Food Quality and Preference 48 (2016) 1–10

Contents lists available at ScienceDirect

Food Quality and Preference

journal homepage: www.elsevier.com/locate/foodqual

# Retronasal odor enhancement by salty and umami tastes

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ARTICLE INFO

*Article history:*
Received 1 July 2015
Received in revised form 7 August 2015
Accepted 10 August 2015
Available online 11 August 2015

*Keywords:*
Congruency
Enhancement
Flavor
Perceptual similarity
Retronasal odor
Saltiness
Umami

ABSTRACT

It has been shown that congruent food odors are enhanced by sweet taste, but not by sour or bitter taste. This raises questions regarding the underlying conditions of retronasal odor enhancement by taste. We speculate that a taste quality that signals the presence of "nutritive" or "beneficial" substances (e.g., sweet carbohydrate), as opposed to potentially harmful substances (e.g., toxins, spoilage), can enhance a congruent odor. This study aimed to investigate this possibility by testing two other taste qualities, saltiness and umami, which signal the presence of minerals and protein. The study also examined the possible occurrence of saltiness and umami enhancement by odors and factors that may affect both taste and odor enhancement. Over five sessions, subjects rated (1) intensities of saltiness, bitterness, umami, and specific odor of tastants (NaCl, MSG, MPG, caffeine), odorants (chicken, soy sauce odor), and all possible binary mixtures, (2) degree of liking/disliking of the odorants in the absence and presence of the tastants, (3) degree of congruency of odorants alone and with tastants, and (4) degree of perceptual similarity between tastants and odorants. Results showed that saltiness and umami enhanced chicken and soy sauce odor intensities, but the odors did not enhance saltiness and umami intensities. Importantly, the degree of odor enhancement was highly correlated with the degree of taste–odor congruency, but less so with the degree of perceptual similarity between taste and odor. These findings confirm our hypotheses that the quality of taste dictates the ability to enhance food odors and that the degree of taste–odor congruency can modulate the degree of odor enhancement.



## 1. Introduction

As much as the gustatory and olfactory systems are physiologically independent, taste and olfaction share the essential function of identifying and aiding in the consumption of safe, nutritious, and highly palatable foods. To perform such tasks, taste and olfaction—in particular retronasal olfaction—interact closely with one another (for review see Delwiche, 2004; Small & Prescott, 2005; Verhagen & Engelen, 2006). Psychophysical evidence of such interactions include phenomena of retronasal odor referral to the mouth (Lim & Johnson, 2011, 2012; Murphy & Cain, 1980; Rozin, 1982), cross-modal summation of sub-threshold taste and smell (Dalton, Doolittle, Nagata, & Breslin, 2000), and taste and odor enhancement (Djordjevic, Zatorre, & Jones-Gotman, 2004; Frank & Byram, 1988; Green, Nachtigal, Hammond, & Lim, 2012; Kuo, Pangborn, & Noble, 1993; Labbe, Damevin, Vaccher, Morgenegg, & Martin, 2006; Schifferstein & Verlegh, 1996; Stevenson, Prescott, & Boakes, 1999; Valdes, Hinreiner, & Simone, 1956; Valdes, Simone, & Hinreiner, 1956).

The phenomena of retronasal odor enhancement by taste and taste enhancement by retronasal odor are particularly relevant to the study of perception and preference of foods. Interestingly, while some consider them to be a true sensory phenomena, others view such interactions—especially taste enhancement by odor—as primarily cognitive in nature, resulting from associative learning, attentional strategy, and/or response bias (see Prescott, 1999 for review). For example, one of the earlier studies of taste–odor interactions reported that the concurrent presentation of tastants and odorants causes odors to be confused with tastes, which can lead to higher intensity ratings of taste (Murphy & Cain, 1980). Schifferstein and Verlegh (1996) later proposed that such effect depended on the perceptual similarity between odors and tastes. This view is also consistent with the hypothesis that the taste-like qualities of odors (e.g., "sweet" or "salty" smelling), which are produced by association with tastes (Prescott, Johnstone, & Francis, 2004; Prescott & Murphy, 2009; Stevenson, 2001; Yeomans, Mobini, Elliman, Walker, & Stevenson, 2006), play an important role in taste enhancement by odor (Stevenson et al., 1999). Taste enhancement by retronasal odor has also been explained by response bias; Frank and colleagues discovered that taste enhancement by retronasal odor occurred to a significant

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http://dx.doi.org/10.1016/j.foodqual.2015.08.004
0950-3293/

degree only when the rating task lacked a suitable response category for the odor (Frank, van der Klaauw, & Schifferstein, 1993). More specifically, in the original study, Frank and Byram (1988) obtained sweetness ratings for a set of taste–odor samples and reported that sweetness was enhanced by strawberry odor. In a follow-up study, the same group reported that the sweetness enhancement by strawberry odor was nil, when subjects rated fruitiness along with sweetness (Frank et al., 1993). This finding was later confirmed and elaborated by Clark and Lawless (1994) who called the cognitive effect of too few response categories on ratings of taste intensity 'dumping'. Nonetheless, it has been shown numerous times that both forms of enhancement occur only for congruent taste–odor pairs.

In an effort to understand the underlying sensory and cognitive mechanisms, we have performed a series of experiments, which measured both forms of enhancement by taking an analytical strategy; i.e., by asking subjects to give full attention to appropriate response categories and thus rate all relevant taste and odor attributes for mixtures of various tastants and odorants. The results from our initial study indicated that, consistent with the earlier findings (Clark & Lawless, 1994; Frank et al., 1993), when dumping was avoided taste enhancement by odor was nil, while retronasal odor enhancement by sucrose was evident for all 3 test odors (citral, furaneol, and vanillin) (Green et al., 2012). Similar results were found when odor was presented in vapor phase via the mouth, while tasting sucrose separately but simultaneously, suggesting that odor enhancement by sucrose is a perceptual phenomenon that occurs independently of physicochemical interactions between flavor components (Fujimaru & Lim, 2013). Notably, the effect was even more pronounced in two food systems, vanilla custard and a flavored drink (Green et al., 2012). In contrast, findings from our most recent study showed that citric acid and caffeine were not able to enhance citral and coffee odor, although the pairs of citral and citric acid, and coffee odor and caffeine were rated highly congruent (Lim, Fujimaru, & Linscott, 2014). Combined together, these findings suggest that taste–odor congruency is a necessary but not sufficient condition for retronasal odor enhancement. More importantly, our findings raise an interesting question regarding the function of retronasal odor enhancement by sucrose in flavor perception. One speculation is that by increasing the salience of flavor, odor enhancement may help strengthen the associative link between the flavor of a food and its metabolic consequences (Green et al., 2012). Based on this hypothesis, it is expected that odor enhancement may be induced by saltiness and umami, which signal the presence of "beneficial" or "nutritive" substances for our bodily functions.

Saltiness and umami are considered as the tastes of salt and protein, which are essential for human bodily function. Their representative substances, sodium and glutamate, are naturally found in diverse foods, although they are also used as food additives. In fact, a large amount of sodium and monosodium glutamate (MSG) intake comes from either processed or restaurant-prepared foods (Havas, Dickinson, & Wilson, 2007; Mattes & Donnelly, 1991; Mhurchu et al., 2011; Rhodes, Titherley, Norman, Wood, & Lord, 1991). Due to health related concerns, the food industry has thus been challenged to reduce sodium content in food products (Campbell et al., 2014; Dickinson & Havas, 2007; Havas et al., 2007). Rightfully or not, many consumers have also become wary of consuming foods with added MSG. Though most studies show that no proven health risk is associated with the consumption of MSG (Jinap & Hajeb, 2010; Walker & Lupien, 2000), the FDA acknowledges there may be a portion of the population that is sensitive to it (FDA., 2013). In any case, there have been many studies exploring potential approaches to lower sodium and MSG contents in food products (for review, see Doyle & Glass, 2010). One such strategy has been the application of taste enhancement by food odors. Research in the use of "salty" odors as a potential reduction method has been particularly extensive (Batenburg & van der Velden, 2011; Lawrence, Salles, Septier, Busch, & Thomas-Danguin, 2009; Lawrence et al., 2011; Manabe, 2008; Nasri, Beno, Septier, Salles, & Thomas-Danguin, 2011; Seo et al., 2011). This approach has been shown to be possible, although it has also been demonstrated that its effectiveness depends on the level of salt concentration; saltiness enhancement by congruent odors was pronounced in stimuli with a low or medium salt content, but not with a high salt content (Nasri et al., 2011; Seo et al., 2011). In addition, some of the above mentioned studies did not control for factors that may have affected the occurrence of taste enhancement by odor (e.g., dumping).

The primary objective of the present study was, therefore, to investigate the potential for both types of enhancement, retronasal odor enhancement by salty and umami tastes, and saltiness and umami taste enhancement by retronasally perceived food odors, by using a psychophysical procedure that controls for the potential of dumping. As salty and umami taste stimuli, we used sodium chloride (NaCl), monopotassium glutamate (MPG), and monosodium glutamate (MSG). While MSG is considered a typical umami substance, it also contains one equivalent of sodium, thus evokes saltiness as well. The use of both MPG and MSG will provide a unique opportunity to test the role of salty and umami tastes *per se* in retronasal odor enhancement. A related objective was to fully understand the roles that congruency and perceptual similarity between taste and odor play in the occurrence of both enhancements. In the past, the terms congruency and perceptual similarity have been used without clear distinction. For the purpose of this study, we define congruency and perceptual similarity as the degree to which taste and odor components are reminiscent of a flavor object (e.g., coffee odor and sweetness of sucrose together resembling sweetened coffee) and as the degree to which one component shares the quality of another (e.g., coffee odor having the quality of "bitter" taste, but not "sweet" taste), respectively. Finally, both NaCl and MSG are known to increase hedonic values of foods. This raises the question of whether enhancement of flavor components (i.e., taste enhancement by retronasal odor or retronasal odor enhancement by taste) is a byproduct of the 'halo' effect (Clark & Lawless, 1994). This possibility was tested by measuring potential hedonic enhancement by salty and umami tastants and comparing the effect directly to intensity enhancement.

## 2. Method

### 2.1. Subjects

A total of 35 subjects (26 females and 9 males) between 18 and 45 years of age (mean = 25 years old) were initially recruited from the Oregon State University campus and the surrounding community. Individuals interested in participating in a flavor study were asked to fill out screening questionnaires. Inclusion criteria were: (1) non-smokers; (2) not pregnant or lactating; (3) not taking any prescription pain medication; (4) free from deficits in taste and smell; (5) free of oral lesions, and canker sores; (6) free from piercings of the tongue, lip, or cheek; (7) free from food allergies; (8) fluent English speakers; (9) not a vegetarian or vegan; and (10) familiar with the flavor of chicken and soy sauce. Respondents who qualified and agreed to participate were invited into the study. The subjects were asked to refrain from eating spicy food or using any strong-scented personal care products on the day of testing. They were further asked not to eat or drink anything, except for water, or to consume any menthol products (e.g., gum, toothpaste, or mouthwash) for at least 1 h prior to their scheduled test sessions. The experimental protocol was approved by the