bitter, and umami may vary (Doty, Chen, & Overend, 2017; Hettinger, Gent, Marks, & Frank, 1999).

The intrinsic factors that possibly affect the sense of taste, include gender, age, genetics, and ethnicity (Dias et al., 2013; Doets & Kremer, 2015; Fischer et al., 2013; Martin & Sollars, 2017; Methven et al., 2012; Williams, Bartoshuk, Fillingim, & Dotson, 2016). The extrinsic factors possibly affecting taste function comprise health and health-behavior-related factors, such as smoking, weight, diseases, and medication (Doets & Kremer, 2015; Doty, Shah, & Bromley, 2008; Fischer et al., 2013; Hardikar, Hoechenberger, Villringer, & Ohla, 2017; Pepino, Finkbeiner, Beauchamp, & Mennella, 2010). In contrast, there are also studies showing no associations between these factors and taste function (Fischer et al., 2013; Konstantinidis, Chatziavramidis, Printza, Metaxas, & Constantinidis, 2010; Methven et al., 2012; Mojet, Heidema, & Christ-Hazelhof, 2003; Pepino et al., 2010). Thus, more studies that encompass all taste modalities are needed to better understand the factors affecting interindividual variations in taste perception. The additional knowledge gained from such studies could increase the success of efforts to provide personal nutritional guidance and prevent food-intake-related diseases, such as obesity or cardiovascular diseases. Gaining deeper knowledge of the variation in our sensory experiences could help us with interpreting individual experiences.

This study is part of a more extensive research project concerning individual differences in sensory perception and eating behavior. Previously, we reported the extent of interindividual variations in taste sensitivity measured using the intensity judgments of a series of taste solutions (Puputti et al., 2018). Hierarchical clustering of the intensity judgments revealed hypo-, semi-, and hypersensitive tasters in the study population. Hence, the objective here was to further investigate with the same study participants if the variation in taste sensitivity can be explained by personal characteristics and by the capability to identify taste modalities. Additionally, more insight into an individual's capability to recognize taste modalities and the subject characteristics affecting taste recognition was obtained. Gender and age were the included intrinsic factors, whereas BMI and smoking were chosen as the extrinsic factors describing health behavior.

2 | MATERIALS AND METHODS

2.1 | Participants

The participants were recruited by announcements at the University of Turku and public events. In total, 206 Finnish volunteers (19–79 years old) participated in the study. The exclusion criteria included pregnancy and being in a lactating state. Additionally, one person was excluded afterward because of self-reported ageusia after a head trauma. Moreover, all communication was in Finnish, leading to the exclusion of some potential participants. Otherwise, all volunteers were selected for inclusion in the study without prerequisites for a balanced sample regarding any variable, such as an even distribution of gender. After being given a full account of the research aims, written informed consent was obtained from the subjects. They were rewarded with food products after every visit. The study was approved by the Southwest Finland Hospital District's Ethics Committee (145/1801/2014), and it was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments.

2.2 | Sensory evaluation procedure

The taste modalities included sour, bitter, sweet, salty, and umami. Each taste quality was represented by one prototypic tastant, as described in Table 1. Five concentration levels (A = the strongest, E = the mildest; concentration increased by factor 1.78) of each tastant were prepared by dilution in active-carbon filtered water following good laboratory practices. The sample solutions were stored under refrigeration less than 4 days and monosodium salt of L-glutamic acid (MSG) less than 2 days before use. The samples were allowed to settle at room temperature before serving them in two blocks of 14 samples during one session (28 samples in total). The first block included the mildest concentration levels and two blanks (active-carbon filtered water), and the second block included the strongest concentration levels and one blank. The sample presentation order was randomized inside the blocks. This presentation design was planned to prevent the effect of positional bias and excessive fatigue. The samples were evaluated once.

The concentration levels in Table 1 were chosen based on the ASTM International standard (ASTM, 1981) for measuring taste intensity and on previous experience in the sensory evaluation laboratory of Functional Foods Forum. For this reason, the strongest concentration was expected to be readily perceivable for the majority with normal taste function. Additionally, stronger concentration levels could have caused a severe ceiling effect with the line scales that were used for taste intensity judgments.

The study participants were instructed not to wear intensely scented cosmetics and fragrances during the test day. Furthermore,

TABLE 1 Taste samples

Taste	Prototypic tastant	Sample A (mM)	Sample B (mM)	Sample C (mM)	Sample D (mM)	Sample E (mM)
Sour	Citric acid[a]	3.33	1.87	1.05	0.57	0.33
Bitter	Caffeine[a]	3.60	2.03	1.14	0.62	0.36
Sweet	Sucrose[b]	58.4	32.9	18.5	10.5	5.84
Salty	Sodium chloride (NaCl)[a]	34.2	19.2	10.8	5.99	3.42
Umami	L-glutamic acid, monosodium salt (MSG)[a]	10.7	6.01	3.38	1.87	1.07

[a]Produced by Sigma-Aldrich, St. Louis, MO.
[b]Produced by Alfa Aesar GmbH&Co KG, Karlsruhe, Germany.

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eating, drinking other than water, chewing gum, and smoking were forbidden 1 hr before the test. The subjects were given thorough verbal and written instructions on how to evaluate the samples. Additionally, the subjects tasted the strongest dilution of each tastant to become familiar with the taste qualities and the tasting procedure.

Five milliliters of sample was served in a glass beaker marked with a random three-digit code. The subjects were instructed to sip the sample, spin it around their mouth and tongue for 5 s, and spit it out. Between the samples, the subjects were advised to rinse their mouths with active-carbon filtered water. Furthermore, a cream cracker was provided for additional mouth neutralization.

First, the intensity of a sample was rated on a continuous line scale (from 0 to 10). The scale was anchored both numerically and verbally as follows: 0 = "no sensation," 2 = "very mild," 4 = "quite mild," 6 = "quite strong," 8 = "very strong," and 10 = "extremely strong." Moreover, the subjects were instructed to rate the intensity above zero if they perceived something else than pure water. In addition, a five on the scale should have been a clear taste sensation. The subjects were asked to make a mark on the line scale at any point they preferred. These intensity judgments were used to determine taste sensitivity as described in Section 2.3. Second, the subjects were asked about the recognition of the taste quality with a forced choice question. The response options were "sweet," "salty," "sour," "bitter," "umami," "water," and, "something else." The application of these results is described in Section 2.4.

The sensory tests were performed in the sensory evaluation laboratory of Functional Foods Forum (ISO8589), the University of Turku. The responses were collected with Compusense *five* plus software (Compusense, Inc., Guelph, Canada).

2.3 | Taste sensitivity: Modality-specific and general

The taste sensitivities of the subjects were determined previously in Puputti et al. (2018). The standardized intensity ratings (rescaled to population mean zero and standard deviation one) were analyzed with hierarchical clustering leading to data-driven segmentation. A three-cluster segmentation was retained for each taste modality (Table 2). For each taste modality, the least sensitive cluster was marked with 1 (e.g., SW1 for sweet cluster 1) and called hyposensitive tasters, the middle cluster was marked with 2 (e.g., SW2) and called semisensitive tasters, and the most sensitive cluster was marked with 3 (e.g., SW3) and called hypersensitive tasters.

In addition to the taste modality-specific sensitivity, general taste sensitivity was analyzed with the taste sensitivity score (Puputti et al., 2018). The score was determined as the mean of the taste modality-specific sensitivity cluster memberships (score range 1.0–3.0). Thus, the closer the score was to three, the more sensitive the individual.

2.4 | Taste recognition: Modality-specific and general

Because there were five concentration levels for each taste modality, a subject could correctly recognize (e.g., a sucrose solution as sweet) zero to five samples within a taste modality. Only the subjects, who had evaluated all five samples per taste modality were included in the analyses of the recognition results.

In addition to the modality-specific recognition, the general capability to recognize taste modalities was analyzed with a taste recognition score. The score was determined by taking the average of the total correct recognitions of all taste qualities. Thus, the theoretical score range was from 0.0 (all samples incorrectly identified) to 5.0 (all samples correctly identified). Only the subjects who had evaluated all samples were analyzed (n = 199).

TABLE 2 Subject characteristics (n = 205)

Variable	*n*	%	Data missing (*n*)
Age	205		0
19–34 years	88	42.9	
35–49 years	59	28.8	
50–79 years	58	28.3	
Gender	205		0
Female	164	80.0	
Male	41	20.0	
BMI	198		7
<25.0	111	56.1	
25.0–29.9	51	24.9	
≥30.0	36	17.6	
Smoking	198		7
Currently/formerly	51	25.8	
Nonsmoker	147	74.2	
Sour sensitivity	202		3
SO1	51	25.2	
SO2	102	50.5	
SO3	49	24.3	
Bitter sensitivity	201		4
BI1	35	17.4	
BI2	87	43.3	
BI3	79	39.3	
Sweet sensitivity	204		1
SW1	83	40.7	
SW2	80	39.2	
SW3	41	20.1	
Salty sensitivity	203		2
SA1	116	57.1	
SA2	51	25.1	
SA3	36	17.7	
Umami sensitivity	203		2
UM1	30	14.8	
UM2	135	66.5	
UM3	38	18.7	

Taste sensitivity groups: 1 = the least sensitive, 2 = the semisensitive, 3 = the most sensitive.

2.5 | Predictors

Webropol online questionnaires (Webropol, Inc., Helsinki, Finland) were used for the data collection of subject characteristics and health behavior. Gender was changed to a dummy variable: 0 = male and 1 = female. Age was divided into three categories: the youngest 19–34 years old (*M* [*SD*] = 27.8 [4.1] years), the middle-aged 35–49 years old (*M* [*SD*] = 42.5 [4.3] years), and the oldest 50–79 years old (*M* [*SD*] = 61.8 [8.5] years). BMI was calculated from self-reported height and weight according to the formula $kg/(m)^2$. The participants were divided into three categories based on BMI: the lean individuals BMI <25.0 (*M* [*SD*] = 21.8 [2.0]) including three underweight persons (BMI <18.5), the overweight individuals BMI = 25.0–29.9 (*M* [SD] = 27.2 [1.4]), and the obese individuals BMI ≥30.0 (*M* [SD] = 34.9 [4.6]). Smoking habit was determined with the response options "yes, daily," "yes, occasionally," "not now but used to," and "no." For the analyses, the first three alternatives were combined into current/former smokers because of the low number of subjects in those categories. Six females (3.8% of females) and no males smoked every day, while seven females (4.4% of females) and four males (10.3% of males) smoked occasionally. One-third of males (*n* = 13) and 13.2% (*n* = 21) of females were former smokers. The group sizes are in Table 2.

2.6 | Statistics

Chi-squared test or Fisher's exact test was applied to analyze the associations between the categorical variables. The taste modality-specific sensitivity was predicted with multinomial logistic regression. The model included gender, age, BMI, smoking, and correct recognitions as the explanatory factors. *T*-test and ANOVA with Tukey as a post-hoc test were applied to explore the effects of the predictor variables (gender, age group, BMI group, and smoking status) on the taste sensitivity score and the taste recognition score. At first, two-way ANOVA was applied with all possible interactions and main effects. Because none of the two-way interactions was statistically significant, they were excluded, leaving only the main effects. The criterion for significance was set to be $p < .05$. All statistical analyses were computed with IBM SPSS Statistics 23.0 (IBM Corporation, Armonk, NY).

Some of the participants did not complete every section of the study because of time constraints, technical issues, or self-reported hypersensitivity to caffeine. Missing data were dealt with in each analysis rather than entirely excluding the subjects with missing data. The number of subjects with missing data was small, ranging from zero (gender) to seven (BMI and smoking status). The subject numbers included in the analyses are provided in tables and figures.

3 | RESULTS

3.1 | Subject characteristics

The subject characteristics are described in Table 2. Gender and smoking were associated (χ^2 [1] = 8.1, $p = .004$), as fewer females than males had a history of smoking. The clear majority of females, 78.6%, reported being nonsmokers, whereas 56.4% of males had no history of smoking. Additionally, BMI was associated with smoking (χ^2 [2] = 13.9, $p = .001$). The lean individuals were predominantly nonsmokers (81.1% of the lean individuals) as were the overweight individuals (76.5% of them), whereas half of the obese participants were current or former smokers.

Furthermore, age and BMI were associated (χ^2 [4] = 24.2, $p < .001$). The majority (75.3%) of the youngest individuals whereas under half of the middle-aged or the oldest individuals were lean. Otherwise, the background variables were not associated.

3.2 | Taste recognitions

The distributions of responses for the taste modality recognition are shown in Figure 1. As expected, the correct recognition rate increased with concentration. The majority recognized the taste of three or four strongest dilutions correctly in each taste quality. For the mildest dilutions of citric acid, sourness was confused with bitterness. Moreover, bitter was also the most frequently chosen incorrect response for the other citric acid samples, though the frequency was under the chance level (the odds of guessing any response option was 1/7 = 0.1429).

Although the sour taste of citric acid was confused with bitter taste, the caffeine bitterness was seldom confused with sourness. The most frequent incorrect response was water, which was chosen above the chance level for the three most dilute samples. Additionally, if sucrose dilutions were not recognized as sweet, they were perceived as water.

The salty taste of NaCl was confused with umami in the three most dilute samples, and additionally, the most dilute sample was perceived as water by 35.3% of the participants. In addition to salty–umami confusion, umami–salty confusion also appeared. Salty was selected frequently for the three strongest samples of MSG. The majority perceived the most dilute sample as umami or water. Furthermore, bitter was selected by 14.4% of the subjects.

Associations between the correct recognitions and subject characteristics are presented in Table 3. Gender was associated with sour taste recognition (t [200] = –2.2, $p = .032$) with females identifying sour taste better. Age was related to taste recognition in every taste modality ($F_{sour}(2, 199) = 6.1$, $p = .003$; $F_{bitter}[2, 199] = 9.7$, $p < .001$; $F_{sweet}[2, 200] = 3.6$, $p = .030$; $F_{salty}[2, 200] = 4.0$, $p = .020$; $F_{umami}[2, 199] = 8.5$, $p < .001$). In general, the oldest participants made fewer correct recognitions. However, for the sweet taste, the only difference was that the middle-aged participants correctly recognized more samples than the youngest participants. Umami recognition was also associated with BMI (F [2, 192] = 3.8, $p < .025$); the lean participants correctly recognized more samples than the overweight participants. The other subject characteristics were not significantly associated with modality-specific recognition.

Figure 2 illustrates the taste recognition score distribution. The mean score was 3.09 (*SD* 0.70), and the score range was 1.2–4.8. Thus, the average number of correct recognitions was 15, the minimum six, and the maximum 24 of 25 samples. Gender, BMI group, and

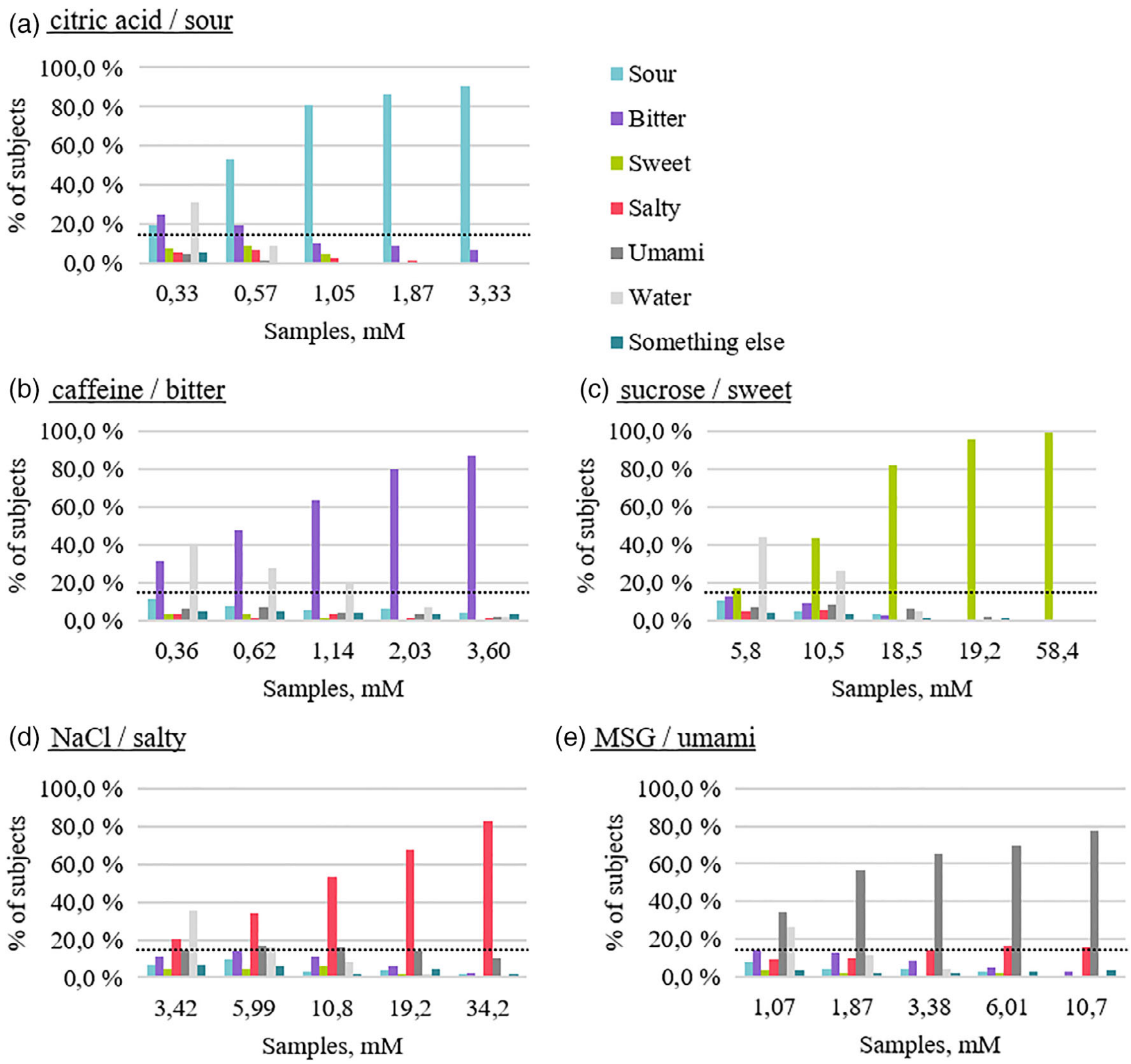

FIGURE 1 Distributions of taste recognitions for all samples: (a) sour citric acid (n = 203–204), (b) bitter caffeine (n = 202), (c) sweet sucrose (n = 203–204), (d) salty NaCl (n = 203–204), and (e) umami monosodium salt of L-glutamic acid (MSG; n = 202–204). The dotted line is the chance level (14.3%) for guessing correctly

smoking status were not related to the taste recognition score (ANOVA). Instead, age was significantly associated with the taste recognition score (F [2, 185] = 13.2, p < .001). Tukey's test indicated that both the youngest (M [SD] = 3.25 [0.66]) and the middle-aged (M [SD] = 3.22 [0.65]) participants had higher scores than the oldest participants (M [SD] = 2.67 [0.64]).

3.3 | Predicting taste sensitivity

3.3.1 | Subject characteristics within sensitivity groups

The subject characteristics divided into the sensitivity clusters are presented as Supporting Information in the online version of the article. Gender and age were unequally distributed between the sour clusters (χ^2 [2] = 10.1, p = .006; χ^2 [4] = 9.9, p = .042, respectively). Proportionally more males were in the hyposensitive cluster (40.0%) than in the hypersensitive cluster (7.5%) while females were more equally divided between these clusters (21.6 and 28.4% of females, respectively). Similar to the sour clusters, the age groups were unequally distributed between the bitter, salty, and umami sensitivity clusters (χ^2 [4] = 28.4, p < .001; χ^2 [4] = 9.80, p = .044; χ^2 [4] = 22.4, p < .001, respectively) as the youngest group was more sensitive than the oldest group. The BMI groups were also unequally distributed for the umami clusters (χ^2 [4] = 17.2, p = .002); proportionally fewer lean people and more obese people belonged to the least sensitive cluster than to the hypersensitive cluster. Otherwise, there were no associations.

3.3.2 | Predicting taste-specific sensitivity with logistic regression

A logistic regression model adjusted with age, gender, BMI, smoking status, and correct taste recognition rate was applied to predict taste sensitivity. An odds ratio indicates a relative risk ratio between the comparison group and the reference group of the predictor variable

TABLE 3 Associations between correct taste recognition and subject characteristics

	Sour		Bitter		Sweet		Salty		Umami	
	Mean (*SD*)	*n* (%)	Mean (*SD*)	*n* (%)	Mean (*SD*)	*n* (%)	Mean (*SD*)	*n* (%)	Mean (*SD*)	*n* (%)
Gender										
Female	**3.40 (1.02)**	162 (80.2)	3.08 (1.37)	162 (80.2)	3.33 (0.90)	162 (79.8)	2.64 (1.19)	162 (79.8)	3.09 (1.39)	161 (79.7)
Male	**3.00 (1.18)**	40 (19.8)	3.15 (1.39)	40 (19.8)	3.59 (0.89)	41 (20.2)	2.39 (1.07)	41 (20.2)	2.85 (1.37)	41 (20.3)
Data missing		3		3		2		2		3
Age										
19–34 years	**3.47a (0.91)**	88 (43.6)	**3.44a (1.34)**	88 (43.6)	**3.23b (0.88)**	88 (43.3)	**2.78a (1.09)**	88 (43.3)	**3.34a (1.27)**	88 (43.3)
35–49 years	**3.50a (1.00)**	58 (28.7)	**3.17a (1.18)**	59 (29.2)	**3.63a (0.91)**	59 (29.1)	**2.63ab (1.14)**	59 (29.1)	**3.19a (1.36)**	59 (29.1)
50–79 years	**2.91b (1.24)**	56 (27.7)	**2.45b (1.41)**	55 (27.2)	**3.38ab (0.89)**	56 (27.6)	**2.23b (1.25)**	56 (27.6)	**2.42b (1.42)**	56 (27.6)
Data missing		3		3		2		2		2
BMI										
<25.0	3.39 (0.94)	109 (55.9)	3.26 (1.35)	108 (55.4)	3.40 (0.87)	109 (55.6)	2.63 (1.21)	109 (55.6)	**3.31a (1.35)**	108 (55.4)
25.0–29.9	3.08 (1.21)	51 (26.2)	2.92 (1.52)	51 (26.2)	3.35 (0.77)	51 (26.0)	2.61 (1.15)	51 (26.0)	**2.71b (1.38)**	51 (26.2)
≥30.0	3.49 (1.12)	35 (17.9)	2.94 (1.26)	36 (18.5)	3.39 (1.15)	36 (18.4)	2.50 (1.13)	36 (18.4)	**2.86 ab (1.46)**	36 (18.5)
Data missing		10		10		9		9		10
Smoking										
Nonsmoker	3.35 (1.05)	146 (74.9)	3.05 (1.40)	145 (74.4)	3.34 (0.80)	146 (74.5)	2.63 (1.19)	146 (74.5)	3.04 (1.39)	145 (74.4)
Currently/ formerly	3.27 (1.09)	49 (25.1)	3.30 (1.33)	50 (25.6)	3.54 (1.15)	50 (25.5)	2.52 (1.16)	50 (25.5)	3.14 (1.41)	50 (25.6)
Data missing		10		10		9		9		10
All subjects	3.32 (1.06)	203	3.09 (1.37)	202	3.38 (0.90)	203	2.59 (1.17)	203	3.04 (1.39)	202

Notes: Variables with statistically significantly different means between variable groups are bolded. *T*-test or ANOVA for comparing group means; different letters after the mean value indicate statistically significant differences according to Tukey's test.

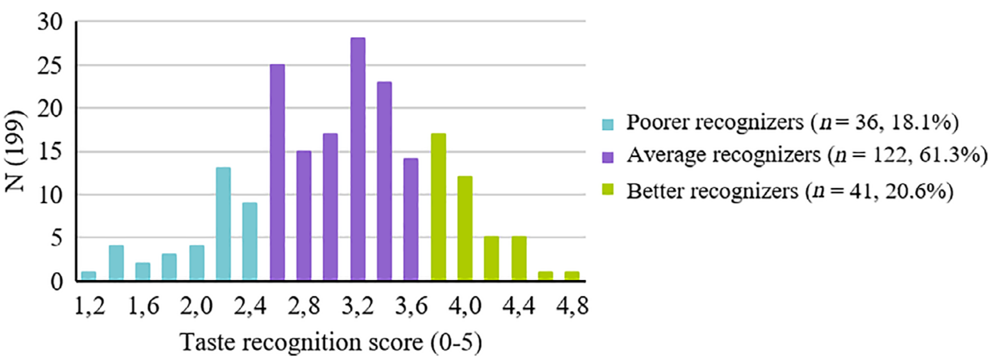

FIGURE 2 Taste recognition score distribution

to fall in the comparison group rather than in the reference group of the dependent variable when adjusted with the other factors in the regression model.

The model fitted well for each taste modality with Goodness-of-Fit test statistics above the significance level. The models significantly explained taste sensitivity except for the sweet and salty tastes (−2-log-likelihood = 220.9, χ^2 [14] = 22.5, $p = .069$, and −2-log-likelihood = 220.8, χ^2 [14] = 21.7, $p = .085$, respectively). However, there was a trend for saltiness such that the oldest subjects were more likely than the youngest or the middle-aged subjects to be hyposensitive and not semisensitive.

Gender was the only significant predictor of sour sensitivity when adjusted for the other factors (Table 4). Females were more likely to be hypersensitive. The main effect of age group was insignificant, but there was a trend such that the oldest rather than the youngest participants were more likely hyposensitive than semi or hypersensitive.

Age and correct bitter taste recognition had significant main effects on bitter sensitivity (Table 5). When compared to the oldest subjects, the youngest subjects were 3.45 (1/OR in Table 5) times more likely to be hypersensitive than semisensitive. A higher recognition rate predicted more sensitivity. For example, a one unit increase in correct recognition increased the odds of being hypersensitive rather than hyposensitive by a factor of 4.17 (1/OR in Table 5).

Age, BMI, and umami recognition had significant main effects on umami sensitivity (Table 6). The oldest rather than the youngest participants were 8.33 times more likely to be hyposensitive than hypersensitive and 5.56 times more likely to be hyposensitive than semisensitive. Considering BMI, the obese subjects were more likely

TABLE 4 Results of a multinomial logistic regression predicting sour sensitivity with subject characteristics and sour recognition

Sour (n = 195)	SO1, ref. SO3 OR (95 % CL)	SO2, ref. SO3 OR (95 % CL)	SO1, ref. SO2 OR (95 % CL)	Model fit statistics
Male[a]	6.09* (1.52–24.44)	4.28* (1.16–15.84)	1.42 (0.61–3.31)	−2-log-likelihood
Age[b]				241.5, χ^2 (14) = 24.6, p = .039
18–34	0.29* (0.09–0.92)	0.83 (0.30–2.26)	0.35* (0.14–0.88)	Nagelkerke pseudo-R^2
35–49	0.37 (0.12–1.18)	0.55 (0.19–1.60)	0.68 (0.28–1.67)	0.135
BMI[c]				Goodness-of-fit
<25.0	0.42 (0.12–1.53)	0.42 (0.14–1.26)	1.01 (0.37–2.77)	ns
25.0–29.9	0.84 (0.21–3.40)	0.61 (0.17–2.15)	1.38 (0.48–3.93)	
Nonsmoker[d]	1.41 (0.49–4.07)	1.24 (0.50–3.03)	1.14 (0.48–2.69)	
Sour taste recognition	0.87 (0.56–1.34)	0.86 (0.59–1.27)	1.01 (0.72–1.41)	

Notes: Odds ratios (95% confidence levels) for all pairs of sensitivity groups and model fit statistics are displayed. Variables having a significant main effect in the model are bolded. SO1 was the least sensitive, SO2 the semisensitive, and SO3 the most sensitive cluster.
[a]Reference category female.
[b]Reference category 55–79 years old.
[c]Reference category ≥30.0.
[d]Reference category current or former smoker.
*p < .05.

TABLE 5 Results of a multinomial logistic regression predicting bitter sensitivity with subject characteristics

Bitter (n = 194)	BI1, ref. BI3 OR (95 % CL)	BI2, ref. BI3 OR (95 % CL)	BI1, ref. BI2 OR (95 % CL)	Model fit statistics
Male[a]	2.83 (0.78–10.31)	1.01 (0.40–2.52)	2.80 (0.87–9.07)	−2-log-likelihood
Age[b]			Goodness-of-fit	198.8, χ^2 (14) = 85.5, p < .001
18–34	0.30 (0.08–1.13)	0.29** (0.11–0.72)	1.07 (0.32–3.53)	Nagelkerke pseudo-R^2 0.409
35–49	0.58 (0.15–2.30)	0.94 (0.37–2.43)	0.62 (0.19–2.06)	
BMI[c]				
<25.0	0.43 (0.10–1.85)	0.68 (0.26–1.80)	0.64 (0.17–2.36)	ns
25.0–29.9	0.66 (0.14–3.16)	0.62 (0.21–1.87)	1.06 (0.27–4.20)	
Nonsmoker[d]	1.99 (0.50–7.85)	0.91 (0.40–2.05)	2.19 (0.61–7.81)	
Bitter taste recognition	0.24*** (0.15–0.39)	0.69* (0.51–0.93)	0.35*** (0.23–0.54)	

Notes: Odds ratios (95% confidence levels) for all pairs of sensitivity groups and model fit statistics are displayed. Variables having a significant main effect in the model are bolded. BI1 was the least sensitive, BI2 the semisensitive, and BI3 the most sensitive cluster.
[a]Reference category female.
[b]Reference category 55–79 years old.
[c]Reference category ≥30.0.
[d]Reference category current or former smoker.
*p < .05. **p < .01. ***p < .001.

to be less sensitive than the lean subjects. Additionally, when compared to the overweight participants, the obese participants were more likely to be hyposensitive than hypersensitive. As the correct recognition rate increased, the probability of being more sensitive increased. For example, as the recognition rate increased by one unit, a participant was 2 times (1/OR in Table 6) more likely to be hypersensitive than hyposensitive.

3.3.3 | Predicting general taste sensitivity

Two-way ANOVA was applied to investigate the effects of gender, age group, BMI group, smoking status, and the taste recognition score on the taste sensitivity score but none of the two-way interactions was significant. Of the main effects, gender (F [1, 183] = 6.77, p = .010) and age (F [2, 183] = 4.93, p = .008) were significant. Males had on average level 0.236 units lower sensitivity score than females. Additionally, the youngest had 0.335 units and the middle-aged participants 0.265 units higher score than the oldest participants.

4 | DISCUSSION

The factors affecting taste sensitivity were investigated in this study. Age was the main predictor of taste sensitivity and recognition. The

TABLE 6 Results of a multinomial logistic regression predicting umami sensitivity with subject characteristics

Umami (*n* = 194)		UM1, ref. UM3 OR (95 % CL)	UM2, ref. UM3 OR (95 % CL)	UM1, ref. UM2 OR (95 % CL)	Model fit statistics
Male[a]		3.79 (0.83–17.30)	2.29 (0.69–7.59)	1.66 (0.58–4.75)	−2-log-likelihood
Age[b]					191.5, χ^2 (14) = 51.6, p < .001
	18–34	0.12** (0.02–0.58)	0.64 (0.21–2.00)	0.18** (0.05–0.65)	Nagelkerke pseudo-R^2
	35–49	0.25 (0.05–1.16)	0.69 (0.20–2.37)	0.36 (0.12–1.06)	0.284
BMI[c]					Goodness-of-fit
	<25.0	0.028** (0.003–0.289)	0.10* (0.01–0.80)	0.28* (0.09–0.93)	ns
	25.0–29.9	0.059* (0.005–0.665)	0.15 (0.02–1.38)	0.39 (0.12–1.27)	
Nonsmoker[d]		1.96 (0.47–8.15)	1.13 (0.42–3.00)	1.74 (0.57–5.32)	
Umami taste recognition		0.50** (0.32 –0.77)	0.72* (0.53–1.00)	0.69* (0.49–0.96)	

Notes: Odds ratios (95% confidence levels) for all pairs of sensitivity groups and model fit statistics are displayed. Variables having a significant main effect in the model are bolded. UM1 was the least sensitive, UM2 the semisensitive, and UM3 the most sensitive cluster.
[a]Reference category female.
[b]Reference category 55–79 years old.
[c]Reference category ≥30.0.
[d]Reference category current or former smoker.
*p < .05. **p < .01.

older subjects were more likely to perceive the taste samples milder and to correctly recognize fewer samples than the younger subjects. This phenomenon was observed for the taste sensitivity score, the taste recognition score, and all taste modalities except for the sweet taste. This result supports earlier findings conducted with water solutions of the same compounds in supra-threshold intensities (Methven et al., 2012; Mojet et al., 2003; Simchen, Koebnick, Hoyer, Issanchou, & Zunft, 2006) and findings considering detection and recognition thresholds (Methven et al., 2012). Interestingly, Methven et al. (2012) noted that results for NaCl, citric acid, and caffeine intensity rating in relation to age have been fairly consistent, whereas results for sucrose have been variable. Mojet et al. (2003) found an age-effect for sucrose as well as for the other taste qualities regardless of the prototypic compound within a taste quality. In contrast to this study by Mojet et al. (2003), we used lower concentrations of taste solutions except for caffeine.

In many studies on the age-effect on taste sensitivity, the elderly group was older than that in this study (Methven et al., 2012; Mojet et al., 2003; Simchen et al., 2006). Although deterioration is a continuous process, the age-effect seems more evident after turning 60 years old (Methven et al., 2012). Hence, the age effect could have been even more obvious in this study if a higher cut-off point for the oldest group was used. However, this shift would have made the group too small for further statistical analysis.

Contrary to many studies, Fischer et al. (2013) found no age effect when age was adjusted with multiple factors that possibly affect taste sensitivity. However, they presented the tastants with paper discs, used stronger intensities of tastants than we did, and did not include the umami taste. Overall, there are various methods used to study the effect of aging on taste sensitivity. It seems evident that sensitivity and capability to recognize taste modalities decrease with age based on our and earlier findings (Methven et al., 2012). Age-related changes in central processing of the brain might cause weaker sense of taste (Doets & Kremer, 2015). The evidence of physiological changes in taste buds caused by healthy aging is controversial, but the decreased amount and changed composition of saliva that occur in older age may reduce taste function (Doets & Kremer, 2015; Sasano, Satoh-Kuriwada, & Shoji, 2015). According to Sasano et al. (2015), increased sensitivity to umami may promote salivary secretion. As the role of umami sensitivity seems to be a highly relevant factor in adequate and palatable nutrition among the elderly, umami should be an essential part of sensory studies.

In addition to age, gender appeared to be a significant predictor of the taste sensitivity score and sour sensitivity and recognition. Males were less sensitive than females. Mojet et al. (2003) found no overall gender effect using mostly higher concentrations than we did. Simchen et al. (2006) used similar concentrations as we did and found males to be less sensitive to sucrose, NaCl, and citric acid. However, contrary to our study, they used quinine hydrochloride for bitter taste and umami was excluded. Additionally, Fischer et al. (2013) found a similar gender effect with stronger concentrations impregnated on paper discs (umami was not included). Many studies have reported gender differences in taste function, but the underlying mechanisms require further investigation. Currently, research suggests differences in the gustatory system (Martin & Sollars, 2017). The sex hormones probably have a significant influence.

The BMI group was associated with umami sensitivity. A high BMI predicted low sensitivity. This result should be interpreted cautiously because of the low number of obese subjects and hyposensitive umami tasters. This result disagrees with that of Pepino et al. (2010), as in their study, a higher BMI was associated only with higher MSG thresholds (lower sensitivity), not with supra-threshold intensities.

Hardikar et al. (2017) observed that obese individuals perceived sour, sweet, and salty as more intense than lean individuals. They did not include umami in their research. Additionally, they used very high concentrations for the supra-threshold intensity measurement; thus, the results might not be comparable. Additionally, Simchen et al. (2006) found an age × BMI interaction effect on the taste score, which was determined without umami.

Smoking status was not associated with taste sensitivity or recognition. This is in line with Pepino et al. (2010). However, Fischer et al. (2013) found that smokers perceived sourness and bitterness as more intense than nonsmokers. Vennemann, Hummel, and Berger (2008) found that only heavy smoking, not smoking in general, affected taste recognition using strong concentrations and a different method than we did. They did not note if they introduced the taste qualities to the subjects before the actual test. Konstantinidis et al. (2010) found no effect of smoking on taste function measured with taste strips and as an intensity measure of a drop of taste solutions. However, they reported that smoking might affect fungiform papillae morphology, especially the microcirculation in them.

The effect of smoking on taste function has been poorly studied. The conventional procedure is to exclude smokers from sensory studies; thus, data are scarce. More research is needed to better understand the relationship between taste intensity perception and past smoking, current smoking, and never smoking habits, in addition to the number of cigarettes smoked per day. In this study, only a few subjects were current smokers. For the statistical analyses, they were combined in the same category with former smokers, albeit a former smoking habit may not affect current taste sensitivity (Chéruel, Jarlier, & Sancho-Garnier, 2017). Thus, this might explain our results and general conclusions should not be made. However, we wanted to analyze, if the smoking status explained taste perception in this study population.

Taste sensitivity and recognition were related only for the bitter and umami tastes; the more sensitive subjects had more correct recognitions. This was an expected result because we reported earlier (Puputti et al., 2018) that the subjects least sensitive to bitterness or umami perceived the taste modality as very mild, the intensity curves distinct from the curves for the semi and most sensitive groups. For the other taste modalities, the least sensitive group was not very distinct from the more sensitive groups, which resulted in similar recognition capabilities. Finally, the taste recognition score was not related to the taste sensitivity score that represented the general taste sensitivity.

The most common taste confusions were umami–salty and salty–umami confusions. These confusions may partly be explained by the salty taste of MSG which was used for the umami solutions. Although the subjects tasted umami before the actual taste test, poor capability in umami recognition may be a consequence of unfamiliarity to umami among the subjects, as prior experience affects the ease of taste recognition (Hettinger et al., 1999). Furthermore, the sour taste of citric acid was confused with bitterness to some extent; however, the bitterness of caffeine was not confused with sourness; rather, it was perceived as water. Similarly, if a sucrose solution was not perceived as sweet, it was reported to be tasteless.

Studies on taste recognition/confusion are difficult to compare because various compounds, methods, and response alternatives have been used. Doty et al. (2017) reported sour–bitter and bitter–sour confusions as being the most common; nevertheless, umami was not part of their research, they used a different method, and the concentrations were much stronger than those used in our study. In their study, saltiness was also mixed with bitterness and sourness, but these confusions were not common in our study. In agreement with our study, the sweetness of sucrose was the most frequently correctly recognized taste modality. Hyde and Feller (1981) also reported sour–bitter confusions (umami was not included in their study). Our results support the finding of Doty et al. (2017) that recognition is associated with age. While in our study age was the only factor related to recognition, they also found a PTC taster status effect, gender effect on salty–bitter confusion, and smoking status effect on bitter–sour confusion—surprisingly, past smokers were better at distinguishing between bitter and sour than never smokers.

In general, a wide variety of sensory evaluation methods have been used to assess taste function (Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015). Additionally, testing procedures, such as choice of taste compounds, concentration levels of taste solutions, judgment scales, and method of taste stimulation (e.g., whole-mouth sip of solution, a drop of a solution on the tongue, spraying a solution, placing a taste strip impregnated with a taste solution on the tongue), differ highly among studies. This partly explains the conflicting results and conclusions.

Even though five taste modalities were included, the number of subjects was high for a sensory study and a whole-mouth multi-concentration taste test was applied in this study, there are some limitations to consider when interpreting the results. First, only one prototypic compound was used. On the other hand, Mojet et al. (2003) found no compound-specific differences within taste modalities between genders or age groups. The selection of the compounds was based on the ISO8586 and ASTM International standards.

Second, this study was part of a more extensive research project, and the participants also completed other tests on their visit. As a result, we decided on a comprehensible scale for intensity ratings that is commonly used in consumer studies and sensory laboratories and that required no time-consuming training of the participants. We decided to measure intensity without any reference stimulus or a cross-modal reference, such as weights or tones. Instead, thorough written and verbal instructions on how to use the scale were given. The possible problem of scale usage was addressed by analyzing the standardized ratings with hierarchical clustering. If the scale-use bias or ceiling effect were serious issues in this case, the logistic regression analysis would have indicated stronger associations between the taste clusters in our previous work (Puputti et al., 2018).

Third, the sample population was unbalanced for gender, BMI, and, smoking. However, a representative population sample was not our aim, and all volunteers were welcome to participate. Moreover, although the numbers in the groups of men, obese, and smokers were smaller than their reference groups, the numbers were larger than those in many earlier studies.

One concern might also be possible fatigue arising from long testing session. The session took approximately 120 min including discussions between the laboratory staff and the participants (making clear the aim of the study and telling the instructions for every test section). In addition to the taste samples mentioned in Section 2.2, the participants concluded other sensory tests related to sight and smell. The procedure was carefully designed to minimize excessive fatigue and to keep up the interest. The participants could proceed at their own pace as long as they followed the instructions, and they had the possibility to quit testing any moment (no one did). The participants were very enthusiastic and motivated because they could learn by experience about their senses.

5 | CONCLUSIONS

This study considered both taste sensitivity and recognition, and included five taste modalities—also umami, that is, neglected many times. Our findings support the previous data that a weakened taste sensitivity and recognition are associated with older age. Additionally, males were less sensitive than females, similar to some previous findings. To further understand the role of smoking in taste function, additional studies are required. We showed that umami should not be neglected in taste research. These results also add to the understanding of the variation in the capability to recognize taste qualities. The sweet taste was the most accurately recognized, whereas sour–bitter, umami–salty, and, salty–umami were the most frequent confusions. In consumer studies, it should not be taken for granted that people know what is meant with sourness, bitterness, or with other taste modalities. Leaders of trained panels must acknowledge that panelists' perception of taste can vary enormously. As gender and age seem to associate with taste perception, their balance in consumer or trained panels should be designed carefully. It is convenient to recruit participants near the research facilities (e.g., campus area). Often this has resulted in a specific panel: young women who are students or highly educated. Undoubtedly, this can cause limitations to a study. In addition to taste function, gender and age are related to eating behavior. Therefore, a better understanding of the connection between these personal characteristics, taste function, and food intake could promote successful guidance in personal nutrition and enhanced prevention of food-intake-related diseases.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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