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INFLUENCE OF THE PERCEIVED TASTE INTENSITY OF CHEMESTHETIC STIMULI ON SWALLOWING PARAMETERS GIVEN AGE AND GENETIC TASTE DIFFERENCES IN HEALTHY ADULT WOMEN

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Abstract

Purpose—This study examined whether the perceived taste intensity of liquids with chemesthetic properties influenced lingua-palatal pressures and submental surface electromyography (sEMG) in swallowing, compared to water.

Method—Swallowing behaviors were studied in 80 healthy women, stratified by age-group and genetic taste-status. General Labeled Magnitude Scale ratings of taste intensity were collected for deionized water; carbonated water; 2.7 % w/v citric acid; and diluted ethanol. These stimuli were swallowed, with measurement of tongue-palate pressures and submental sEMG. Path analysis differentiated stimulus, genetic taste-status, age, and perceived taste intensity effects on swallowing. Signal amplitude during effortful saliva swallowing served as a covariate accounting for differences in participant strength.

Results—Significant differences in taste intensity were seen across liquids: citric acid > ethanol > carbonated water > water. Supertasters perceived greater taste intensity than nontasters. Lingua-palatal pressure and sEMG amplitudes were correlated with the strength covariate. Anterior palate pressures and sEMG amplitudes were significantly higher for the citric acid stimulus. Perceived taste intensity was a significant mediator of stimulus differences.

Conclusions—These data support the idea that sensory input transmitted via chorda tympani and trigeminal afferent pathways may lead to cortical facilitation and/or modulation of swallowing.

Keywords

Deglutition; swallowing; chemesthesis; taste; tongue pressure; electromyography

INTRODUCTION

Brain injuries, such as a stroke, progressive disease or trauma, often affect an individual's ability to swallow food and liquids safely. Consequently, malnutrition, dehydration and aspiration pneumonia are common problems for these individuals. Only a small number of studies have investigated the effect of taste on swallowing although taste appears to influence some swallowing behaviors in healthy adults and individuals with neurogenic oropharyngeal dysphagia (Chee, Arshad, Singh, Mistry, & Hamdy, 2005; Ding, Logemann, Larson, & Rademaker, 2003; Krival & Bates; Leow, Huckabee, Sharma, & Tooley, 2007; Logemann et al., 1995; Michou, Mastan, Ahmed, Mistry, & Hamdy, 2012; Palmer, McCulloch, Jaffe, & Neel, 2005; Pelletier & Dhanaraj, 2006; Pelletier & Lawless, 2003; Plonk, Butler, Grace-Martin, & Pelletier, 2011; Rofes, Arreola, Martin, & Clave, 2012; Todd, Butler, Plonk, Grace-Martin, & Pelletier, 2012a, 2012b). It has been hypothesized that increased taste intensity will elicit heightened activation of sensory neurons in the nucleus tractus solitarius (NTS), which in turn may increase the stimulation of motor neurons in the nucleus ambiguus (NA), thus giving rise to a faster, stronger swallow response (Ding et al., 2003). Cortical facilitation of swallowing via trigeminal nerve afferent pathways and corticobulbar inputs to the NTS is also plausible.

In one study, high concentrations of taste stimuli with perceived irritant properties (indicating trigeminal as well as taste cranial nerve stimulation) evoked increased lingual swallowing pressure amplitudes compared to water in young healthy adults (Pelletier & Dhanaraj, 2006). The trigeminal nerve innervates the fungiform papillae (where taste buds lie) on the anterior tongue; the activation of these trigeminal sensory receptors results in oral sensations such as the fizziness of carbonation, the heat of chili peppers or the cool of menthol and has become known as *chemesthesia* (Green, 2000), a sensation of irritation produced by chemical stimulation. At this point, it is not known whether pure chemesthesia by itself elicits differences in swallowing behaviors, such as increased lingua-palatal swallowing pressures, nor whether taste stimuli that do not have chemesthetic components can influence swallowing behaviors. It also is not known how an individual's perception and experience of a stimulus influences a swallow. Perception is different from the stimulus itself, e.g., a high concentration of a bitter substance may be perceived as very bitter, or not, due to individual variations in genetic, gender, aging and pathological conditions (Bartoshuk, 1993, 2000; Bartoshuk & Beauchamp, 1994; Bartoshuk et al., 2004; Bartoshuk, Duffy, & Miller, 1994; Bartoshuk, Duffy, Reed, & Williams, 1996; Bartoshuk, Rifkin, Marks, & Bars, 1986). The influence of perceived taste intensity on swallowing behaviors has not been evaluated to date.

Aging may be an important factor affecting lingua-palatal pressures and muscle activity in swallowing. Although aging does not appear to affect peak lingua-palatal swallowing pressures, it has been suggested that older adults are at increased risk of dysphagia because they have lower overall functional reserve (the difference in swallowing pressures seen between maximum isometric tasks and swallowing tasks) and a longer duration of lingual swallowing pressures (Nicosia et al., 2000; Robbins, Levine, Wood, Roecker, & Luschei, 1995). It is not known whether the experience of chemesthesia and its influence on swallowing physiology will diminish with age, although it has been posited that age-related

differences in taste sensitivity might reduce the influence of taste stimuli on swallowing (Ding et al., 2003).

There is evidence that individuals who vary in their taste perception of the bitter compound 6-*n*-propylthiouracil (PROP) have different densities of fungiform papillae on their tongues, and consequently, experience differences in the perceived taste intensity of other taste stimuli (Bartoshuk, 1993; Reedy, Haines, & Campbell, 2005). This is due to their genetics. Homozygous individuals born with a recessive taste allele on chromosome 7 are labeled *non-tasters* because they are unable to taste the bitterness of PROP. Tasters of PROP fall into two groups due to incomplete dominance; heterozygous individuals (*medium tasters*) perceive moderate bitterness while those with homozygous PROP sensitivity are called *supertasters* and have an intense response to PROP. Given that supertasters have a higher density of fungiform papillae and apparent increased trigeminal sensation perception compared to non-tasters (Karrer et al., 1992), supertasters may logically be expected to display a heightened behavioral response to chemesthetic stimuli in the form of relatively greater increases in lingual swallowing pressures and sEMG signals of swallowing muscle activity compared to non-tasters. In other words, individual genetic taste-status may be a factor influencing swallowing behavior.

The aims of this study were to test the following hypotheses in healthy adult females with normal swallowing function:

1. Genetic taste-status and age will influence the perceived taste intensity of stimuli with putative trigeminal irritant properties;
2. Swallowing functional reserve will influence the amplitudes of lingua-palatal pressure and submental sEMG amplitudes seen in swallowing;
3. Stimuli with chemesthetic properties will elicit increased lingual swallowing pressures and submental sEMG amplitudes;
4. Perceived taste intensity will modulate the degree to which stimuli with chemesthetic properties influence swallowing behaviors (lingua-palatal pressures and submental sEMG activity).

METHODS

Participants

Eighty healthy adult women in two age groups participated in the study ($n = 40$ in each age group consisting of 18–35 yrs and 60+ yrs). Participants were recruited via fliers and newspaper/television ads in the local community. Each age group was further divided into 20 non-tasters and 20 supertasters (Table 1) based on their bitterness rating of 6-*n*-propylthiouracil (PROP) using the general Labeled Magnitude Scale (gLMS) (Figure 1). Only women were recruited because they are statistically more likely to be nontasters or supertasters than men (Bartoshuk et al., 1994). The number of subjects in each genetic taste group was prospectively determined to provide close to 0.90 power to detect differences between the groups should they exist, based on two decades of research by Bartoshuk (2004), and Keppel's estimates of sample sizes for small, medium and large experimental

effects in the behavioral sciences (Keppel, 1991). Inclusion criteria included healthy women living independently in the community, a score of ≥ 25 or greater on the Mini Mental State Examination (MMSE) (Folstein, Folstein, & McHugh, 1975), and a bitterness rating of ≥ 20 for non-taster status and ≥ 50 for supertaster status using the gLMS (Bartoshuk et al., 2004).

Initial Screening

A total of 222 women were screened for inclusion in the study. Ninety-seven participants failed to meet the inclusion criteria; all failed due to bitterness ratings indicating medium taster status except one older participant. She scored 25 on the MMSE and while that score would constitute acceptance into the study, her responses were extremely delayed and it was necessary to repeat the instructions numerous times, indicating significant cognitive impairment. One hundred twenty-five participants were accepted; fifteen could not return for the research session due to scheduling difficulties while 30 were not invited back because the quota in their age/genetic taste group was already met.

Stimuli

Five ml samples of four liquid stimuli were prepared using deionized water as the diluent (Millipore 60 Liter Progard™ Tank; Lot #FSKN82798, Serial #FYEN25621). Deionized water served as the neutral stimulus, without any expected taste or chemesthesis. A high-intensity sour stimulus, with both taste and chemesthetic properties, was made using deionized water and citric acid (0.128 M, 2.7% w/v - the same concentration as used in previous sour bolus dysphagia studies; Science Lab.com Lot #C6H807H20). A 50:50 dilution of deionized water and ethyl alcohol, 200 proof, absolute (Pharmco Products, Brookfield, CT 06804) was used as a chemesthetic (burning) stimulus expected to have neutral taste. Seltzer water (Polar™ Seltzer water with no sodium, Polar Beverages, Worcester, MA 01615), was used as a second chemesthetic (fizzy) but neutral taste stimulus. Samples were presented to each participant in a randomized order and chilled directly from a refrigerator ($\leq 5^{\circ}\text{C}$) in 30 cc clear plastic cups labeled with a three-digit random number. Participants were blinded to the stimuli presented with the exception of the seltzer water. This stimulus was opened in the presence of the participant, measured and consumed immediately, in order to maintain the fizziness of the liquid during sampling.

Protocol

Participants were fitted with a nasal cannula, three surface electrodes applied under the chin (i.e., to the right and above the angle of the neck), and a two-bulb, air-filled lingua-palatal pressure array secured midline on the roof of the mouth just behind the upper teeth with a medical adhesive strip. Prior to any data collection, participants were asked to sit quietly for at least 5 min to adjust to the equipment. During this acclimatization period, participants completed a taste questionnaire verbally presented by the investigator. They rated their remembered intensity of sensations for past events or food experiences, such as the strongest smell of a flower and the strongest oral burn experienced (e.g., chili peppers) using the general Labeled Magnitude Scale (gLMS).

Data collection commenced with four saliva swallowing tasks (one effortful swallow and three regular-effort saliva swallows. The effortful swallow was collected for the purposes of

capturing a strength measure analogous to functional reserve. Bolus swallowing then proceeded with the chilled, individually randomized taste samples, swallowed in a typical manner. Between each sample, participants were required to rinse their mouths at least three times with water or until no taste or chemesthetic mouthfeel was present. Immediately after swallowing each sample, participants were asked to state the taste quality perceived (sweet, sour, salty or bitter), if any, and to rate its intensity using the gLMS. Additionally, gLMS ratings for perceived burning/stinging (ethanol and citric acid stimuli) and perceived fizziness (carbonated water) were collected.

Data Processing

In the strong majority of cases, perceived taste intensity for the deionized water stimulus was rated as zero, reflecting that the person perceived an absence of taste for that stimulus. In order to include perceptions of taste intensity for the water stimulus in the subsequent statistical models, a random number generator was used to generate non-zero values between -3 and 3 as substitutions for the zero data values, with the mean and standard deviation values falling as close to zero as possible. Chemesthesis was rated as being present for the carbonated and ethanol stimuli. However, due to the lack of a broad distribution of perceived chemesthesis (either fizziness or burning/stinging) across a continuum for the stimuli used in this study, it was determined not to be appropriate to explore the intensity of perceived chemesthesis as a continuous covariate and potential modulator of swallowing behavior. Consequently, it was decided that perceived taste intensity would be the sensory quality used as the covariate in our subsequent analyses.

Based on prior examples in the literature, we recognized the possibility that the amplitude data for both lingua-palatal pressure and sEMG waveforms might vary across participants due to minor differences in sensor location, as well as between participant differences in strength and functional reserve. This issue has typically been addressed by normalizing data against a maximum effort reference task, typically a maximum isometric task (Steele & Huckabee, 2007; Youmans, Youmans, & Stierwalt, 2009). Given the absence of a maximum isometric reference task in the data collection protocol for this study, we investigated the dependence of the observed amplitudes for lingua-palatal pressure and sEMG data during bolus swallowing tasks on two possible reference values: a) the maximum amplitude value obtained across a baseline task of 3 non-effortful saliva swallows (Yeates, Steele, & Pelletier, 2010); and b) the amplitude value seen during a single effortful saliva swallow task. Linear regression showed that between 10 and 21% of the variation in amplitude values were explained by a participant's effortful saliva swallowing amplitude, suggesting a probable influence of strength on observed amplitude values (see Figure 2). Consequently, it was decided that the subsequent ANOVA analyses involving amplitude should incorporate a covariate of effortful saliva swallow amplitude (recorded at the same sensor), to account for the influence of this value on the primary questions of the study.

ANALYSIS

Statistics

Descriptive statistics were calculated for all parameters. A path analysis approach was then taken as follows (see Figure 3 for an illustration):

1. A mixed model linear analysis of variance (ANOVA) was performed to evaluate the effects of stimulus, genetic taste-status and age-group on perceived taste intensity (Path A);
2. Mixed model linear ANOVAs were performed separately for each physiological waveform (1: anterior palate pressure bulb; 2: mid-palate pressure bulb; 3: submental sEMG) to determine the effects of stimulus, age-group and genetic taste-status on the dependent variable of amplitude (incorporating a covariate of effortful saliva swallow signal amplitude) (Path C);
3. Mixed model linear ANOVAs were performed separately for each physiological waveform and to determine the modulatory influence of a perceived taste intensity covariate on taste, genetic taste-status and age effects on the dependent variable of amplitude (Path B).

Anterior palate pressures will be referred to as Path B_i, with mid-palate pressures and submental sEMG referred to as paths B_{ij} and B_{iii}, respectively. For the mixed model ANOVAs, model fit was explored using a variety of different covariance structures. A heterogeneous compound symmetry structure was determined to have the best fit with the data.

RESULTS

Table 2 provides a cross-tabulation of perceived taste quality for the four different stimuli. The data verify that deionized water was perceived by the majority (85%) of participants as having no taste. When a taste was reported, it was usually classified as bitter. The citric acid was perceived by the majority of participants (84%) to be sour tasting; a bitter taste quality was reported by 15% of participants with this stimulus. The carbonated stimulus was either perceived to have no taste (40%) or a bitter taste (39%) in the majority of cases; this was the only stimulus where perceived saltiness was reported in more than one case. Finally, the diluted ethanol stimulus was perceived to be bitter in the majority of cases (79%) and to have no taste by 14% of participants. A burning/stinging sensation was reported for both the citric acid and the ethanol stimuli, with the intensity of the burning sensation being stronger for the ethanol, with a 95% confidence interval of 19–63 on the gLMS, and only mild (95% CI: 0–26) for the citric acid stimulus. It is noteworthy, that the highest degree of reported burning for the citric acid stimulus was seen in the older supertaster subgroup. Perceived fizziness was only rated for the carbonated stimulus, with a 95% confidence interval from 13–45 on the gLMS. The young non-taster subgroup reported the lowest intensity of perceived fizziness.

Table 3 shows descriptive statistics for perceptual ratings of taste intensity by age-group and genetic taste-status for the four stimuli. Perceived burning/stinging and fizziness ratings are

also shown for the ethanol and citric acid and the carbonated stimuli, respectively. Descriptive statistics for lingua-palatal pressure and submental sEMG amplitudes are shown in mmHg and μV , respectively by sensor (anterior palate pressure bulb; mid-palate pressure bulb; submental sEMG sensor), age-group and genetic taste-status for the four stimuli in Table 4. Values in Table 4 are modeled at the mean values for the covariate of effortful saliva swallow amplitude for each signal.

Path A

Regarding the effects of stimulus, age-group and genetic taste-status on perceived taste intensity, statistically significant differences between stimuli [$F(3, 228) = 155.64, p = 0.000$] and genetic taste-status groups [$F(1, 76) = 8.59, p = 0.004$] were observed. These results showed an ascending gradient of perceived intensity from water to carbonation, to ethanol, to the citric acid stimulus, with significant increases between each stimulus along this gradient. Super-tasters reported significantly higher perceived taste intensity than non-tasters for all stimuli. Additionally, there was a significant interaction between these two factors [$F(3, 228) = 3.14, p = 0.026$], such that the differences in taste intensity across stimuli were perceived as greater by the supertasters than the differences perceived by the non-tasters. The difference in perceived intensity between age-groups was also significant [$F(1, 76) = 3.984, p = 0.05$], with heightened intensity reported by the older participants. There were no statistically significant interactions with age for taste intensity perception. These results are illustrated in Figure 4.

Path C

Genetic taste status was not found to have any influence on lingua-palatal pressure or sEMG swallowing amplitudes. Observed amplitudes for liquid pressure and sEMG were all significantly positively correlated with the covariate of effortful saliva swallow amplitude, as shown previously in Figure 3. A statistically significant main effect of stimulus was seen for lingua-palatal pressure amplitude at the anterior bulb [$F(3, 203.17) = 3.75, p = 0.012$], with the greatest pressure amplitudes elicited by the citric acid stimulus and these being significantly higher than those seen for water. Anterior palate pressures varied significantly according to, and displayed a positive correlation with, the covariate of effortful saliva swallow amplitude [$F(1, 66.97) = 12.29, p = 0.001$]. No stimulus effects were seen for lingua-palatal pressure amplitudes at the mid bulb, but these also varied significantly in relation to the pressure amplitudes seen in the effortful saliva swallowing task [$F(1, 69.00) = 29.21, p = 0.000$]. For the sEMG data, a significant main effect of stimulus was seen [$F(3, 162.98) = 20.81, p = 0.000$], with both the citric acid and the ethanol stimuli eliciting higher amplitudes than the water and carbonated stimuli. Significantly lower sEMG amplitudes were seen in the older participant group [$F(1, 67.98) = 11.66, p = 0.001$], and sEMG amplitudes again varied significantly as a function of, and displaying a positive correlation with effortful saliva swallow task values [$F(1, 67.89) = 50.99, p = 0.000$].

Path B_i (Anterior Palate Pressures)

At the level of the full statistical model, significant effects of stimulus [$F(3, 177.42) = 5.477, p = 0.001$] and effortful saliva swallow amplitude [$F(1, 142.58) = 4.95, p = 0.028$, positive

correlation], were seen for anterior palate pressures, as described in the prior explorations for path C. A number of significant 2-way and 3-way interactions were also observed between factors of stimulus, effortful saliva swallow strength, genetic taste status and perceived taste intensity. Given that age did not show any significant influence on these results, it was removed from the model, leaving a statistically significant 3-way interaction between stimulus, effortful saliva swallow strength and perceived taste intensity [$F(3, 203.88 = 2.70, p = 0.047)$] and significant main effects of stimulus [$F(3, 200.59 = 4.15, p = 0.007)$], effortful saliva swallow strength [$F(1, 133.64 = 6.22, p = 0.014)$] and a 2-way stimulus X perceived intensity interaction [$F(3, 203.89 = 3.36, p = 0.02)$]. Figure 5 illustrates these effects, with anterior palate pressure amplitudes shown in values transformed relative to effortful saliva swallow strength. Here, it is seen that anterior palate pressures decline with increasing intensity of the carbonated stimulus, and show the opposite pattern, increasing amplitudes with increasing intensity, with the citric acid stimulus. There is no apparent effect of taste intensity for the ethanol stimulus.

Path B_{ii} (Mid-palate Pressures)

At the level of the full statistical model, a single significant main effect of effortful saliva swallow strength [$F(1, 140.47 = 12.76, p = 0.000)$] was seen for mid-palate pressures, with higher pressures seen in those with stronger effortful saliva swallow values. This remained the case when age-group was removed from the model, with the influence of effortful saliva swallow strength being slightly enhanced [$F(1, 127.99 = 16.81, p = 0.000)$].

Path B_{iii} (Submental sEMG)

Similarly, submental sEMG amplitudes showed a single significant effect of effortful saliva swallow amplitude [$F(1, 152.16) = 28.14, p = 0.000$, positive correlation], at the level of the full model. When simplified to remove consideration of the influence of age-group, additional findings in the form of a significant 4-way interaction (stimulus X genetic taste status X effortful saliva swallow strength X perceived intensity) [$F(3, 211.44 = 2.98, p = 0.03)$] as well as a significant 2-way stimulus X effortful saliva swallow strength interaction [$F(3, 197.10 = 7.59, p = 0.000)$] and a significant main effect of stimulus [$F(3, 197.57 = 2.98, p = 0.033)$] became apparent. As illustrated in Figure 6, with sEMG amplitudes displayed in values transformed relative to the effortful saliva swallow strength covariate, all three chemesthetic stimuli showed a weak trend of eliciting greater amplitudes of submental muscle contraction with greater perceived taste intensities in the non-tasters. However, in the supertaster group, a much stronger effect is seen for the citric acid stimulus, which elicited stronger amplitudes of muscle contraction at higher perceived stimulus intensities.

DISCUSSION

This is, to our knowledge, the first study in the dysphagia literature to explore differences in swallowing with chemesthetic stimuli as a function of the perceived taste intensity of those stimuli, while controlling for genetic taste status. A number of key findings are worthy of discussion.

Beginning with stimulus perception, it is interesting to note that our participants reported the perception of a taste in cases where we had expected there to be no taste. The ethanol stimulus was reported to have a bitter taste in the majority of cases, while the carbonated water was perceived as either bitter or salty by almost half of the participants. We suspect that when faced with the binary task of indicating whether or not they perceived a taste, these participants chose to report a taste when the nature of the sensation was more likely to be chemesthetic. The perception of saltiness with the carbonated water may be explained by the fact that sodium bicarbonate was an ingredient in the recipe. Interestingly, even deionized water was reported to have a bitter taste by 11% of the participants. The reported perceptions of chemesthesia in this study were associated with specific stimuli. The carbonated stimulus was reported to be fizzy, while the citric acid stimulus was perceived to cause a slight burning/stinging sensation, in comparison to the ethanol, which was perceived as causing a moderate burning/stinging sensation.

It is clear that supertasters experience heightened taste intensities for the carbonated, ethanol and citric acid stimuli used in this study. Both supertasters and nontasters in our study sample reported a gradient of perceived intensity across stimuli, with the highest reported intensities seen for the 2.7% citric acid solution. This finding confirms that participants in prior studies involving a sour stimulus of this concentration were likely perceive these sour stimuli as being of high intensity. Interestingly, however, carbonated stimuli had a much lower perceived taste intensity than the citric acid stimulus in both genetic taste subgroups in our sample. The ethanol stimulus, which is unlikely to be practical for use in clinical settings, also elicited strong ratings in both groups for taste intensity, but these were not as strong as the ratings seen for the citric acid stimulus. These findings would appear to be convergent with the available literature suggesting that sour stimuli may have the potential to influence swallowing behavior. However, evidence of different perceived intensities between nontasters and supertasters suggests that clinicians may need to consider genetic taste status as a factor that influences a patient's likelihood of responding favorably to manipulations of bolus taste and chemesthesia.

Turning to the Path C results, exploring swallowing parameters without consideration of perceived taste intensity, there are several noteworthy findings. First, it is clear that both tongue-palate pressure measures and submental sEMG measures in this study varied as a function of the participant's strength, as indexed by the effortful saliva swallowing task covariate. While inter-participant variations have been long recognized to be a factor in EMG data, requiring normalization or transformation for interpretation, this study suggests that the same is true for lingua-palatal pressures. When the effortful saliva swallow strength covariate is taken into account, these data show a remarkable lack of variation in tongue-palate pressures attributable to age. This finding is consistent with prior literature suggesting that age-related differences in tongue pressure and functional reserve may be limited to differences in maximal effort tasks, and may not be evident in bolus swallowing tasks (Nicosia et al., 2000; Youmans et al., 2009).

Second, the path C analyses in this study show an interesting pattern of variations in anterior tongue-palate pressures and submental sEMG measures across stimuli, but no such pattern for the mid-palate pressure data. In both cases, the citric acid stimulus elicited stronger

amplitudes than water. The lack of any stimulus-related differences in mid-palate pressure may reflect greater inherent variability in pressure measures at this location, perhaps attributable to differences in palatal vault height across participants, as reported in prior studies (Steele, Bailey, & Molfenter, 2010). Alternatively, this finding may suggest that differences in swallowing behavior related to the experience of tasting a stimulus occur primarily in the anterior oral cavity and influence the initial driving forces of the anterior tongue. Genioglossus muscle activity is likely to be captured in the composite submental sEMG signal, perhaps providing a rationale for the fact that this effect was also seen in those data. Quite why stimulus-dependent heightened amplitudes of anterior tongue-palate pressure are not translating to similar patterns at a more distal pressure sensor location remains unclear.

When the influence of perceived taste intensity is factored into the analysis of swallowing behavior (path B), the results of this study provide further support for the potential of high intensity sour stimuli to influence swallowing. Higher amplitudes of anterior tongue-pressure and submental sEMG were seen with greater perceived intensity of this stimulus, with the sEMG effect being particularly strong in supertasters.

This study is not without limitations. The protocol included a single effortful saliva swallow task as a means of measuring differences in strength across participants. This measure is not the same as the conventional approach to measuring functional reserve, which involves a comparison of maximum isometric tongue-palate pressure tasks to regular effort saliva swallows (Steele, 2012). A single repetition of this task may also be inadequate to properly characterize variability in strength across participants. Additionally, the data on perceived taste intensity do not take the palatability or hedonics of the taste experience into account. Future work should explore both the intensity of a stimulus and the degree to which a participant likes or dislikes the stimulus, to properly understand the influence of these sensory parameters on swallowing behaviors.

CONCLUSIONS

In conclusion, this study provides evidence that high intensity sour stimuli do influence the amplitudes of anterior tongue-palate pressures and submental muscle contraction seen in swallowing. Importantly, variations in swallowing behavior attributable to this taste stimulus are mediated by the perceived sensory intensity of the stimulus and differ between those who are classified as supertasters and nontasters, based on genetic factors. This finding suggests that it may be important to understand taste genetics when determining whether manipulations of stimulus taste may be of benefit for patients with dysphagia. Further, the three stimuli explored in this study were chosen based on their presumed chemesthetic properties, that is, activation of trigeminal nerve receptors. Chemesthesis is different than taste perception. Future studies are needed to tease out the different contributions of taste intensity and chemesthesis intensity on swallowing, using a continuum of chemesthetic intensities in addition to taste intensities.

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Figure 1.
General Labeled Magnitude Scale (Bartoshuk et al.).

Figure 2.
 Relationship between bolus swallowing signal amplitudes and strength, as indexed by effortful saliva swallow signal amplitudes.

Figure 3.
Path analysis used in this study to explore the influence of differences in perceived taste intensity for four liquids on swallowing behaviors.

Figure 4. Results of the Path A analysis, showing differences in perceived taste intensity for four liquids as a function of age-group and genetic taste status.

Figure 5. Results of the Path B_i analysis, showing the influence of perceived differences in taste intensity for four liquids on the amplitude of anterior tongue-palate pressures.

Figure 6.

Results of the Path B_{iii} analysis, showing the influence of perceived differences in taste intensity for four liquids on the amplitude of submental sEMG in nontaster and supertaster subgroups.

Table 1

Mean Age (Standard Deviation) of Participants, Grouped by Age and Genetic Taste Status

	Young	Older
Non-tasters	25.8 (4.7)	71.5 (8.7)
Supertasters	26.5 (3.4)	72.6 (7.4)

Table 2

Frequencies (number and percent) of taste quality perception for the four stimuli in the experiment.

Perceived Taste Quality	Stimulus							
	Water		High citric acid		Carbonated		Ethanol	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Sweet	1	1%	0	0%	2	3%	1	1%
Sour	1	1%	67	84%	6	8%	5	6%
Salty	1	1%	1	1%	8	10%	0	0%
Bitter	9	11%	12	15%	31	39%	63	79%
No taste	68	85%	0	0%	33	41%	11	14%

Table 3

Descriptive statistics for ratings of perceived taste intensity, burning and fizziness for four liquid stimuli by age-group and genetic taste status.

Stimulus	Age-Group	Genetic Taste Status	Mean Perceived Taste Intensity (0–100 on the gLMS)	95% Confidence Interval		Mean Perceived Burning (0–100 on the gLMS)	95% Confidence Interval		Mean Perceived Fizziness (0–100 on the gLMS)	95% Confidence Interval	
				Lower Bound	Upper Bound		Lower Bound	Upper Bound		Lower Bound	Upper Bound
Water	Young	Nontaster	0.10	–8.92 ^a	9.12 ^a	n/a	n/a	n/a	n/a	n/a	n/a
		Supertaster	1.40	–7.62 ^a	10.42 ^a	n/a	n/a	n/a	n/a	n/a	n/a
Carbonated	Old	Nontaster	0.00	–9.02 ^a	9.02 ^a	n/a	n/a	n/a	n/a	n/a	n/a
		Supertaster	2.30	–6.72 ^a	11.32 ^a	n/a	n/a	n/a	n/a	n/a	n/a
	Young	Nontaster	9.60	0.58	18.62	n/a	n/a	n/a	20.35	13.19	27.51
		Supertaster	12.20	3.18	21.22	n/a	n/a	n/a	30.35	19.35	41.35
Ethanol	Old	Nontaster	12.85	3.83	21.87	n/a	n/a	n/a	32.45	19.80	45.10
		Supertaster	14.60	5.58	23.62	n/a	n/a	n/a	32.55	22.12	42.98
	Young	Nontaster	30.15	21.13	39.17	27.60	18.93	36.27	n/a	n/a	n/a
		Supertaster	45.30	36.28	54.32	50.90	38.35	63.45	n/a	n/a	n/a
Hi Sour	Old	Nontaster	42.45	33.43	51.47	44.40	29.02	59.78	n/a	n/a	n/a
		Supertaster	53.00	43.98	62.02	48.10	34.00	62.20	n/a	n/a	n/a
	Young	Nontaster	42.20	33.18	51.22	3.70	0	8.50	n/a	n/a	n/a
		Supertaster	62.15	53.13	71.17	1.60	0	3.77	n/a	n/a	n/a
	Old	Nontaster	55.20	46.18	64.22	2.55	0	6.09	n/a	n/a	n/a
		Supertaster	67.75	58.73	76.77	13.80	1.43	26.17	n/a	n/a	n/a

^aNon-zero values were artificially modeled to facilitate inclusion of the data in the statistical models

n/a = not applicable (specific chemesthetic sensations were not explored for these stimuli)

Table 4

Descriptive statistics for swallowing parameters (lingua-palatal pressures and submental sEMG), shown by stimulus, age-group and genetic taste-status.

Parameter	Stimulus	Age-Group	Genetic Taste Status	Mean Swallowing Amplitude	95% Confidence Interval	
					Lower Bound	Upper Bound
Anterior Palate Pressures (mm Hg)	Water	Young	Nontaster	139.69 ^a	94.68	184.71
			Supertaster	167.98 ^a	119.41	216.54
		Old	Nontaster	118.79 ^a	74.97	162.61
			Supertaster	152.17 ^a	108.22	196.11
	Carbonated	Young	Nontaster	142.14 ^a	97.12	187.16
			Supertaster	206.94 ^a	159.18	254.69
		Old	Nontaster	170.80 ^a	126.98	214.62
			Supertaster	160.58 ^a	116.63	204.53
	Ethanol	Young	Nontaster	136.10 ^a	91.08	181.12
			Supertaster	154.69 ^a	106.93	202.45
		Old	Nontaster	172.44 ^a	128.62	216.26
			Supertaster	134.87 ^a	90.92	178.82
Mid-Palate Pressures (mm Hg)	Citric acid	Young	Nontaster	167.10 ^a	122.09	212.12
			Supertaster	194.30 ^a	146.54	242.06
		Old	Nontaster	162.28 ^a	118.45	206.09
			Supertaster	167.43 ^a	123.48	211.38
	Water	Young	Nontaster	140.85 ^b	107.52	174.17
			Supertaster	167.74 ^b	132.78	202.69
		Old	Nontaster	146.09 ^b	114.42	177.76
			Supertaster	150.95 ^b	118.52	183.37
	Carbonated	Young	Nontaster	136.23 ^b	102.91	169.55
			Supertaster	181.53 ^b	147.14	215.93
		Old	Nontaster	166.11 ^b	134.44	197.78

Parameter	Stimulus	Age-Group	Genetic Taste Status	Mean Swallowing Amplitude	95% Confidence Interval		
					Lower Bound	Upper Bound	
Submental sEMG (μV)	Ethanol	Young	Supertaster	161.49 ^b	129.07	193.92	
			Nontaster	129.46 ^b	96.14	162.78	
			Supertaster	174.75 ^b	140.35	209.14	
		Old	Nontaster	160.08 ^b	128.41	191.75	
			Supertaster	154.40 ^b	121.97	186.82	
			Nontaster	167.48 ^b	134.16	200.80	
	Citric acid	Young	Supertaster	182.75 ^b	148.35	217.15	
			Nontaster	149.43 ^b	117.76	181.10	
			Supertaster	171.05 ^b	138.62	203.47	
		Water	Young	Nontaster	27.45 ^c	14.50	40.40
				Supertaster	39.54 ^c	26.01	53.07
			Old	Nontaster	44.45 ^c	32.22	56.67
	Supertaster			48.37 ^c	36.21	60.54	
	Carbonated	Young	Nontaster	25.86 ^c	13.18	38.54	
			Supertaster	40.09 ^c	26.54	53.64	
			Nontaster	50.44 ^c	38.22	62.66	
Old		Supertaster	51.50 ^c	39.34	63.66		
		Nontaster	40.66 ^c	27.98	53.34		
		Supertaster	50.90 ^c	37.36	64.43		
Ethanol	Young	Nontaster	68.59 ^c	56.37	80.81		
		Supertaster	65.14 ^c	52.98	77.31		
		Nontaster	55.29 ^c	42.38	68.19		
	Old	Supertaster	56.99 ^c	43.44	70.54		
		Nontaster	73.78 ^c	61.56	86.00		
		Supertaster	68.04 ^c	55.87	80.20		

- ^a Modeled at the mean covariate value for effortful saliva swallow strength of 292.87 mm Hg.
- ^b Modeled at the mean covariate value for effortful saliva swallow strength of 279.58 mm Hg.
- ^c Modeled at the mean covariate value for effortful saliva swallow strength of 75.27 μ V.