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Multidimensional measurement of individual differences in taste perception

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ABSTRACT

Individual taste sensitivity has been claimed to affect food consumption and health. The methods used to assess taste sensitivity are various and thus, cause conflicting results. Thresholds, PROP intensity or fungiform papillae density only partly describe taste function. They may not relate to the actual taste perception in food because of compounds, concentration levels, or the measurement levels used. The objective of the study was to measure individual taste function extensively. With hierarchical clustering, we aimed to reveal taste sensitivity groups among people. Another aim was to investigate the associations between taste qualities. In addition, an overall taste sensitivity score was determined to analyze the generalized taste sensitivity.

The sensory study was carried out with Finnish volunteers (N = 205, age 19–79, 80% females). Citric acid, caffeine, sucrose, NaCl, and MSG were used as the prototypic taste compounds. The subjects rated the intensity of five concentration levels of each tastant.

Hierarchical clustering made it possible to analyze the complex data. The results of clustering were distinctive for taste modalities and the number of subjects in the clusters varied. In general, the clusters could be labeled as more sensitive, semi-sensitive, and less sensitive tasters. In bitter and umami tastes one cluster consisted of hyposensitive subjects. The membership in a taste cluster could be partly predicted by the sensitivity to other taste modalities. This study showed that a minority may be hyper- or hyposensitive to all taste modalities. On the other hand, the majority, the semi-sensitive tasters, can be a very heterogeneous group.

1. Introduction

Taste is an important contributor to food liking and consumption. The traditionally accepted taste qualities are sweet, salty, sour, bitter and umami. Interindividual variation in taste perception may be partly explained by physiological differences or cognitive processing of the taste signals in the brain (Bachmanov & Beauchamp, 2007). Taste sensitivity may affect eating behavior and health, although the evidence is scarce and focuses on taste genetics (Cox, Hendrie, & Carty, 2015; Hayes, Feeney, & Allen, 2013; Hayes, Sullivan, & Duffy, 2010; Monteleone et al., 2017; Sandell et al., 2014, 2015).

Individual perception of taste is challenging to measure. Traditionally five different methods have been used to define taste sensitivity: detection and recognition threshold (DT and RT, respectively), suprathreshold intensity measure, 6-n-propylthiouracil (PROP) taster status and fungiform papillae (FP) count (Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015). DT and RT focus on very low concentrations which are not relevant in a food context. These thresholds do not correlate with suprathreshold intensities (Keast & Roper, 2007; Mojet, Christ-Hazelhof, & Heidema, 2005). Thus explaining food selection with individual DT or RT can be misleading (Low, Lacy, McBride, & Keast, 2016). Taste sensitivity to PROP has been used to classify people as supertasters, medium tasters, and non-tasters. Some have found PROP bitterness intensity to correlate with other tastant perception (Bajec & Pickering, 2008; Fischer et al., 2014; Hayes, Bartoshuk, Kidd, & Duffy, 2008). However, PROP tasting measures sensitivity to only one bitter compound, and its role as an indicator for global taste function has been questioned (Fischer et al., 2014; Lim, Urban, & Green, 2008; Webb et al., 2015). FP has been considered to relate to taste function by housing the taste receptor cells. Nonetheless, FP density is a physical feature and does not imply how an individual perceives taste in reality (Feeney & Hayes, 2014; Fischer et al., 2013). Thus, considering the actual perception of food, the suprathreshold intensity measure may be the most relevant method to define taste sensitivity.

Most of the publications on individual taste perception have focused on RT, DT, or PROP. The few existing results from other tastants suggest moderate correlations between intensities. Lim et al. (2008) found correlations (Pearson's r 0.33–0.43) between sucrose, NaCl, QHCl and citric acid intensities. However, they represented the taste stimuli by

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rolling cotton swabs across the tip of the tongue, which is not as reliable method as whole-mouth sipping because the intensity perception may vary across regions on the tongue (Feeney & Hayes, 2014; Williams, Bartoshuk, Fillingim, & Dotson, 2016). Nonetheless, Webb et al. (2015) also found suprathreshold intensities to correlate (Pearson's $r = 0.34–0.56$) between all taste qualities. Moreover, Hwang et al. (2016) reported a moderate association between bitterness and sweetness. These results support the idea of generalized taste sensitivity or hypergeusia as suggested by Hayes and Keast (2011).

This study is part of a larger research project focusing on individual differences in sensory perception. The object of this study was to investigate the differences in taste perception between individuals. The hypothesis was that people can be classified into different sensitivity groups based on their intensity ratings. Another objective was to investigate the commonality between individual sensitivities taking different taste qualities in various concentrations into account. In addition, the idea of generalized taste sensitivity was analyzed. To achieve these objectives in a large research, we needed simple and rapid methods to measure several stimuli intensities. Thus we used line scales for rating the stimuli, and hierarchical clustering to perform data-driven clustering of subjects into taste-specific sensitivity groups.

2. Materials and methods

2.1. Participants

The sensory test was carried out in the sensory laboratory of Functional Foods Forum (University of Turku) in accordance with the ISO8589 standard. Altogether 206 adults (19–79 years) participated in the sensory tests. The test location determined that most of the participants lived in Turku or the surrounding areas in South-West Finland. The exclusion criteria were pregnancy or a lactating state. One person was later excluded because of taste loss after an accident. All the subjects were not able to complete all the sections of the research mainly because of a lack of time, technical issues or hypersensitivity to caffeine. These subjects were only excluded on an analysis by analysis basis rather than being entirely excluded. The number of excluded subjects was small varying from zero (age and gender as background information) to seven (smoking as background information). The final number of subjects are marked in Tables 2 and 3, and Figs. 1 and 2.

The subjects were recruited by advertisements around the University, on the University web pages and at public events. They were instructed to avoid eating, drinking anything other than water, chewing gum and smoking one hour prior the test. The subjects were not trained but before every section, they received both verbal and written instructions. All of the subjects provided written informed consent and were rewarded after every visit. The study was reviewed by the Southwest Finland Hospital District's Ethics Committee (145/1801/2014).

2.2. Taste stimuli

Five taste qualities were involved: sour, bitter, sweet, salty, and umami. One prototypic tastant for every quality was chosen. Five dilutions of every tastant were prepared in active-carbon filtered water, as is described in Table 1. Afterward, the mildest dilution of every tastant was excluded from the analyses being too mild for the test conditions based on inconsistent evaluation by many participants. The solutions were prepared less than four days before use except for MSG, which was prepared less than two days before, following good laboratory practices. Samples were stored under refrigeration in glass bottles and allowed to return to room temperature before serving.

The concentration levels were chosen based on our previous experience. The strongest samples were in line with ASTM standard for measuring taste intensity. Additionally, they are easily perceivable for the majority of individuals with normal taste function in our experience. We decided the other samples would be milder (concentration increase 0.25log). Stronger samples could have caused a ceiling effect when using line scales.

The sample presentation was designed to prevent excessive fatigue and the effect of positional bias. The samples were served in two sets of 14 samples during one session. The first set involved the mildest dilutions: the E and D dilutions of each tastant, the C dilution of NaCl and citric acid, and two blank samples (active-carbon filtered water) in random order. The rest of the dilutions and a blank sample in random order formed the second set. The C dilution of NaCl and citric acid were assigned to the first set because the salty and sour tastes are easier to rinse off than bitter or umami taste which may easily retain in the mouth. Thus, they could have interfered the evaluation of the mildest samples. In addition, the C dilution of sucrose was assigned to the second set because it was expected to be the most easily recognizable taste.

The subjects received 5 ml of each sample in a glass beaker marked with three-digit codes. They were advised to sip the entire sample, spin it around the mouth for five seconds and then spit it out into an adjacent basin. The instructions included rinsing the mouth with active-carbon filtered water and, if needed, eating a piece of cream cracker between samples. Samples were evaluated once.

2.3. Tasting procedure

Participants were familiarized with the tasting procedure and the taste qualities by tasting the strongest dilution of every tastant. If a taste quality was incorrectly identified, the subject tasted the sample again. The participants rated the intensities of taste samples using line scales anchored both verbally and numerically (0–10): 0 = "no sensation", 2 = "very mild", 4 = "quite mild", 6 = "quite strong", 8 = "very strong", 10 = "extremely strong". The subjects were instructed to rate the intensity above zero if they perceived something else than pure water. The subjects were also instructed verbally that value five on the scale should be a clearly detectable taste sensation and value ten as strong in intensity that the subject would not like to taste it again. After the intensity rating, the subjects indicated the taste quality they recognized (the results not included here).

Compusense *five* Plus software (Compusense, Guelph, Canada) was used for data collection in the sensory laboratory. Background information was collected with Webropol (Webropol Inc, Helsinki, Finland) online questionnaires. All communication was in Finnish.

2.4. Statistics

Hierarchical clustering was used for data-driven segmentation of the subjects. The clustering was performed on the standardized intensity ratings using the squared Euclidean distance measure and Ward's method. A three-cluster solution was retained for every taste quality. Retaining more clusters could have led to overfitting and have resulted in too small clusters for further statistical analyses.

The least sensitive cluster was labeled with 1, the most sensitive cluster with 3, and the middle cluster with 2. The overall taste sensitivity score was the mean of all clusters (range 1–3). The score was calculated for each participant based on the clusters to which he/she belonged. Those who scored 1.0–1.4 were considered hyposensitive tasters because they belonged to cluster 1 in the majority of the taste qualities (and to cluster 2 at most in the others). Hypersensitive tasters scored 2.6–3.0 being in cluster 3 in three taste qualities at least (and in cluster 2 at least in the others). Semi-sensitive tasters scored 1.6–2.4. Only those subjects who had evaluated all the samples were taken into account ($N = 199$, six missing).

The differences in intensity ratings between the clusters were analyzed with one-way MANOVA and Tukey's or Tamhane's (when equal variances not assumed) test as a *post hoc* test. Multinomial logistic regression was used to study the associations between taste clusters. For