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Different Neural Processing of Umami and Salty Taste Determined by Umami Identification Ability Independent of Repeated Umami Exposure

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Abstract—There is a large inter-individual variation for umami taste perception. However the neural mechanism for this variability is not well understood. This study investigated brain responses to umami and salty taste among individuals with different umami identification abilities and the effect of repeated oral umami exposure on umami identification and neural processing of taste perceptions. Fifteen participants with high umami identification ability (''High Tasters, HT) and fifteen with low umami identification ability (''Low Tasters", LT) underwent three weeks of controlled exposure to umami taste (umami training). Prior to and after the training, participants underwent fMRI scans during which the umami taste solution and a control taste (salty) solution were delivered to their mouth using a gustometer. Taste intensity and pleasantness were rated after each scan. Umami taste identification was assessed before and after the umami training using ''Taste Strips" test. Neuroimaging results showed different central processing of umami and salty taste based on umami identification ability, in which the umami LT had stronger activation in the thalamus and hippocampus while the umami HT showed stronger activation in the primary gustatory cortex. In addition, umami identification was significantly improved after umami training for LT. However, it was not reflected in changes in neural activation. The current study shows that attention and association/memory related brain structures play a significant role in the perception of umami taste; and with reference to the results of repeated umami exposure, the presence of very subtle changes regarding the neural processing.

Keywords: functional magnetic resonance imaging (fMRI), taste perception, umami identification, repeated exposure.

INTRODUCTION

Umami is a basic taste (Kurihara, 2009), which stems from a Japanese term meaning ''good taste" or ''delicious" (Chandrashekar et al., 2006; Roper, 2007), and is often used to describe a meaty, savory flavor. In humans the main substance eliciting umami taste is L-glutamate, an amino acid abundantly found in food that often occurs as monosodium glutamate (MSG) (Garcia-Bailo et al., 2009). MSG are found naturally in a wide array of vegetables such as tomatoes, potatoes, mushrooms, carrots, and various seaweeds, as well as fish, seafood, meat, and cheese (Kurihara and Kashiwayanagi, 2000; Kurihara, 2009). Umami taste is highly significant in the palatability of food flavors (Rolls, 2009), and is important for the maintenance of health (Prescott, 2004; Shoji et al., 2016). Regarding the cerebral processing of umami taste, it is well established that the neural representation of umami taste is in the primary and secondary gustatory cortex, including the anterior insula, frontal operculum, and the orbitofrontal cortex (de Araujo et al., 2003; Schoenfeld et al., 2004; McCabe and Rolls, 2007; Nakamura et al., 2011; Singh et al., 2015; Prinster et al., 2017).

There are significant variations for umami taste perception in the general population (Lugaz et al., 2002; Singh et al., 2010). Individual differences in umami taste sensitivity result from genetic variations in taste receptors (Shigemura et al., 2009a,b), or other determinants of taste physiology such as dietary conditions and hormonal levels (Loper et al., 2015). However, much less had been explored regarding the central mechanisms for the perceptual variability regarding umami taste. In addition, umami taste is less familiar as compared to other tastes and is commonly confounded with salty taste (Overberg et al., 2012). There were only 3.8% of people from Germany reporting awareness of the umami taste (Singh et al., 2010). Previous research has shown that the sensitivity to umami taste is largely dependent on the familiarity with that taste (Kobayashi et al., 2006; Singh et al., 2015). Interestingly, brain responses to umami can change

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Abbreviations: fMRI, functional Magnetic Resonance Imaging; MSG, monosodium glutamate.

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following repeated exposure to umami - "umami training" (Singh et al., 2015).

The objectives of the current study were: (1) to investigate the neural mechanism that influence responses oral umami taste stimuli among people with different abilities for umami taste identification; and (2) to investigate the effect of repeated umami taste exposure on umami taste identification.

EXPERIMENTAL PROCEDURES

Participants

Thirty adult participants (age range 20–33 years, mean age years 24.6 years; body mass index BMI 19–30.5, mean 23.6) were recruited for the study including 21 males (age range 20–33 years, mean age 24.8 years; BMI 19–30.5, mean 23.9) and 9 females (age range 21–27 years, mean age 24.2 years; BMI 20.3–27.2, mean 22.9). Participants' gustatory function was screened via taste sprays that consist of supra-threshold concentrations of "sweet" (sucrose), "sour" (citric acid), "salty" (sodium chloride), and "bitter" (quinine hydrochloride) (Welge-Luessen et al., 2013). All participants were able to identify each of the four tastes correctly. In addition, participants received an interview regarding other inclusion criteria. Based on self reports, all participants were non-smoking, non-pregnancy or non-breast feeding (female participants), right-handed and with normal olfactory functions. The study was approved by the Ethics Committee at the Technical Dresden (EK number 366082015) and performed in accordance with the WMA Helsinki declaration. Participants provided written informed consent prior to commencement of the study.

Umami taste identification

To identify people with high and low ability of umami taste identification ("High Tasters, HT" and "Low Tasters, LT"), a modified version of the "Taste Strips" test (Burghart, Wedel, Germany; length of 8 cm, tip area of 2 cm^2, impregnated with tastant) was applied (Landis et al., 2009; Mueller et al., 2011). Filter paper strips were impregnated with MSG or sodium chloride (NaCl) solutions, in four concentrations each (0.016, 0.04, 0.1 and 0.25 g/ml). One strip at a time was placed on the tongue, and the mouth was rinsed with tap water after presentation of each strip. Each test step included a triplet of strips, one with a certain concentration of umami (see above) and two with NaCl in the same concentration as had been applied with the Na – Glutamate strip. After each triplet, subjects were asked to identify the strip with the different taste. The entire test comprised eight repetitive steps, with a random sequence of concentrations and every concentration being applied twice (Landis et al., 2009; Manzi and Hummel, 2014). The total number of correct answers was used as a measure of umami identification.

Umami HT and LT were classified according to the umami identification score, with participants above 50% correct identification of the umami taste (5 or more out of 8) were regarded as umami HT, and participants below 50% correct identification of the umami taste strips (3 or less out of 8) were classified as umami LT.

Repeated umami taste exposure

The umami taste repeated exposure followed a three weeks training period during which subjects were provided with samples of umami taste solution in 30-ml spray bottles, along with written instructions and documentation forms. They were asked to apply the training solution twice daily, after rinsing the mouth with water, with approximately 6–8 h between applications, and to document their sensations in a journal (Singh et al., 2015). To ensure compliance, participants were required to return to the lab and have their training bottles exchanged every week. The umami identification test was performed before and after the training period. A schematic of the study design is depicted in Fig. 1.

functional Magnetic Resonance Imaging (fMRI) experimental design

Umami taste was represented by MSG. As a control stimulus, salty taste (NaCl) was used. A gustometer (Burghart GU002; Burghart, Wedel, Germany) was utilized for taste stimulation during the fMRI scanning procedure (Iannilli et al., 2012; Seo et al., 2013; Singh et al., 2015). Umami and salty solutions (0.25 g/ml each) were applied onto the tongue using Teflon™ tubing and a plastic mouthpiece. Teflon® tubing carrying the stimulation and rinsing liquids was fed through the wall. From the mouthpiece held between subjects' lips, droplets of stimuli, rinse or water were delivered onto the tongue.

Participants underwent two fMRI sessions: one prior to (PRE), and one after (POST) the training phase of umami taste. In both sessions, identical functional scanning procedures were performed, following the scheme of a block design with 20 s (eight scans) period of stimulation (ON condition), rinsing, and rest (OFF condition) constituting one block. The block designed acquisition scheme yielded 48 scans per tastant in each participant during the PRE and POST session, respectively, and as many control scans with water as stimulant (Iannilli et al., 2012).

During ON periods, one of the tastants was delivered, while during OFF periods water (Evian®, Danone Waters, Frankfurt, Germany) was applied to the tongue. Synthetic saliva (KCl [25 mM] plus $NaHCO_3$ [0.25 mM]) was used to rinse the mouth after taste stimulation. Blocks were repeated three times within one run, with alternating sequences of umami and salt stimulation, and four runs were performed with short breaks in between, each stimulant thus being repeated six times. After each fMRI run, subjects verbally rated the intensity and pleasantness of both tastants via intercom, on a rating scale (range for intensity: from 0 = no sensation to 10 = maximum intensity; for pleasantness: from −5 = very unpleasant to 5 = very pleasant). The duration of an entire functional MRI session was approximately 15 min. The design is depicted in Fig. 2.