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# Electromyographic Response of the Labial Muscles during Normal Liquid Swallows Using a Spoon, a Straw, and a Cup

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**Abstract.** In this investigation, surface electromyographic (EMG) recordings were used to make qualitative and quantitative analyses of labial muscle activity during three swallowing tasks, incorporating the use of various drinking implements. EMG was recorded from four quadrants of the perioral region and from the submental muscle complex in 11 normal adult females. Swallowing tasks included liquid extraction from a spoon, a straw, and a cup and posterior bolus propulsion of a 5 ml, thin liquid. Average EMG values obtained during a maximal lip compression task were used to normalize labial muscle responses for each subject thus allowing between-subject comparisons. Variable activity patterns were noted in the perioral muscles once the lips were contacted by a drinking implement. Subjects used a greater percentage of maximal labial muscle activity to remove liquid from an implement than to swallow the liquid. A greater level of EMG was recorded in the lips during straw usage as compared with spoon or cup usage. Significant intrasubject and intersubject variability in labial function occurred during liquid removal using a drinking implement and during the oral swallow in these normal subjects.

**Key words:** Electromyography — Lips — Swallowing — Drinking implement — Deglutition — Deglutition disorders.

The lips play a notable role in the oral phase of swallowing for removal of food from a utensil [1,2] and for bolus containment within the oral cavity [3–7]. In conjunction with the teeth, gums, and tongue, the lips provide an anterior barrier to a bolus contained within the oral cavity and may even help direct the bolus posteriorally upon initiation of the oral swallow.

Clinicians sometimes recommend the use of a straw if a patient demonstrates oral spillage of liquids while using a cup, although the observation of reduced oral spillage with straw usage has not been validated with empirical testing. It may be that puckering around a straw mocks the early developmental skill of sucking and requires less coordinated activity among the perioral quadrants than that required with cup usage. However, no data exist that contrast the amount of labial muscle activity produced during swallowing via spoon, straw, and cup. If more activity does occur in the lips with straw usage, then perhaps more labial muscle activity must be lost before a functional disturbance in oral bolus containment with use of a straw is noticed. If true, this may account for the observation that patients with labial muscle weakness seem to demonstrate less oral spillage when using a straw than when using a cup to swallow liquid. Recommendations for use of a particular implement for consuming liquids with minimal oral spillage may be made with collection of data delineating muscle activity with various drinking implements.

Although labial function during swallowing has been described by several authors, quantitative data are lacking that contrast labial muscle activity during usage of conventional drinking implements and during posterior bolus propulsion of liquid during the oral swallow. This study was conducted to provide preliminary information defining labial muscle function in normal young adults during the preparatory and oral phases of swallowing for thin liquids.

## Materials and Methods

### *Subjects*

Eleven females aged 18–25 years were recruited as subjects for this study from Northwestern University undergraduates. The protocol was

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approved by the Northwestern University Institutional Review Board and all subjects provided written consent prior to testing.

None of the subjects had a history of any neurologic or swallowing impairment, surgical procedures performed on the lips, such as a repaired cleft lip or cosmetic reconstruction, or dental procedures, beyond a regular checkup, within 6 months of the study. Professional wind instrument players were excluded from the study. The Oral Speech Mechanism Screening Examination (St. Louis and Ruscello, 1987) was administered to all subjects to validate the presence of normal structure and function.

## *Apparatus*

### Electrodes and Electrode Placement

Surface electrodes were constructed from phosphor bronze discs with a surface diameter of 5 mm, and an ultra-thin, teflon-insulated, stainless steel wire was soldered to each disc. A dollop of electrolyte gel and flexible tape, trimmed to the contour of the lips, were used to promote signal conductivity and to affix the electrodes to the subject's skin, respectively. A ground electrode was affixed to the subject's earlobe. Signal conductivity and clarity for each electrode were validated via an ohm meter and an oscilloscope. The electrode resistances were constant at the four sites described below.

Electrode pairs were placed at four locations on the lips: (1) 25% of the total distance from the center of the base of the columella to the modiolus, (2) 75% of the total distance for the left and right upper lip; lower lip placements were at (3) 25% and (4) 75% distances from the center to the modiolus. Figure 1 illustrates electrode placement on a subject's lips.

Submental EMG activity was recorded from a pair of commercially available surface electrodes (Beckman Instruments, Inc.) placed over the mylohyoid-geniohyoid-anterior-digastric muscle complex in an anterior-posterior alignment following palpation of the submental area as the subject swallowed. The small bronze discs allowed less restrictive labial movement than the Beckman electrodes, but were not constructed specifically for the submental area as submental EMG was recorded only as a monitor for initiation of the oral swallow [8,9].

### Drinking Implements and Liquid

Orange Pippin brand apple juice at room temperature was administered to all subjects in 5 ml portions via (1) a plastic teaspoon, (2) a thin, glass test tube containing a regular drinking straw (cut in half), and (3) a ''nose cut-out'' styrofoam cup. The test tube was used to support the straw and to allow the liquid to be sipped in a single swallow. Pilot testing revealed a consistent 1 ml residual of liquid after the subject was cued to remove the liquid because of the configuration of the test tube. Therefore, 6 ml of liquid was placed in the test tube on the first swallow trial and subsequent refills for the second and third trials were 5 ml. Tilting the head back to receive the liquid by cup was avoided with the use of a ''nose cut-out cup,'' whereby, subjects tilted the cup upward while the head remained stationary. Keeping the head upright was deemed necessary to eliminate the effects of gravity on posterior bolus propulsion.

## *Experimental Tasks*

To simulate a ''normal'' swallowing condition, each subject self-administered the calibrated 5 ml of apple juice while seated comfortably in a dental chair with head position controlled by the use of a headrest. A normal ''single sip and swallow'' condition was implemented and is described below. This condition often inherently includes a pause after liquid extraction. Light cues, presented every 1.8 sec, and large-print words signifying the parts of the swallow task were placed directly in front of the subject. The light cues prompted subjects for task initiation and delineated parts of the swallow in the figures.

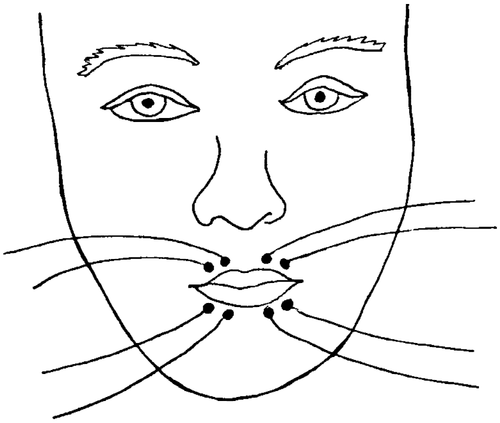

**Fig. 1.** Illustration of placement of electrodes on a subject's lips.

### Maximal Lip Compression Trials

Three consecutive trials of a maximal lip compression task preceded three swallowing trials using either a spoon, a straw, or a cup (described below). The lip compression task and swallowing task were separated by a 3-min interval to avoid effects of fatigue from compressing the lips. Maximal lip compression measures served to normalize the data within each task to permit between-subject comparisons. Subjects were told to ''Close the lips normally. Squeeze the lips together as hard as you can, then relax the lips. Do this three times in concert with the light cues.''

### Swallow Trials

Removal of liquid from a drinking implement (i.e., *before* the oral phase of the swallow) and posterior propulsion of the bolus (i.e., *during* the oral phase of the swallow) were segmented in the present study so that muscle activity in the lips before and during the oral swallow could be examined independently. Subjects were instructed to ''dry swallow'' before each swallow task was initiated to reduce the occurrence of a swallow extraneous to that prompted by the light cue. Swallows were monitored by visual identification of hyolaryngeal elevation. Each of three swallow trials consisted of four light cues to prompt subjects as follows:

Step 1–Relax. Subjects held the implement in their hand with the lips at rest. This command was included to obtain baseline EMG and to ready the subjects for the next step.

Step 2–Touch. Subjects placed the implement in contact with the lips to prepare for Step 3. Step 2 served to reduce the effect that variable hand movement may have on delivery of the liquid while permitting subjects to self-administer the liquid. It was also included to allow comparison of baseline EMG and activity that occurs when the lips are contacted by an implement.

Step 3–Remove. This step involved taking the liquid from the spoon, straw, or cup in a natural manner, then removing the implement from the mouth. Removing the implement after stripping the

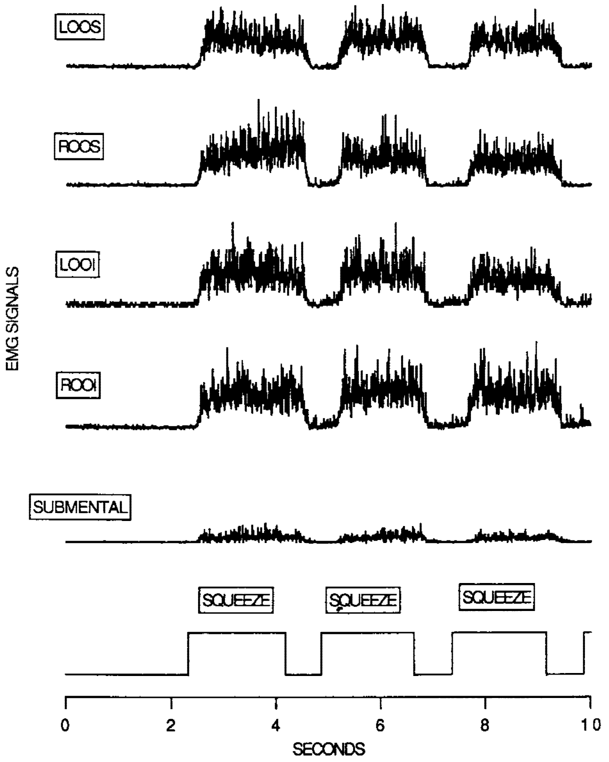


**Fig. 2.** EMG recording of three trials of maximal lip compression for subject 6. Scale markings are consistent across all EMG channels. LOOS = left orbicularis oris superior; ROOS = right orbicularis oris superior; LOOI = left orbicularis oris inferior; ROOI = right orbicularis oris inferior.

liquid eliminated interference of the implement during the oral swallow.

Step 4–Swallow. Instructions for this step included swallowing the liquid in a single swallow.

### Subject Training

Prior to placing the electrodes on the subject's skin, each subject practiced all experimental tasks to become proficient in performing the steps without the risk of loosening the electrodes. Minimizing head movement, performing behaviors as prompted by the light cues, and familiarizing subjects with the experimental protocol were objectives of the training period.

### Data Recording and Data Analysis

Signals from the electrodes were differentially amplified with Grass AC preamplifiers (model P511) and filtered (100 Hz, high pass, 2.5 KHz, low pass). Signals were full-wave rectified and smoothed with a time constant of 15 msec. Online monitoring was done with a Tektronics and a Phillips oscilloscope. Light cues were administered every 1.8 sec by a Grass S88 stimulator. EMG signals were recorded directly onto FM tape for subsequent digitization using BrainWave (BrainWave Systems Corporation).

Average maximal EMG for the lip compression task (subject 6) (Fig. 2) was calculated across the four lip quadrant signals using Igor Pro (Wavemetrics, Inc.) by placing cursors on the onset and offset of the light cue pulse (i.e., 1.8 sec duration). Measures were made for each labial quadrant and averaged over three trials.

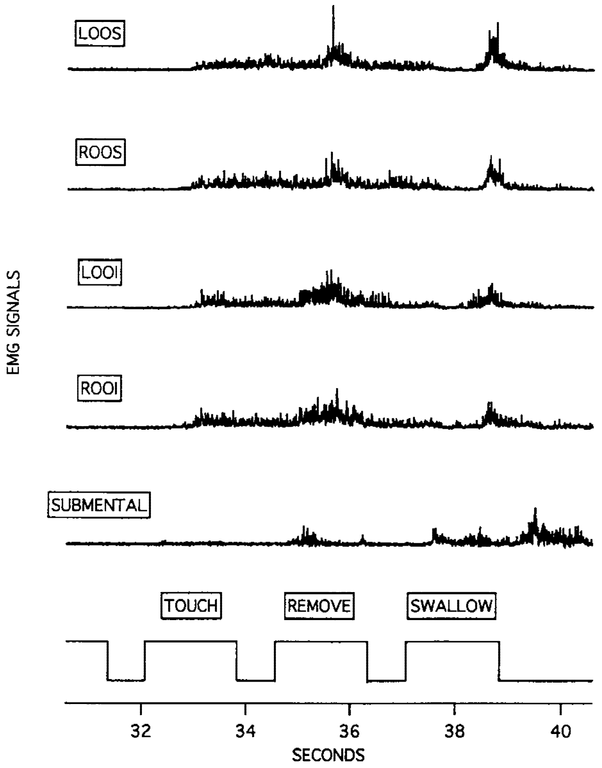


**Fig. 3.** EMG recording for subject 11 during the swallow task using a spoon. Scale markings are consistent across all EMG channels. (See Fig. 2 for abbreviations.)

Likewise, measurements for the swallowing tasks were made by placing cursors on the light cue pulse for the ''Remove'' and ''Swallow'' cues and calculated across the four lip quadrant signals (see Figs. 3–5) (subjects 11, 1, 2, respectively). These swallow task measurements consisted of the average EMG in each quadrant across three trials divided by the average EMG generated during the maximal lip compression task in each quadrant across three trials. This ratio was calculated so that the activity occurring during the swallow tasks could be expressed as a percentage of maximum.

## Results

### EMG Recordings with the Lips at Rest

Baseline EMG recordings, collected prior to initiation of the maximal lip compression task and the swallowing tasks, revealed the absence of myoelectric activity when the labial and submental muscles were at rest. However, an inconsistent activity pattern in the lip quadrants between the trials of maximal lip compression (Fig. 2) and between the parts of the swallowing task (Figs. 3–5) was evident within and between subjects.

### EMG Recordings for Maximal Lip Compression

Activity patterns in the four lip quadrants during maximal compression, as seen in Figure 2, were characterized

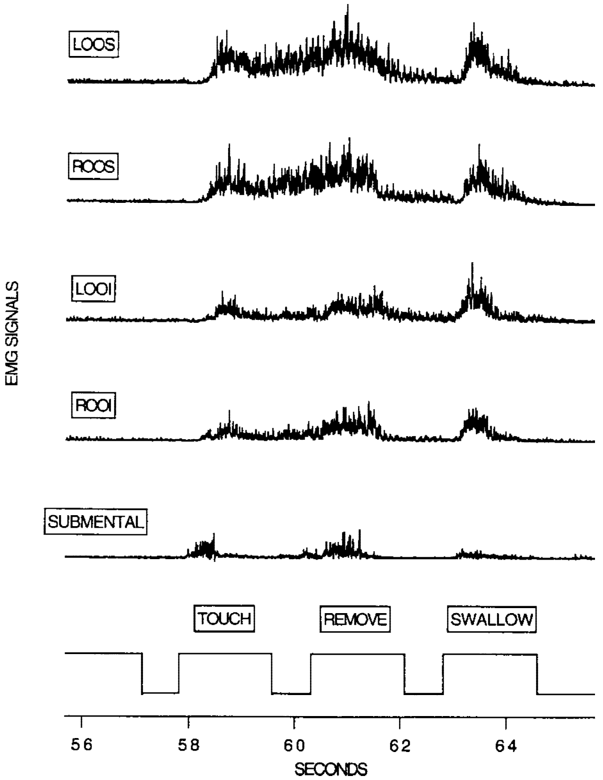


**Fig. 4.** EMG recording for subject 1 during the swallow task using a straw. Scale markings are consistent across all EMG channels. (See Fig. 2 for abbreviations.)

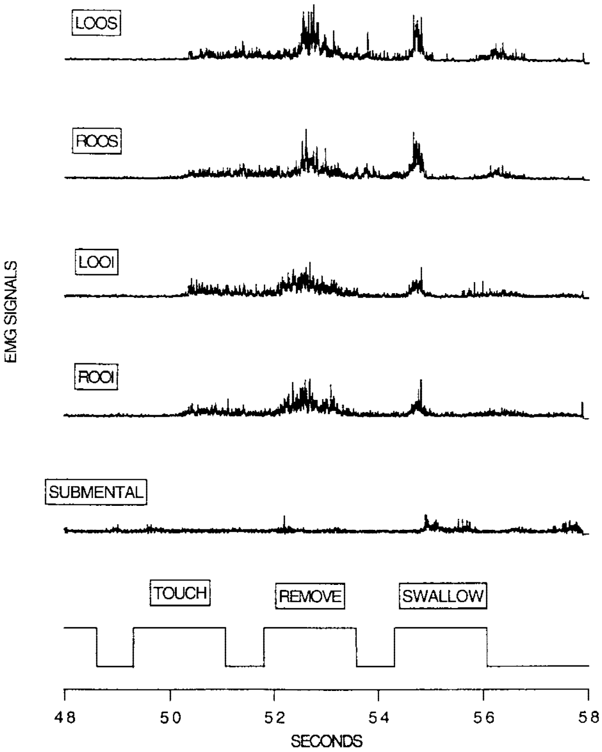


**Fig. 5.** EMG recording for subject 2 during the swallow task using a cup. Scale markings are consistent across all EMG channels. (See Fig. 2 for abbreviations.)

by simultaneous onset and offset in all subjects, thus suggesting roughly equivalent coordination patterns between quadrants for this task. Submental muscle activation was synchronous with labial muscle activation indicating that the labial muscles do not contract in isolation during maximal lip compression.

### *EMG Recordings for Liquid Removal and the Oral Phase of the Swallow*

#### Qualitative Analysis

Very little muscle activity was recorded in any lip quadrant for any subject when the spoon or cup contacted the lips (''Touch'' cue in Figs. 3 and 5), but marked activity was evident when the straw contacted the lips to prepare for liquid removal (''Touch'' cue in Fig. 4). All subjects showed activation of the labial and submental muscles when (1) removing liquid from an implement and (2) propelling the liquid bolus in the oral cavity (''Remove'' and ''Swallow'' cues in Figs. 3–5, respectively).

Figures 3, 4, and 5 reveal slightly asynchronous *onset* and *offset* of myoelectric activity in the labial quadrants during liquid removal and during the oral swallow with a noted tendency toward stronger coupling of the upper (LOOS-ROOS) and lower lips (LOOI-ROOI) compared with the left (LOOS-LOOI) and right (ROOS-ROOI) sides of the lips. Quantitative techniques permitting empirical confirmation of this observation were not incorporated in the present study, but this observation has been previously identified by other investigators in various tasks involving the lips [10]. Specific muscle activity patterns across the four labial quadrants for a given swallow task are not identical.

#### Quantitative Analysis

Of particular interest in this study was determining the average amount of EMG present in the labial muscles during liquid removal using various implements and during the oral swallow. As stated previously, average labial EMG for liquid removal via spoon, straw, and cup and average EMG during the oral swallow was expressed as a percentage of activity generated during a maximal lip compression task for each quadrant over three trials. Table 1 shows repeated measures analysis of variance (ANOVA) results using Systat (Systat, Inc.) with a $p < 0.05$ confidence level.

A significant main effect for ''Task'' in Table 1 indicates that statistically different EMG values were obtained during the liquid removal and oral swallow tasks. Significant differences were also observed in the average amount of labial muscle activity used to remove liquid

**Table 1.** Repeated measures ANOVA for task, implement, and quadrant for all subjects

| Source | F | $p$* |
|---|---|---|
| Task | 80.722 | 0.000* |
| Implement | 4.270 | 0.029* |
| Quadrant | 0.620 | 0.608 |
| Task x Implement | 10.895 | 0.001* |
| Task x Quadrant | 0.147 | 0.931 |
| Implement x Quadrant | 2.709 | 0.021* |
| Task x Implement x Quadrant | 3.241 | 0.008* |

*$p < 0.05$.

**Table 2.** Mean percentages of maximal lip compression and ranges of mean percentage across all subjects for removing liquid by spoon, straw, and cup for swallowing liquid

| | Removing liquid | | Swallowing liquid | |
|---|---|---|---|---|
| | Mean % of maximum | Range of mean % across subjects | Mean % of maximum | Range of mean % across subjects |
| Spoon | 0.82 | 0.776–0.926 | 0.43 | 0.373–0.533 |
| Straw | 1.35 | 1.251–1.449 | 0.33 | 0.313–0.361 |
| Cup | 0.88 | 0.772–1.015 | 0.40 | 0.322–0.433 |

via spoon, straw, and cup, as reflected by the main effect for ‘‘Implement.’’ However, EMG activity among the four lip quadrants was not statistically significant (i.e., ‘‘Quadrant’’ $p = 0.608$). Interaction effects occurred for ‘‘Task and Implement,’’ ‘‘Implement and Quadrant,’’ and ‘‘Task, Implement, and Quadrant.’’ That is, calculations including ‘‘Implement’’ showed interaction effects thought to be attributable to the fact that EMG generated during liquid extraction via straw exceeded all other measures, including EMG during the maximal lip compression task. No interaction between task and quadrant was observed.

Table 2 shows that subjects used approximately 82%, 135%, and 88% of EMG generated during maximal lip compression to remove liquid from a spoon, straw, and cup, respectively. For the oral swallow, 43%, 33%, and 40% of EMG generated during the lip compression task was used following liquid extraction by spoon, straw, and cup, respectively.

The ranges provided in Table 2 for percentage of maximal lip compression used to extract liquid from an implement and to propel a bolus in the oral cavity highlight the intersubject variability demonstrated for both of these tasks. It appears that slightly more variability was evidenced when subjects removed liquid from various implements, particularly when a cup was used to extract liquid (i.e., 0.772–1.015), than when liquid was swallowed.

## Discussion

This study examined EMG in the labial musculature during liquid removal from various drinking implements and during the oral swallow. Findings indicate that myoelectric activity is absent when the lips are at rest, which is in agreement with results from previous investigations [5,7,11]. This observation is applicable when the lips are in a true ‘‘resting’’ position (i.e., baseline condition). However, variable activity patterns across lip quadrants were observed between trials in the maximal lip compression task and between the parts of the swallowing task once the lips were contacted by a drinking implement. No consistent pattern of activity was noted within or between subjects. Assumptions that the lips are indeed ‘‘at rest’’ between trials of compression or between parts of a swallowing task cannot be made. Allowing sufficient time between trials or parts of a task if active engagement of the lips is not needed may increase the likelihood that activity will return to baseline, and this time will likely vary from one individual to another.

Myoelectric activity was consistently evident in all quadrants for all subjects in this study during the oral swallow, but was not consistently displayed in all lip quadrants while liquid was held in the mouth in preparation for posterior bolus propulsion. Therefore, although closed lips may help provide a physical barrier to the anterior flow of liquid from the oral cavity, it appears that labial muscle activation is not necessary to hold a 5 ml, thin liquid bolus in the oral cavity without anterior spillage of liquid. Larger volumes of liquid, however, may require active engagement of the labial muscles to prevent oral spillage of liquids prior to initiation of the oral swallow.

Quantitative analyses of the average amount of myoelectric activity generated during liquid removal did not reveal significant differences among the quadrants. However, qualitative analyses of the EMG tracings revealed different activity patterns among quadrants and among trials for a given implement. Goffman and Smith [12] stated that motor unit territories are distinct in each perioral quadrant and that the four quadrants are innervated separately by nonoverlapping subnuclei in the brainstem. Data from Wohlert and Goffman [10] further support the idea of functional independence among the lip quadrants whereby coupling between the lip quadrants was stronger bilaterally (upper vs. lower lip) than ipsilaterally (right vs. left side of the lips) for lip protrusion, chewing, and speech. Results of the present study also support the concept of functional independence of the lip quadrants and a stronger tendency toward coupling of the upper and lower lips than of the left and right sides of the lips during liquid swallows, although the methodology used in the present study did not allow statistical testing of this observation.

As seen in Table 2, a greater percentage of EMG produced during the maximal lip compression task was used to remove liquid from an implement (82%–135%) than to swallow the liquid (33%–43%). In normal speech, researchers have determined that we use between 10% and 30% of maximal force levels in the orofacial musculature [13–15]. O'Dwyer et al. [16] noted that approximately 30% of maximum is used during the production of various facial expressions. Hence, it appears that labial muscle activity for posterior bolus propulsion (33%–43%) slightly exceeds that produced during speech (10%–30%) and facial expression (30%), but labial activity for removal of a 5 ml, thin liquid bolus from an implement (82%–135%) greatly exceeds what occurs during speech or facial expression.

As stated previously, 43%, 33%, and 40% of activity generated during the maximal lip compression task was used by the lips to propel a 5 ml, thin liquid bolus in the oral cavity following liquid extraction via spoon, straw, and cup, respectively. It may be that stripping liquid from a particular implement positions the bolus differently within the oral cavity and thus requires more or less labial activity during posterior bolus propulsion. Or, these results may reflect normal variability in the specific physiologic actions occurring during the oral phase of swallowing [9,17–21]. These speculations may be confirmed or negated by pairing EMG with videofluoroscopy to define the bolus location within the oral cavity and by replicating this experiment to determine the reliability of the results.

One surprising outcome of this study was that extracting liquid by straw produced more myoelectric activity in the labial muscles than when maximally compressing the lips. That is, 135% of maximal labial compression was obtained when the lips removed liquid via straw. It is possible that additional muscle groups are recruited during puckering inherent in straw usage, although EMG during maximal lip protrusion does not differ significantly from EMG during maximal lip compression [7]. Because straw swallows yielded higher magnitudes than maximal compression of the lips, using a straw as an exercise to improve labial muscle strength may be beneficial in clinical settings in addition to traditional exercises involving compressing and protruding the lips. This may be accomplished either with actual liquid swallows by straw or with the bottom of the straw occluded by a gloved finger, depending on the safety of a patient's swallow. Further testing of this suggested therapeutic technique is warranted to assess its efficacy in various patient populations. Moreover, studies employing EMG technology to assess labial function should consider the notion that various labial tasks may be needed to determine what truly provides ''maximal'' labial activity.

Swallowing liquid via straw not only provided greater labial EMG than maximal lip compression and swallowing via cup and spoon, but clinically, often results in less oral spillage in patients with reduced labial muscle strength. It may be that positioning the lips in a ''pucker'' for straw usage physically restricts the free flow of liquid from the mouth that is more likely to occur with a weaker seal inherent in cup and spoon usage. Perhaps a patient must lose more strength in the lips before experiencing oral spillage of liquids with a straw, as more myoelectric activity was seen during straw usage than cup usage. We have yet to determine the specific amount of labial strength that must be lost before a functional disturbance in liquid removal from an implement and oral bolus containment without oral spillage are observed. Additional studies should examine normal subjects of differing ages to warrant comparison with various patient groups of differing ages with labial muscle dysfunction.

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