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The Influence of Taste on Swallowing Apnea, Oral Preparation Time, and Duration and Amplitude of Submental Muscle Contraction

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Abstract

Prior research has documented a modulating effect of taste on swallowing. We hypothesized that presentation of tastant stimuli would be a significant variable in swallowing–respiratory coordination, duration of oral bolus preparation, and submental muscle contraction. Twenty-three healthy females were presented with 1-cm^3 gelatin samples flavored with 4 tastants of increasing intensities. Visual analogue scale ratings of perceived intensity of each were used to identify relative equivalent concentrations across the 4 tastants. Data were then collected during ingestion of 5 trials of the 4 equivalent tastants using measurements of nasal airflow and submental surface electromyography (sEMG) to record biomechanical measures. Chi-square analysis failed to identify a statistically significant influence of taste on the phase location of swallowing apnea. Repeated measures analysis of variance demonstrated significant taste effects for oral preparation time, submental sEMG amplitude, and duration ($P < 0.02$). Sweet tastants were prepared for a shorter time when compared with bitter tastants. Swallow duration for sour, salty, and bitter tastants were longer than sweet and neutral tastants. Sour tastants resulted in the greatest amplitude of submental muscle contraction during swallowing. This study supports existing research that found that sour substances were swallowed with more effort when compared with other tastes.

Key words: bitter, deglutition, salty, sour, surface electromyography, sweet

Introduction

Eating and drinking are mostly pleasurable activities and the act of deglutition, or swallowing, is influenced by the taste of the food and drink ingested. Although the human tongue is able to recognize many different taste compounds, there are 4 universally accepted tastes: sweet, salty, sour, and bitter. Special receptors for water found in the oropharynx have also been described by Lindermann (1996) and Miller (1999).

Bolus properties such as temperature, volume, and texture are known to modulate swallowing behavior through adaptation of biomechanical and temporal measures. Tastant properties such as palatability and intensity of taste may have similar effects (Lindermann 1996; Smith and Margolskee 2001). Using surface electromyography (sEMG), Ding et al. (2003) found stronger submental muscle contraction for salty boluses compared with sweet and sour boluses. The authors also found shorter sEMG onset times for sweet and sour boluses. Palmer et al. (2005) supported this finding using intramuscular EMG for sour versus water swallows. They reported stronger muscle contraction of submental muscles when sour boluses were used. In addition, the amount of time required for all 3 submental muscles (mylohyoid, geniohyoid, and anterior belly of digastric) to activate was closely approximated for sour boluses.

In a study comparing one group of patients with dysphagia due to stroke and another group with dysphagia following other neurological events, Logemann et al. (1995) found that sour liquid boluses led to an improvement in the onset of oral phase in both groups, with a reduction in frequency of aspiration in the latter group. They hypothesized that sour boluses facilitated a more organized swallow by increasing preswallow sensory input to the brainstem, thus allowing for more rapid approximation of the threshold required

for triggering a swallow. Although sour boluses improved oral and pharyngeal phases of swallow, and even reduced aspiration, sweet–sour bolus eliminated this benefit, even if it did improve palatability (Pelletier and Lawless 2003). In contrast, Hamdy et al. (2003) found the opposite effects of sour boluses in their population. Instead of facilitating swallows, liquid sour boluses decreased the capacity and speed of swallow, especially if the boluses were also cold. In a group of young, healthy adults, Chee et al. (2005) reported that glucose, citrus, and saline were found to decrease swallowing speed when compared with water.

To date, the influence of taste on the physiology of swallowing remains equivocal. This may be in part due to differences in methods employed. The type of stimulus presented poses a challenge when interpreting data on taste studies and may account for the inconsistencies in results. Researchers have employed application of sour stimulus by means of a lemon glycerine swab onto the faucial arches, (Sciortino et al. 2003), liquid boluses ranging from 1 ml (Logemann et al. 1995) to 50 ml (Hamdy et al. 2003; Chee et al. 2005) delivered orally, and also liquid boluses that are infused directly into the pharyngeal region (Kajii et al. 2002). Although studies that compare different tastes on swallowing biomechanics have ranged from 2 to 8 tastants, no studies have sought to establish equivalent taste intensities. This may be a substantial methodological oversight as differences found in swallowing behavior found by previous researchers may be attributed to an overall increase in sensory input rather than actual differences in taste.

These researchers have hypothesized that peripheral sensory receptors in the taste buds must be stimulated to approximate the sensory threshold of swallows in the brainstem for stronger, more timely swallows (Kajii et al. 2002; Pelletier and Lawless 2003). If this were true, it would be important to investigate the effects of different tastes in a methodical manner as this may have implications on therapy techniques employed by clinicians working with the dysphagic population. Although liquid boluses are used most frequently, a bolus consistency that allows for adequate stimulation of the taste buds while reflecting normal eating habits would be ideal. Semisolid tastants that would require the participants to masticate before swallowing may allow for prolonged stimulation of peripheral sensory receptors compared with liquid boluses.

The aim of this study was to gain a better understanding of the role of taste in modulating swallowing using a novel masticated stimulus. A preliminary study was carried out to establish the equivalent taste intensity across 4 tastants: sweet, sour, salty, and bitter. This ensured that stimuli used for a following study had been judged to be most similar in taste intensity. A subsequent study was carried out to investigate the influence of taste on physiology of swallowing using sEMG and respiratory airflow measures. We hypothesized that taste stimuli would differentially affect phase and duration of swallowing apnea, duration of oral preparation, and duration and amplitude of submental muscle contraction and that respiration would occur predominantly in midexpiration for all tastants in young, healthy females. Specifically, we hypothesized that swallowing apnea duration would be longer for bitter tastants compared with sweet, sour, and salty tastants. Furthermore, we expected duration and peak of submental muscle contraction for sour tastants to be greater than other tastants.

Materials and methods

Phase 1

Sucrose, citric acid, sodium, and quinine were used to represent sweet, sour, salty, and bitter tastes, respectively. These compounds were chosen based on their thresholds for taste identification (Given and Paredes 2002) and that the fine and dry crystal form allowed for standardization of measurement. All compounds were weighed using the Ohaus ''Adventurer'' analytical balance (Model AR2140), with an accuracy of $\times 10^{-4}$ g. Table 1 shows the minimum threshold weight of the substance required for identification and each level of concentration used in this experiment. With the exception of sucrose with 7 levels of concentration, 5 levels of concentrations were obtained for all other tastes by doubling the minimum threshold level for each taste. Pilot data had indicated that sucrose would be required in higher concentrations to equal the perception of taste intensity of the other tastants, thus, 2 additional levels were prepared.

Preparation of samples

Fifty grams of gelatin crystals were dissolved in 1 l of pure boiling water. Each preweighed taste substance was placed in a clean plastic container. Two hundred milliliter of gelatin liquid was poured into each container of tastant through a fine strainer and stirred until the taste substance dissolved completely. The liquid gelatin was allowed to cool and set without refrigeration. After 2 h, the set gelatin samples were cut into cubes measuring 1 cm^3. All samples were prepared on the morning of Phase 1 of the study.

Procedure

This phase of the study was conducted in one session. Twenty-three female participants (mean age = 25 years, range 20–45) were recruited from a university undergraduate course. Exclusion criteria included a history of neurological, gastroesophageal, or pulmonary diseases affecting swallowing. Research participants were seated upright in a chair facing a wall. Although all participants completed the task in a single session, they were not allowed visual or verbal contact or communication. They were presented with a neutral gelatin sample and asked to ''chew and swallow as they normally would.'' Participants were explicitly told: ''This sample represents a neutral taste.'' Following this, they were presented with one sample of the lowest and highest

Table 1 Taste compounds used in preparation of tastants

Taste	Sweet	Sour	Salty	Bitter
Compound	Sucrose	Citric acid	Sodium chloride	Quinine
Minimum threshold level (MTL) (M)[a]	0.01 M	0.023 M	0.01 M	8 μM
Weight of substance at MTL (g)	3.422	1.105	0.584	0.0026
Concentration levels (g/l of water + 200 ml of gelatine)				
1	3.422	1.105	0.584	0.003
2	6.844	2.209	1.168	0.006
3	13.688	**4.419**[b]	2.336	0.012
4	27.376	8.838	**4.672**[b]	**0.024**[b]
5	54.752	17.676	9.334	0.048
6	**109.504**[b]			
7	219.008			

[a]From Given and Paredes (2002).
[b]Concentration of tastants selected for Phase 2.

concentration of sweet tastant to become familiar with the minimum and maximum concentrations of a sweet taste. Participants were instructed: "The minimum concentration is represented at the far left and the maximum concentration is represented at the far right end of this 15 cm Visual Analogue Scale (VAS)." Identification of lowest and highest concentrations used in the study was repeated for the sour, salty, and bitter taste samples. Following the minimum–maximum recognition task, participants were given 23 samples (7 levels of sweet; 5 levels of sour, salty, and bitter; and 1 neutral) presented in random order and asked to rate each tastant on the VAS. No written descriptors were provided on the scale. An oral rinse and expectoration were performed prior to the procedure and between each sample. Participants were told to rid the mouth of any lingering aftertaste before the next sample. All participants rinsed and expectorated at least once and were given the option to rinse more than once if necessary.

A total of 529 VAS ratings were analyzed for taste intensity ratings. A centimeter ruler was used to measure the distance marked by participants from the left border of the 15-cmVAS. Mean, mode, and median values for each taste sample were obtained. Results indicate that the calculated mode had concentrations that were perceived to be most similar across tastes (Figure 1). These concentrations were used in the preparation of taste samples for Phase 2 of the study.

Phase 2

Equipment

Measurement of submental sEMG and respiratory airflow were collected using the Kay Elemetrics Digital Swallowing Workstation (Lincoln Park, NJ, Model 7200). Bipolar surface electrodes were placed at midline under the chin and overlying the submental muscle group to allow measurement of relative strength and timing of anterior suprahyoid muscle contraction associated with the onset of anterior hyoid excursion during pharyngeal swallowing. Swallowing–respiratory coordination was monitored using nasal prongs placed at the entrance of the nose that measured inspiratory and expiratory airflow. During quiet breathing, an upward excursion of the tracing denoted expiration, whereas a downward excursion of the tracing denoted inspiration. During swallowing, respiration ceased briefly, and a corresponding swallowing apnea was observed. These measurements are annotated in Figure 2. The sEMG and nasal airflow signals were recorded and stored for later analysis.

Procedure

Phase 2 of the study was carried out at the swallowing research laboratory within 2–4 weeks of completion of Phase 1. For this study, individual data collection sessions were scheduled for 25 healthy females (mean age = 24.2 years, range 20–45), 23 of whom had provided data for Phase 1. After placement of the sEMG electrodes and nasal cannula, participants were given 3 min to adjust to the presence of the nasal cannula before presentation of the first test sample. Following the adjustment time, participants were given 250 ml of water as an oral rinse prior to data collection. Each participant was presented 5 gelatin cubes of each tastant in random order using the equivalent taste intensities established in Phase 1 of the study (highlighted in bold in Table 1). In addition, 5 neutral gelatin cubes were randomly interspersed. Participants were given clear instructions: "Take the sample in your mouth, chew it up as you normally would,

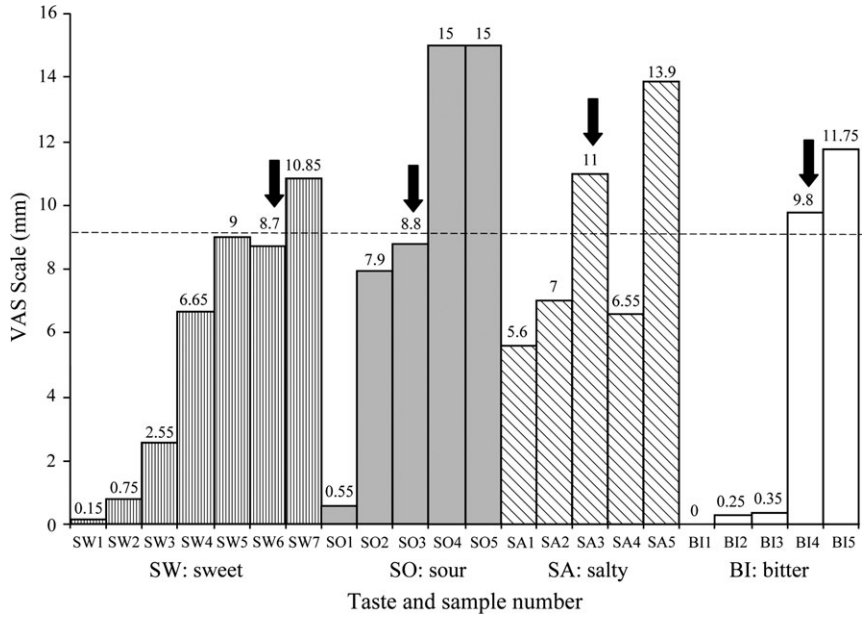

Figure 1 VAS mode values for each taste sample.

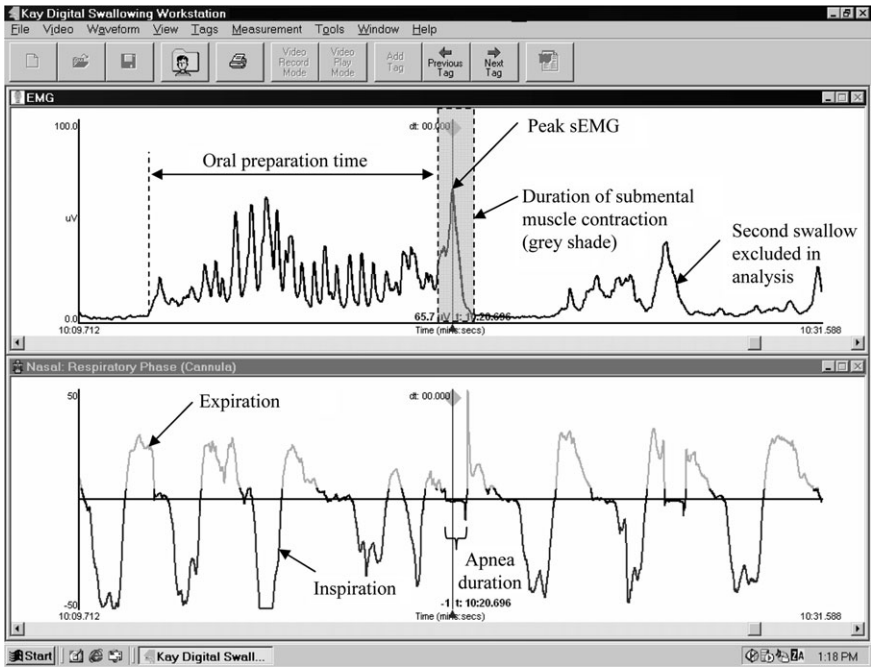

Figure 2 Annotated example of sEMG signal and nasal airflow tracing.

and swallow when you are ready. Please raise your hand to signal completion of the swallow.'' Oral rinse with expectoration was performed between tastants to ensure that the taste of each sample did not influence subsequent swallows. Although some participants provided feedback on the unpleasant taste of some samples, no participants had difficulty completing the task.

A total of 625 swallows were analyzed. Five measurements were taken from each swallow during off-line analysis of the data. The phase of respiration in which swallowing occurred was coded as midexpiratory, midinspiratory, the transition between inspiration and expiration, or the transition between expiration and inspiration. The duration of swallowing apnea, in millisecond, was measured directly from the

respiratory waveform tracing. The duration of oral preparation was defined as the onset of sEMG activity to the base of the peak associated with the start of a swallow. The duration of submental sEMG was defined as the onset of a rapidly increasing sEMG excursion immediately after chewing time to the return of the tracing to the baseline surrounding the peak amplitude. Only data from the first swallow were analyzed; if a participant took more than one swallow for the given tastant, subsequent swallows were not examined. Peak amplitude of submental muscle contraction was defined as the highest peak of sEMG tracing during the swallow immediately after chewing. As floor of mouth muscle activity during chewing may present a higher amplitude sEMG signal than during swallowing, identification of swallowing apnea using nasal respiratory airflow tracing assisted in identification of the pharyngeal swallow (Figure 2).

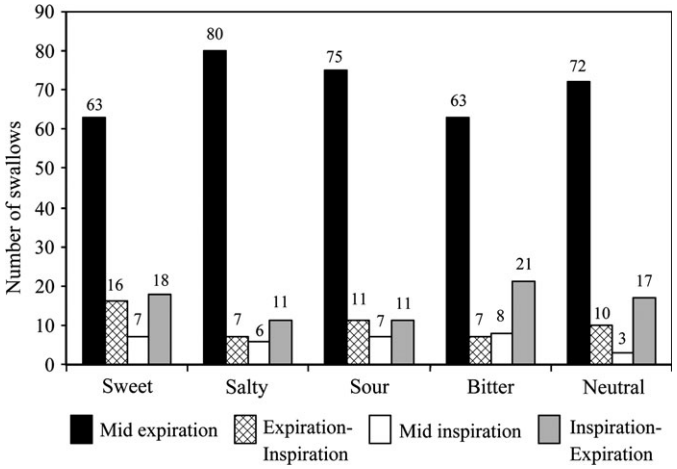

Figure 3 Distribution of the swallowing apnea phase across the 5 tastants.

Data analysis

Measurements were evaluated using a computer statistical package (SPSS release 11.5). An α level of 0.05 was adopted for all analyses. Chi-square analysis with factors of subject and phase were completed to evaluate phase by trial interactions and phase by tastant interactions across subjects. Repeated measures analyses of variance (ANOVAs) were undertaken to investigate the effect of trial, taste and taste by trial on duration of swallowing apnea, oral preparation time, and duration and amplitude of submental sEMG. The sphericity assumption for repeated measures was tested using Mauchly's test, and the Hyunh–Feldt adjustment was applied when this assumption was not met.

Results

Phase and duration of swallowing apnea

The onset of swallowing apnea within the midexpiratory phase of respiration was the most prevalent pattern of coordination between respiration and swallowing (r = 369.768, $P < 0.001$), irrespective of tastant. This pattern of swallowing–respiratory coordination occurred on 68.8% of swallowing; this was followed by 15.2% of swallows occurring at the inspiratory–expiratory cusp, 9.9% at the expiratory–inspiratory cusp, and only 6% of swallows occurring midinspiration.

Figure 3 summarizes the distribution of the swallowing apnea phase across the 5 tastants in the experiment. Chi-square analysis failed to identify a significantly different distribution of phase prevalence between the 4 tastants and a neutral trial (r = 15.86, P = 0.198). Finally, repeated measures ANOVA documents no significant main effect for taste on the dependent variable of duration of swallowing apnea (F (1,4) = 0.625, P = 0.646).

Table 2 summarizes the duration of oral bolus preparation, duration of submental sEMG, and mean amplitude of submental sEMG for all tastants. Statistical analysis revealed no significant trial effect on oral preparation time, duration of swallow, or submental sEMG amplitude (Table 3). All 3 variables were stable across the 5 trials within a given taste. In addition, there was no identified trial by taste interaction on any variable. There was, however, significant main effects of taste on the variables of oral preparation, duration, and strength of swallow (Table 3). Tables 4, 5, and 6 display subsequent pairwise comparisons for these variables.

Table 2 The influence of taste on duration of oral bolus preparation, duration of submental sEMG, and amplitude of submental sEMG

Taste	Duration of oral bolus preparation		Duration of submental sEMG		Amplitude of submental sEMG	
	Mean (s)	SD	Mean (s)	SD	Mean (μV)	SD
Sweet	9.049	2.77	1.214	0.21	68.700	28.64
Sour	9.038	4.03	1.234	0.23	82.756	33.13
Bitter	10.896	5.34	1.361	0.42	72.318	29.67
Salty	10.547	4.80	1.302	0.35	70.347	27.90
Neutral	10.299	4.50	1.167	0.23	70.449	32.24

Oral preparation time

Sour tastants had the shortest oral bolus preparation time followed closely by sweet tastants (9.049 vs. 9.038 s), although the difference was not statistically significant (Table 4). In contrast, duration of oral preparation for sour tastants was significantly shorter than the duration calculated for the bitter and salty tastants. Similarly, at a mean of 10.896, bitter boluses were prepared for a significantly longer time when compared with sweet and sour tastants (Table 4). There were no significant differences in oral preparation time for neutral, salty, and bitter tastants when compared with each other.

Table 3 Taste and trial effects on duration of oral bolus preparation, duration of oral bolus preparation, duration of submental sEMG, and amplitude of submental sEMG

	Duration of oral bolus preparation			Duration of submental sEMG			Peak amplitude of submental sEMG		
	F	df	*P*	*F*	df	*P*	*F*	df	*P*
Taste	3.7	2.6,62.1	<0.02[a]	3.6	2.6,61.7	<0.02[a]	18.2	3.6,87	<0.000[a]
Trial	1.1	2.5,60.5	<0.36	0.64	3.3,79.4	<0.61	1.2	2.2,3.5	<0.301
Taste × trial	0.96	8.1,195.5	<0.47	1.1	6.3,151.3	<0.37	1.3	6.8,164.3	<0.250

[a]Significant at α level of 0.05.

Table 4 Pairwise comparisons of the influence of taste on duration of oral bolus preparation

Taste	Taste comparison	Significance	95% Confidence interval for difference	
			Lower bound	Upper bound
Sweet	Sour	0.987	−1.360	1.382
	Bitter	0.009[a]	−3.192	−0.501
	Salty	0.014[a]	−2.666	−0.329
	Neutral	0.015[a]	−2.234	−0.265
Sour	Bitter	0.030[a]	−3.519	−0.196
	Salty	0.099	−3.325	0.308
	Neutral	0.139	−2.960	0.439
Bitter	Salty	0.498	−0.698	1.395
	Neutral	0.105	−0.134	1.328
Salty	Neutral	0.572	−0.645	1.141

[a]Significant at α level of 0.05.

Duration of submental sEMG

Similar patterns were found for the duration of submental sEMG as for the oral preparation time. Duration of submental sEMG activity for sweet tastants was not significantly different than that of sour tastants (1.214 vs. 1.234 s, Table 2). Both sweet and sour tastants had significantly shorter duration of submental sEMG contraction time when compared with bitter tastants (Table 5). The duration of submental sEMG activity for salty tastants was not significantly different from bitter tastants, but bitter tastants showed significantly longer submental sEMG time compared with all other tastants.

Mean amplitude of submental sEMG

Sour tastants produced significantly higher amplitude of submental muscle contraction when compared with all other boluses (Table 6). Sweet tastants had the lowest measured amplitude of submental sEMG contraction of 68.7 μV (Table 2), followed by salty, neutral and bitter tastants, although these differences were not statistically significant (Table 6).

Discussion

The aim of this study was to examine the effects of taste on swallowing physiology in young healthy adults. We hypothesized that different taste stimuli would affect phase and duration of swallowing apnea, duration of oral preparation, and duration and amplitude of submental muscle contraction. Results suggest that there is no significant effect of taste on measures related to swallowing apnea; however, other measures of swallowing biomechanics were substantially influenced by taste.

Our results showed that sweet and sour tasting samples resulted in the shortest oral preparation time and also the shortest floor of mouth contraction time during swallowing. This is in contrast to bitter tasting samples that resulted in the longest oral preparation and floor of mouth contraction time. The preference for sweet food and drinks has been demonstrated even in young children, whose fondness for sweet orangeade increased over an 8-day, repeated exposure (Liem and de Graaf 2004). Therefore, that it takes the shortest time to chew and swallow sweet tastants is not surprising as sweet substances are frequently associated with feelings of pleasure when ingested and known to have a high hedonic value (Lindermann 1996). In addition, foods that provide the most calories are often sweet, and survival instincts of most organism would lead to preference for sweet, high-calorie foods to ensure survival, even as early as the intrauterine stages of development (Bazyk 1990; Kim et al. 2004).

Just as important, bitter taste perception is crucial for the survival of the organism as this enables them to avoid ingesting harmful substances. Peripheral mechanisms of taste play an important role in the identification of substances that are potentially harmful or toxic. Phase 1 of our study showed that only micromolecular levels of quinine were needed to give the perceived equal taste intensity to sucrose, which required a much higher concentration (0.024 vs. 109.504 g). This is largely due to specialized peripheral taste receptors in humans that are designed to detect minute, submicromolecular quantities of noxious compounds at one extreme and submolecular quantity of compounds that provide calories for energy metabolism at the other (Scott 2004).

As bitter foods are said to have a low hedonic tone (Lindermann 1996) coupled with the tendency toward

Table 5 Pairwise comparisons of the influence of taste on duration of submental sEMG

Taste	Taste comparison	Significance	95% Confidence interval for difference	
			Lower bound	Upper bound
Sweet	Sour	0.638	−0.105	0.065
	Bitter	0.044[a]	−0.290	−0.005
	Salty	0.080	−0.186	0.011
	Neutral	0.167	−0.021	0.115
Sour	Bitter	0.040[a]	−0.249	−0.006
	Salty	0.241	−0.184	0.049
	Neutral	0.213	−0.041	0.174
Bitter	Salty	0.335	−065	0.185
	Neutral	0.030[a]	0.020	0.368
Salty	Neutral	0.016[a]	0.027	0.242

[a]Significant at α level of 0.05.

Table 6 Pairwise comparisons of the influence of taste on peak amplitude of submental sEMG

Taste	Taste comparison	Significance	95% Confidence interval for difference	
			Lower bound	Upper bound
Sweet	Sour	0.001[a]	−20.255	−7.857
	Bitter	0.748	−9.621	2.385
	Salty	1.000	−5.319	2.025
	Neutral	1.000	−6.568	3.070
Sour	Bitter	0.001[a]	3.969	16.906
	Salty	0.001[a]	5.723	19.095
	Neutral	0.001[a]	5.198	19.417
Bitter	Salty	1.000	−3.493	7.435
	Neutral	1.000	−3.016	6.755
Salty	Neutral	1.000	−5.810	5.607

[a]Significant at α level of 0.05.

avoidance or even expectoration, one might expect abbreviated chewing and swallowing times for bitter tastants. Yet, our results show that bitter samples had the longest durations for bolus preparation and submental muscle contraction. Our research participants were explicitly instructed to masticate and swallow all samples regardless of the taste presented, without the option of expectoration. Thus, an extended oral preparation time was likely required to override the tendency to expectorate bitter substances, suggesting hesitancy in swallowing. In the absence of expectoration as a protective mechanism, one might hypothesize that increased duration of floor of mouth contraction, as a marker of hyolaryngeal excursion, would assure prolonged biomechanical apnea for protracted airway protection.

However, our data do not support this. Hiss et al. (2001) defined swallowing apnea as a brief closure of the airway that requires cessation in respiration, thus providing a mechanical apnea that functions as secondary airway protection. This study shows that even though bitter tastes influence swallowing by increasing the duration of submental muscle contraction, swallowing apnea duration (SAD) did not vary as a function of taste ($P = 0.646$). A previous study by Butler et al. (2004) comparing sweet and sour and water also failed to identify the effect of taste on SAD. It is acknowledged that submental sEMG is a measure of only one aspect of pharyngeal swallowing, that of muscle contraction which facilitates anterior hyoid movement. Additionally, it is a complex measure as it represents not only floor of mouth but also intrinsic lingual muscle contraction surrounding swallowing. It is therefore likely that the duration of submental sEMG contraction encapsulates the duration of biomechanical deglutitive apnea during swallowing. As such, bitter tastants may prolong duration of muscle contraction for both lingual and floor of mouth muscle without affecting the duration of apnea. Floor of mouth muscle contraction signals the start of a complex sequence of events in pharyngeal swallowing. Superior and anterior hyoid movement follows the contraction of these muscles, and coupled with the relaxation of the cricopharyngeus, pharyngeal swallow is executed. Prolonged suprahyoid muscle contraction may allow the hyoid to remain elevated for longer periods. This is desirable in individuals with cricopharyngeal phase dysphagia who are unable to maintain upper esophageal sphincter opening due to poor hyolaryngeal lift. To date, there have been no studies that included bitter tastes to evaluate SAD, oral preparation, and submental sEMG contraction times, against which we could compare our findings.

A second explanation for our finding may relate to the concentration of quinine used in the preparation of the tastant samples. In humans and as adults, although bitter substances may be appealing in small doses, such as in coffee, it is aposematic, gradually causing an aversion and avoidance as the concentrations and exposure increases. Using sEMG, Horio (2003) found significant relationships between facial and masticatory muscle activities and hedonics of taste stimuli in adults. Young adults showed greater sEMG amplitude for facial muscles and prolonged chewing when they disliked the food. In addition, Neyraud et al. (2005) reported a decrease in the number of masticatory gestures with a corresponding increase in bolus clearance time with increasing quinine concentrations. Although the known threshold of detection of bitter taste is 8 μM (Given and Paredes 2002), the molarity of bitter tastants used in Phase 2 of this study was doubled 3 times as this was the concentration judged most equal to other tastants. Even though palatability was not assessed in this study, hedonics may have

influenced our results. It is likely that the concentration of bitter tastants used had exceeded the concentration deemed appealing to the taste buds, thus leading to an aversion-type response, with a reluctance to chew and swallow the given tastant.

Although facilitative effects of sour bolus on pharyngeal swallowing have been documented, no studies have looked at taste influence on oral preparatory phase of swallowing and duration of floor of mouth muscle contraction times. Longer oral preparation times for bitter substances may have important implications in management of individuals with dysphagia. These data suggest that bitter substances prolonged oral preparation. In patients with sensory impairment, the prolonged oral preparation encouraged by ingestion of bitter substances may allow for increased sensory input to the brainstem, approximating the thresholds required for swallowing. Although bitter tastes are not used in swallowing rehabilitation due to its unacceptable and lingering aftertaste, our findings may warrant further investigation into the concentration of bitter tastant that is acceptable and still increases chewing times.

Our results also show that for all durational measures, sour tastants are not statistically different from sweet tastants. Instead, analysis revealed that sour tastants may facilitate swallowing by increasing the strength of submental muscle contraction during pharyngeal swallow. This finding is consistent with existing literature that had found similar swallowing behavior. Using sEMG measurements to evaluate the effects of taste on swallow physiology, Ding et al. (2003) and Palmer et al. (2005) found that sour bolus led to higher sEMG and intramuscular EMG levels and faster activation of submental muscle under sweet and sour taste conditions compared with no taste conditions, respectively. When a participant ingests a sour bolus, facial and glossopharyngeal nerve activation are heightened. These sensory fibers innervating the oral and pharyngeal regions synapse in the nuclei of the trigeminal system and in the nucleus tractus solitarius (NTS) (Smith and St John 1999). With heightened stimulation of these nerves, one could anticipate a higher activation of neurons in the NTS. Indeed, the pharyngeal branch of the glossopharyngeal nerve (GPN) innervating the pharyngeal area has been shown to be more sensitive to sour tastes (Hanamori et al. 1988; Ding et al. 2003).

As sensory fibers of the GPN synapse in the nuclei of the trigeminal system and the NTS, neurons from the NTS project to the nucleus ambiguus (NA). In turn, the NA activates cranial motor nuclei that supply the floor of mouth muscles that controls tongue and hyoid movements. Together, the NTS and NA are said to gate the sequential activation of motorneurons required for pharyngeal swallowing (Logemann et al. 1995; Jean 2001). Our results revealed that of the 4 tastants tested, only sour tasting stimulus was swallowed with significantly greater muscle contraction compared with all other tastants. This finding is in line with other researchers who found consistently stronger swallow when sour bolus was used (Ding et al. 2003; Palmer et al. 2005). It may be postulated that sensory characteristics of citric acid as was used in our study was sufficient to increase NTS activation, which lead to an increase in NA motor activation resulting in greater muscle contraction. Even though other tastes may be equipotent in modulating swallows in a similar fashion, this was not evident in our study. Further neurophysiological research would be required to investigate the interaction between peripheral taste receptors and subsequent motor responses.

In addition to the cranial nerves that are important for taste (facial, glossopharyngeal, and vagus), the trigeminal nerve is another sensory pathway in the cranial sensory system that is sensitive to chemical stimuli. Trigeminal stimulation is a term commonly used in the literature that refers to a sensation evoked by a stimulus that is neither taste nor smell (Prescott et al. 1993). Even though stimulation of trigeminal receptors does not elicit a taste response, stimulation of trigeminal nerve endings in the mouth contributes to the overall flavor through modalities like touch, temperature and pain. The concentration of citric acid used in our study, coupled with the trigeminal stimulation response, may further account for the strong sEMG amplitude observed. Anterior and superior movement of the hyoid in the swallowing complex is important in ensuring airway protection, and patients with decreased hyolaryngeal excursion are known to experience prandial aspiration (Bulow et al. 2001). As sEMG amplitude measures muscles that contract to elevate the hyoid, it may be inferred that an increase in sEMG signals would also increase hyolaryngeal excursion. It is evident from our study that sour tastants do lead to an increase in sEMG amplitude, but as to whether this is coupled with an increase in hyolaryngeal lift would need to be supported radiographically.

Clinical implications of this study

Research on the influence of taste on swallowing biomechanics has important implications for clinicians working with patients with neurogenic dysphagia. Speech and language pathologists are professionals who work to rehabilitate swallowing impairment in those with dysphagia. The use of small quantities of sour bolus would allow clinicians to facilitate and supplement the learning of swallowing strategies that require increased muscle effort, such as effortful swallows. An increase in muscle contraction may lead to better pharyngeal bolus motility, leaving decreased postswallow residue and thus minimizing potential airway compromise.

Logemann et al. (1995) documented an improvement in the onset of swallowing response in patients with neurogenic dysphagia using 50% lemon juice. Supraglottic penetration and aspiration in nursing home residents with oropharyngeal dysphagia was successfully reduced with the introduction of teaspoon amounts of 2.7% (w/v) citric acid (Pelletier and Lawless 2003). The investigators found

that the residents were 1.6 times more likely to have a clear airway when given small quantities of citric acid solution compared with water. However, this benefit was lost when a more appealing citric acid–sucrose mixture was introduced to increase palatability.

Hamdy et al. (2003) and Chee et al. (2005) noted that oral delay was observed when 50 ml of sour liquid bolus was ingested. In addition, there was an overall decrease in swallowing efficiency when participants were asked to drink the liquid bolus ''as quickly as is comfortable possible,'' following a swallowing efficiency protocol by Hughes and Wiles (1996). This prompted Palmer et al. (2005) to advocate using small amounts of sour bolus therapeutically and caution against the use of large amounts. The authors suggest that such a large amount of sour bolus would result in hesitancy to swallow, accounting for results by Hamdy et al. (2003). Studies do not support the use of large volumes of sour liquid bolus therapeutically. In our study, 4.4 g of citric acid diluted in 200 ml of gelatin presented as semisolid cubes provided a facilitatory effect amplitude and duration of submental sEMG contraction. It would be an important step to repeat our study in a dysphagic patient population to see if these effects remain beneficial.

We have expanded on prior work by researchers with the use of a novel, masticated stimulus and found similar effects on amplitude of submental muscle sEMG to those identified with liquids. Interestingly, our results revealed longer oral preparation times for bitter tastants, but this may be due to the high concentration used. It is not possible to comment on any potential benefits of using bitter tastes therapeutically at this stage. It is possible that small, appealing doses of bitter tastes may indeed facilitate swallowing. The correlation between prolonged submental sEMG duration and prolonged apnea during ingestion of bitter substances will also require further investigation. Further, as hedonics may influence swallowing responses, it would be of interest for future studies to pair intensity ratings with palatability ratings. Future studies may also include other tastes like ''umami'' as it is also a taste category (Horio 2003). Only young, healthy females were recruited for this study; although Ding et al. (2003) found no gender effects in their study, it would still be important to look for gender and age differences in swallowing behavior as a function of taste. Finally, sEMG may be used as an assessment tool for submental muscle activity, but for precise measurements of pharyngeal swallow timings and function, we recommend using video imaging techniques such as videofluoroscopy.

Conclusion

In summary, our study reveals substantial changes in oral and pharyngeal phases of swallowing behavior as a function of taste. Our results in young healthy adults lead to hypotheses that when evaluated may ultimately be useful for individuals with dysphagia.

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