



Research Article

Activity of Facial and Swallowing Muscles During Water and Sour Bolus Deglutition in Healthy Adult Humans

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Summary

There are very close relationships among deglutition, taste sensations, and facial expressions in humans. However, the associations among mimicking, swallowing, and the suprahyoid/submental muscle group (SM) during deglutition events have yet to be investigated using electrophysiological techniques to elucidate taste sensation and facial expression further. Thus, this study used surface EMG to evaluate synchronous electromyography activity in the facial and swallowing muscles during the swallowing of water and sour boluses in 20 normal healthy adults. All participants were instructed to swallow four bolus volumes (5, 10, 15, and 20 ml) each of a water bolus and a sour bolus (lemon juice) in a neutral head position. EMG recordings were obtained from the orbicularis oculi (OC; a mimic muscle), orbicularis oris (OR; a mimic and swallowing muscle), and SM (deglutition muscles) to determine whether these muscles were synchronously activated during voluntary oropharyngeal swallowing. The mimic (OC and OR) and swallowing muscles (SM) were synchronously activated in more than 90% of participants during water swallowing. Swallowing lemon juice increased the number of spontaneous swallows after the first deglutition and significantly shortened the duration of a single swallowing apnea. The present findings indicate that both taste and the intraoral trigeminal afferents of water and sour boluses excite facial neurons via the nucleus tractus solitarius and/or a central pattern generator. Additionally, sour boluses produced stronger and safer oropharyngeal swallowing in conjunction with increases in facial expressions due to the activation of facial mimic muscles.

Key words: Sour taste, swallowing, EMG, facial expression, orbicularis oculi, trigemino-solitarii-facial pathway

Normal Erişkin Bireylerde Su ve Ekşi Bolus Yutma Sirasında Mimik ve Yutma Kaslarının Senkronizasyonu

Özet

İnsanda yutma sırasında yutma, tat duyusu ve yüz ifadesi ile mimik, yutma ve suprahyoid/submental kas grubu (SM) arasında çok yakın bir ilişki olmasına karşın SM kas aktivitesi ile mimik, tat duyusu ve yüz ifadesi elektrofizyolojik olarak incelenmemiştir. Bu çalışmada su ve ekşi yutma sırasında fasiyel ve yutma kaslarının senkronize EMG aktivitesinin değerlendirilmesi amaçlanmıştır. Bu amaçla, 20 sağlıklı birey elektrofizyolojik olarak incelenmiştir. Tüm bireylere nötral baş pozisyonunda iken 5-, 10-, 15- ve 20- ml su ve ekşi (limon suyu) bolus olarak yutması söylenmiştir. Spontan orofaringeal yutma sırasında

mimik kası olan orbikularis okuli(OC); mimik ve yutma kası olan orbikularis oris (OR); ve yutma kası olan SM'nin aktivitelerinin birlikte senkron olup olmadığı değerlendirilmiştir. Su yutma sırasında normal bireylerin % 90'ında tüm mimik kasları (OC ve OR) ve yutma kasları (SM) nın aktive olduğu görülmüştür. Üstelik, limon suyu yutmanın ilk yutmadan sonra spontan yutma sayısını arttırmıştır ve yutma apne süresini kısaltmıştır. Su ve ekşi bolus yutmanın nükleus traktus solitarius (NTS) ve/veya santral patern jeneratör (CPG) aracılığı ile tat ve intraoral trigeminal afferent fasiyel nöronları uyarmakta olduğunu öne sürüyoruz. Ekşi bolus orofaringeal yutmayı daha güçlü ve güvenli kılmakta ve yüz ifadesini fasiyel kasların uyarılması ile daha belirgin hale getirmektedir.

Anahtar Kelimeler: Ekşi tat, yutma, EMG, yüz ifadesi, orbikularis okuli, trigemino-solitarii-fasiyel yol

INTRODUCTION

Reflexive facial expressions in response to taste stimuli occur in both humans and rats such that stereotypical expressions are produced following different taste qualities (1-5). These reflexive facial expressions can even be elicited at birth prior to any experience with taste stimuli (1,3,6,7). Two types of studies have investigated the relationships among facial mimicry, taste, swallowing, and electromyography (EMG). Additionally, facial expressions in response to different taste stimuli have been investigated in subjects of different ages using EMG, but these studies did not use the EMG to measure the activities of swallowing muscles, such as the submental muscle. Conversely, other studies have investigated the effects of sour and other tastants on swallowing, but did not assess changes in facial expression, such as alterations of the orbicularis oculi (OC) muscle (8-14). Sour boluses alter oropharyngeal swallowing in humans, but no studies have associated this type of stimulus with changes in facial expression (14-16). Nonetheless, there seems to be very close relationships among deglutition, taste sensation, and facial expressions.

In healthy adults, the OC is a strong facial mimic muscle that contributes to oropharyngeal swallowing in conjunction with the synchronous EMG activation of the orbicularis oris (OR) and suprahyoid/submental muscle group (SM) (17). In humans, the cooperation of the OC

and deglutition muscles may primarily occur in response to the taste and nociceptive aspects of intraoral boluses. For example, extremely sour, salty, and bitter foods and very hot water produce OC movements in clinical situations. The OC is a mimic muscle, the OR is both a mimic and a swallowing muscle, and the SM is a swallowing muscle; hence, it is important to determine how they are activated in synchrony during the swallowing of a water bolus or a sour bolus.

It was hypothesised in the present study that sour tastants would increase the excitability of related brainstem structures as well as the synchronous activity of facial and SM muscles to facilitate facial expressions and swallowing. In other words, the present study aimed to demonstrate the effects of the increased input of a sour taste on oropharyngeal swallowing behaviour and facial expressions using electrophysiological techniques in healthy adult humans. It was not possible to assess the suprasedgmental aspects of facial expressions and oropharyngeal swallowing in the present study.

MATERIAL AND METHODS

This study included 20 healthy adult participants (17 females and 3 males) with a mean age of 37.6 years (range: 26-62 years). All participants were volunteers selected from among our hospital staff who had no reported history of olfactory, gustatory, or swallowing disorders, and

were not currently taking any concomitant pharmacological treatments that could influence taste, olfaction, or swallowing. A neurological examination confirmed that participants' facial nerves and mimic muscles were intact. All participants provided written informed consent according to Declaration of Helsinki, and the study was approved by the hospital ethical committee.

During the study measurements, each subject was instructed to sit on a chair and hold his or her head in a neutral upright position. Ambient conditions were as calm and relaxed as possible. Swallowing signals were recorded from the SM with an EMG (SM-EMG) that used bilateral silver chloride electroencephalography (EEG) electrodes (diameter: 10 mm, disc electrodes) taped under the chin over the submental muscle complex (mylohyoid geniohyoid and anterior digastricus) approximately 10 mm from the midline, as previously reported (18). The skin overlying the submental complex was cleaned, and electrogel (Lome EEG paste) was used for the bipolar surface electrodes. The EMG signals were band-pass filtered (100-10 kHz), amplified, rectified, and integrated.

EMG signals were also recorded using electrodes placed on the facial skin surface over the OR and OC muscles on one side (left) (17). To record OR activity, electrodes were attached to the upper and lower lips near the corner of the mouth with an interelectrode distance of approximately 0.6-0.9 cm. To record OC activity, Ag/AgCl bipolar surface electrodes were attached over the lower eyelid at an interelectrode distance of approximately 0.5-0.7 cm; the distance between the OC and OR recording electrodes (from the middle of the OC electrodes to the corner of the mouth on the same side) was >4 cm. The EMG activities of the OC and OR were electronically adjusted in the same manner as the SM-EMG activity except that the

amplitude for each muscle was adjusted according to the magnitude of EMG activity. The amplitude was measured from the baseline to the peak, and the duration was measured from the onset to the end of deflexion according to the baseline. Care was taken to be aware of the short blinking artefact during the OC recording and other blinking artefacts during all recordings, particularly during deglutition. In some cases, there were EMG artefacts in the OR recording prior to the first deglutition, but this was likely due to facial movement intended to avoid leakage of fluid from the mouth.

The respiratory signal was obtained via a nasal cannula placed at the entrance of the nares, which was connected to an airflow sensor transducer (Sleep Sense®, SLP; Tel Aviv, Israel) and interfaced with the EMG apparatus. Airflow direction was recorded with the negative polarity representing inspiration, and the positive polarity representing expiration. The phases of respiration were simultaneously recorded to determine the apnea period; the respiratory signals were also recorded during rest. A plateau in the respiratory signals along the baseline indicated the apnea period, and swallowing apnea was measured from the end of the last respiration cycle to the onset of the next respiration. Instances of respiration cessation due to the second or additional swallows were also measured, but the swallowing apnea period was calculated first. The signals were filtered (0.2-10 kHz), amplified, rectified, and then integrated. A four-channel EMG device (Nicolet-Viking Select V11.0, VIASIS Health Care, Medical Device Directive, Netherlands) was used to record muscle activity; the electrodes were connected to the four channels of the EMG apparatus.

To test the effects of increasing water volume on deglutition, four volumes of water were swallowed (5, 10, 15, and 20 ml) from a disposable cup positioned between the lips. Each participant began to

swallow each bolus immediately after being instructed to do so by the examiner. The water temperature was approximately 23-25°C. For the sour stimulus, 100% lemon juice was freshly prepared from a lemon in the laboratory without water dilution. All participants received the boluses of lemon juice in a stepwise manner (5, 10, 15, and 20 ml) from a disposable cup positioned between lips. The intraoral cavity was rinsed with tap water after each trial, and there were intervals of several minutes between boluses.

The following parameters were measured for each volume of water and lemon juice: (1) number of swallows over 20 sec during the swallowing of 20 ml of liquid; (2) EMG amplitude of the investigated muscle (SM, OC, or OR) measured from baseline to peak during swallowing; (3) EMG duration of the investigated muscle (SM, OC, or OR) measured from the onset to the end; and (4) duration of swallowing apnea measured in the first swallowing. When any suspicion of an artefact occurred, the recording was repeated two or three times.

Statistical Analysis

All statistical analyses were conducted with the Medcalc V11.3.0 statistical package, and all measured quantities are expressed as mean \pm standard deviation (SD). Wilcoxon tests were applied to compare the amplitudes and durations associated with the swallowing movements among the OC, OR, and SM muscles. For all analyses, p-values $0 < 0.05$ were considered to indicate statistical significance.

RESULTS

All 20 participants completed the experiment, and EMG activity was

recorded from the OR, OC, and SM during movements related to deglutitional events in all. The participants averaged one swallow during water swallowing with increasing volumes. In contrast, the same procedure with lemon juice resulted in a mean of more than one swallow during the 20-sec analysis period ($p < 0.0001$; Fig. 1) and a greater number of swallows during the 1-min analysis period ($p < 0.0001$; Table 1). The first swallowing apnea was significantly shorter for the 15- and 20-ml lemon juice boluses compared to the respective water boluses ($p < 0.05$; Table 1, Fig. 2).

The amplitudes and durations of SM, OC, and OR activity were affected differently (Table 1). All muscles were synchronously activated for all swallowing volumes except for two cases (10%) in which OC activity was not clearly recordable (Fig. 3). The mean amplitudes of SM, OC, and OR activity tended to increase, although the values did not significantly differ, and the SM activity amplitude significantly increased while swallowing the 10-ml lemon juice bolus. The mean durations of SM, OR, and OC activity increased when lemon juice was swallowed, but the effects of the sour taste differed among the three muscles. The duration of OR activity was not significantly prolonged for any of the lemon juice boluses, the duration of OC activity was significantly prolonged after the 10- and 15-ml lemon juice bolus, and the duration of SM activity was significantly prolonged after the 15- and 20-ml lemon juice boluses (Table 1, Fig. 4). These findings suggest that lemon juice effectively activated the fundamental muscles involved in deglutition (SM) as well as the mimic muscles (OC).

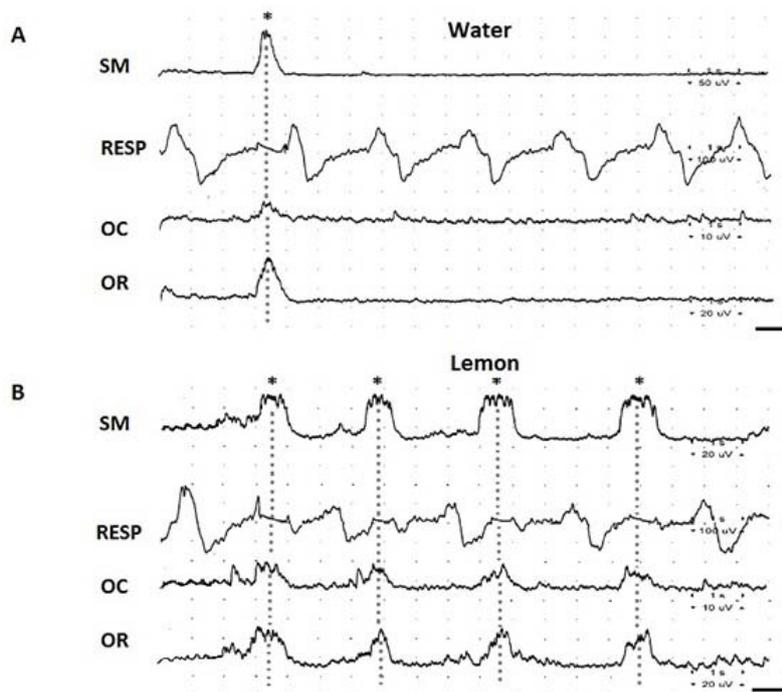


Figure 1: 5 ml water (A) and 5 ml lemon juice (B) swallowing
 SM: submental muscle, Resp:Breathing, OC: Orbicularis Oculi, OR: Orbicularis Oris
 Note: 5 ml lemon juice swallowing produce successive swallows. Duration of SM muscle is increase and in all water and lemon juice swallows, there are clear synchronisation (vertical dotted line).
 Time base of calibration mark was 1 second. The amplitude was written to right side of all traces.

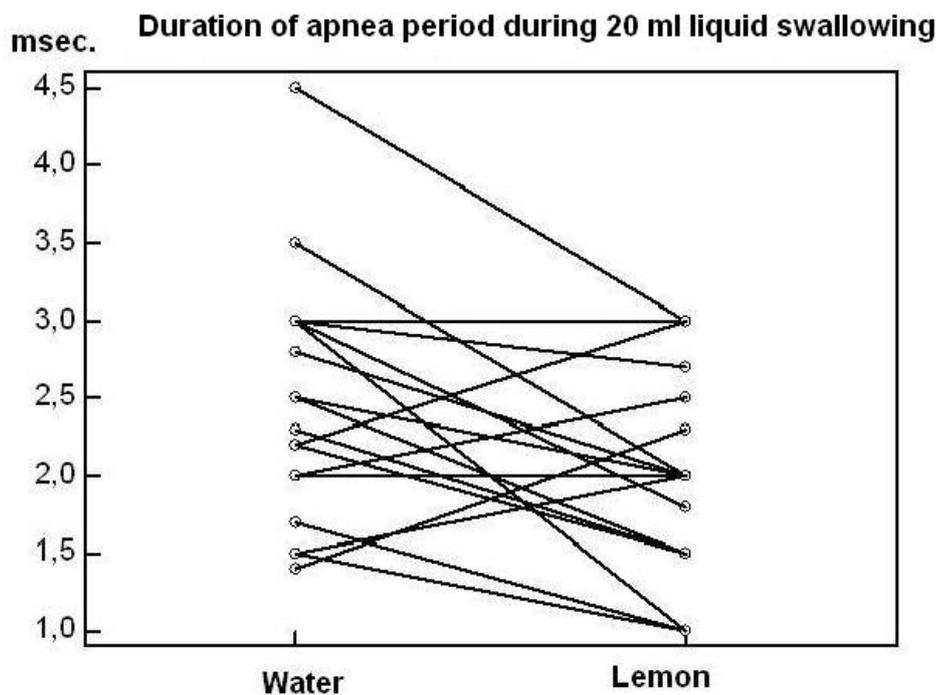


Figure 2: The individual graphics compare the first swallowing apnea duration of SM EMG for each volumes of water and lemon juice swallowing.

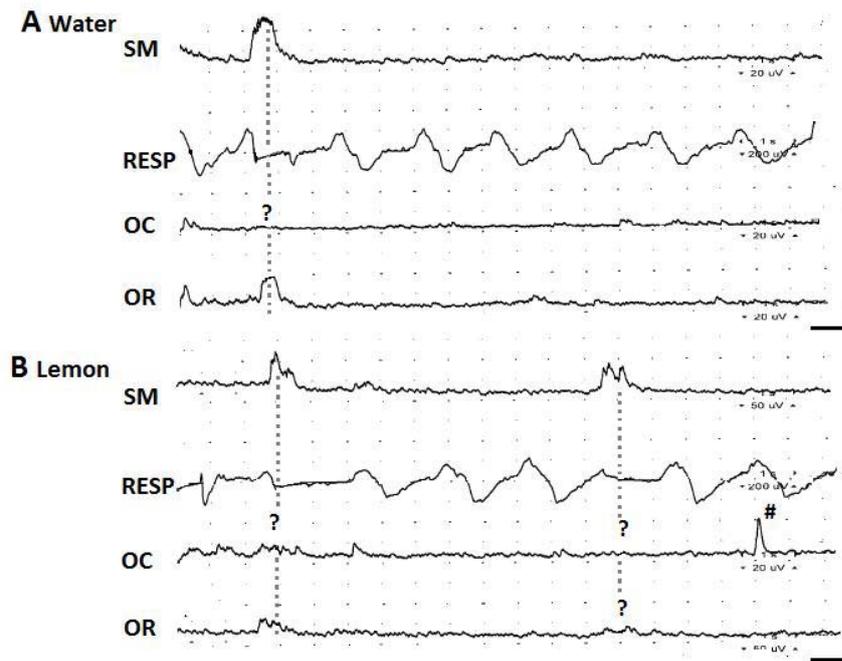


Figure 3: In a normal subject without synchronisation between OC and swallowing muscles. Note the question marks in the OC traces. (There is one spontaneous blinking denoted with #) Calibration mark is 1 second, the amplitude calibrations were written to the right side of all traces.

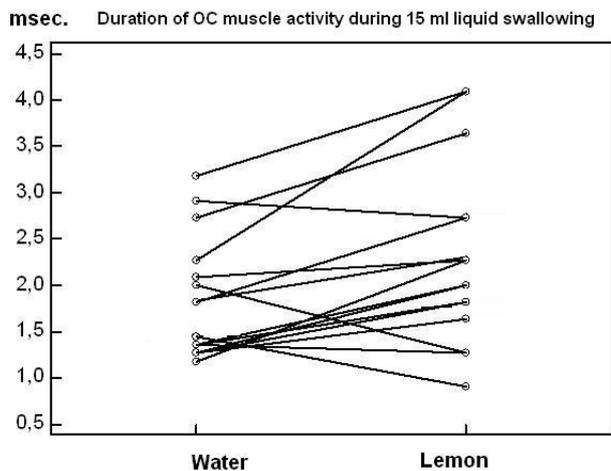


Figure 4: Duration of OC and SM muscles activities during 15 ml water and Lemonade(Lemon) juice on the individual bases.

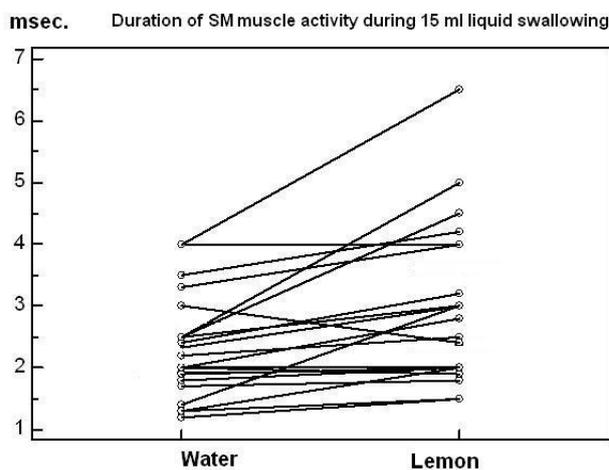


Table-1 The summary of statistical results of comparison water-lemon juice drinking (mean±SD)

	Number of swallowing in 20 sec	SM Amplitude (µV)	SM duration Sec.	First Apnea Duration sec.	OR amplitude (µV)	OR duration sec.	OC amplitude (µV)	OC duration Sec.
5 ml								
water	1,0±0,3	99,7±31,7	2,0±0,7	2,0±0,5	62,3±46,3	2,0±0,9	21,8±9,8	1,3±1,0
lemon	3,7±1,3							
	*							
10 ml								
water	1,1±0,5	95,0±35,1	2,2±0,8	2,3±0,5	56,7±28,0	2,1±0,6	23,2±11,8	1,6±0,6
lemon	3,7±1,3							
	*	**						**
15 ml								
water	1,3±0,5	99,8±35,3	2,3±0,8	2,4±0,4	56,4±62,3	2,1±0,7	20,9±11,0	1,8±0,6
lemon	4,3±1,4							
	*		**	**				**
20 ml								
Water	1,6±0,8	99,7±22,3	2,4±0,6	2,5±0,7	55,7±28,7	2,2±0,8	21,5±9,4	1,9±0,7
lemon	4,6±0,7							
			**	**				

* $p=0,0001$ ** $p<0,05$

DISCUSSION

Çok boşluk olmuş Studies using videofluoroscopy(14,16,19,20) and EMG have shown that the physiological link between a sour taste and swallowing alters and facilitates oropharyngeal swallowing in humans (8-14,21,22). In the present study, the SM exhibited greater activity during sour bolus swallowing than during water swallowing, but this change was only significant with the 10-ml lemon juice bolus (Table 1). However, the SM-EMG duration was significantly longer with larger volumes of the sour stimulus.

The importance of response duration to bolus stimuli has not been stressed in the relevant literature, except by Leow et al. who found that the duration of SM-EMG activity following a sweet tastant did not significantly differ from that after a sour tastant and that taste had no significant

effect on the duration of swallowing or SM-EMG amplitude (12). This could be related to differences in the study methods. The present study used 100% lemon juice, which contains more citric acid, and it is possible that the higher concentration of citric acid remains in the oropharyngeal region for a longer period of time. Consequently, the longer duration of the sour taste would result in the repetitive stimulation of the taste receptors. Thus, citric acid may cause more effective and longer stimulation at the oropharyngeal receptor level and/or the brain stem level. In the brainstem, this likely occurs in the nucleus tractus solitarius (NTS). Increasing volumes of citric acid excite multiple peripheral sensory receptors in a dynamic fashion, activating premotor neurons in this region (23).

The majority of studies investigating swallowing have used the SM as the indicator muscle. Several studies have shown that sour tastants cause the greatest response amplitude of submental muscle contraction during swallowing and that a sour bolus results in stronger muscle contractions, as evidenced by greater electromyographic activity (8,11,12,21,22). Additionally, motor-evoked potentials evoked by transcranial magnetic stimulation and recorded from the submental muscles revealed that sour tastants increased neural excitability during swallowing (8). However, the increase in SM muscle contractions following simultaneous tastant stimulation was not significant compared to baseline (9).

In this study, with the exception of the amplitude of SM activity in response to a 10-ml sour bolus in healthy participants, the amplitudes of SM and OC activity in healthy human participants showed no significant increase with increased volumes of water or a sour bolus when the two were compared. More specifically, the mean amplitudes following each bolus increased, but not to a significant degree, which is in partial agreement with the abovementioned studies. It is possible that the significantly increased response duration observed in the OC following large volumes of lemon juice resulted in the spatial dispersion of activity in these muscles which, in turn, minimized any influence on amplitude. Similarly, OR activity may have exhibited higher amplitude and a longer duration to lemon juice without reaching significance in the present study because its function involves facial expressions as well as deglutition. Involvement in these two different functions may also influence OR activity because it is necessary to close one's mouth tightly while swallowing to prevent the escape of liquid (24,25). On the other hand, facial expressions might entail a more relaxed position for the OC (3,26-29).

Measurements of the first apnea period during the first swallow revealed that the apnea period was significantly shortened (Table 1, Fig. 4). This suggests that the sour taste increased oro-swallowing while the airway was protected due to the shorter apnea period, an important effect of a sour bolus. Strong and prolonged oropharyngeal swallowing, as measured from the OR and SM, can result in fast and short breathing. Spontaneous saliva swallows and their frequency have rarely been mentioned in previous studies (15,30). However, in the present study, the number of spontaneous swallows significantly increased, with individual variation among participants, after swallowing the lemon juice. Pelletier and Lawless observed a significant increase in spontaneous dry swallows after sour stimuli, and the number of subsequent spontaneous swallows after a citric acid preparation was applied to the oral cavity was higher than that after an acid sucrose mixture (20). The present study demonstrated that high numbers of spontaneous swallows can be recorded from the SM as well as from the SM, OR, and OC simultaneously. To our knowledge, this finding has not been described previously. Citric acid stimulation initiates high flow rates of saliva that is rich in bicarbonate, which acts as a buffer for the major salivary glands (6). Ongoing swallowing apnea should not be due to peripheral mechanisms and is likely based on dysfunction in the brainstem, perhaps related to the link between swallowing and respiration (23,24,25,31,32,33). For example, a sour taste modulates activity within central pattern generators (CPGs) in the medulla by enhancing the triggering of swallowing (34). However, sour tastes can play a role in the upregulation of CPGs in the brainstem as well as in cortical swallowing networks (35,36). Similarly, facial expressions can be modified by supramedullary centres. The synchronous activation of the OC with the OR and SM, the swallowing muscles, may be the last

effluent destination of the bilateral linkage between the pontine facial nucleus and the NTS.

High levels of citric acid also elicit the so-called "chemesthesis" sensation, which is mediated by the trigeminal nerve and may play a crucial role in swallowing physiology (37,38,39). Chemesthesis may enhance gustatory input to the NTS, and this enhancement should be evoked and organised by the trigeminal nerve afferents of the oral cavity during the first step of swallowing. Additionally, the OC and OR are likely related to some degree due to connections in the brainstem; the trigeminal nerve afferents that arise from the face and intraoral cavity may represent this linkage. This may underlie the synchronous activity of the OC and OR during lemon juice deglutition.

In this study, 90% of the healthy normal participants exhibited clear synchronisation of the OC, OR, and SM during both water and lemon juice swallowing. Additionally, in the majority of cases, the lemon juice bolus enhanced the size and rate of the electrophysiological swallow responses. Facial expressions in response to different taste stimuli have been studied using participants of different ages (1,5,6,26,27,40,41,42) and the electrical activity of facial muscles has been used to investigate a variety of hedonic emotional and cognitive responses to taste stimuli (27,28,40,41). However, in the present study, the age range was rather large, and this limited any interpretation of age-related effects.

Individual differences in response to a sour bolus may also be related to the "genetic taster status" of an individual human subject (43,44,45). Two cases in the present study exhibited stimulation of the OC, but not synchronous activity of the OC, OR, and SM, after swallowing the lemon juice. This difference may indicate that the taste and mimic functions of some individuals do not cooperate at the medullary level.

From an anatomical point of view, little information is available regarding the functional connections between afferent taste inputs and motoneurons in the facial motor nucleus that are responsible for stereotypical responses to taste stimuli (6). Some projections to the facial motor nucleus originate in the trigeminal sensory complex,(46,47) and fewer originate in the NTS (48,49). Studies of lesioned decerebrated animals demonstrated that the circuits responsible for mimetic facial responses to taste stimuli are located in the brainstem (7). However, this function is likely to be more complex in adult humans.

This study has several general limitations that should be noted. First, the number of participants in the study was relatively small, and participants were not compared according to age groups. Additionally, although it could be easily identified, spontaneous blinking disturbed the regularity and clarity of the EMG data, and its effects on the OC could not be avoided. Fortunately, however, this type of bioelectric activity is clearly different from that evoked by the swallowing function. Second, it is difficult to draw precise conclusions about the nature of brainstem or other central nervous system activation using EMG methods. Thus, future studies should include neural assessments during swallowing. In conclusion, this study found that a sour tastant increased the excitability of brainstem structures and that the synchronous activity of facial and swallowing muscles facilitates facial expressions and oropharyngeal swallowing. Additionally, a water bolus produced synchronous activation of several facial muscles, including the OR and OC.

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