Lung Volume During Swallowing: Single Bolus Swallows in Healthy Young Adults

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Purpose: This study examined the relationship between swallowing and lung volume initiation in healthy adults during single swallows of boluses differing in volume and consistency. Differences in lung volume according to respiratory phase surrounding the swallow were also assessed.

Method: Nine men and 11 women between the ages of 19 and 28 years served as study participants. Lung volume and respiratory phase data were recorded as each participant completed 5 trials each of 10-mL and 20-mL water boluses by cup, and thin and thick paste boluses by spoon, presented in randomized order.

Results: Significant differences in lung volume at swallow initiation were found based on bolus consistency but not on bolus volume. No differences were found for lung volume initiation based on the respiratory phase surrounding the swallow or for the respiratory pattern based on bolus volume or consistency.

Conclusion: Findings of this study extend the existing knowledge base regarding the interaction of the swallow and respiratory systems by identifying targeted lung volumes at swallow initiation. In addition to other swallow-related biomechanical events and respiratory phase relationships surrounding a swallow, the lung volume at swallow initiation may be an important consideration when investigating swallow physiology and physiopathy.

KEY WORDS: swallowing, respiration, swallow motor control, swallow–respiratory integration

Deglutition and respiration share the upper aerodigestive tract, which necessitates the utilization of protective mechanisms to prevent airway compromise during a swallow (Miller, 1982, 1993). Thus, normal coordination between the two systems is precise to ensure timing and movement of the oropharyngeal structures for laryngeal closure and lower airway protection. This coordinative relationship manifests in part as cessation in respiration during the swallow (known as swallow-related apnea) as well as a respiratory phase characteristic surrounding the swallow-related apneic period (Martin, Logemann, Shaker, & Dodds, 1994; Martin-Harris, Brodsky, Price, Michel, & Walters, 2003; Paydarfar & Buerkel, 1995; Perlman, He, Barkmeier, & Van Leer, 2005; Preiksaitis & Mills, 1996; Shaker et al., 1992; Smith, Wolkove, Colacone, & Kreisman, 1989).

For most healthy individuals without dysphagia, single swallows are both preceded and followed by expiration; the expiratory-apnea-expiratory (Ex-Ex) pattern of breathing is present in 71%–100% of healthy individuals (Martin et al., 1994; Martin-Harris et al., 2003, 2005; Preiksaitis & Mills, 1996). Delivery method and the presence or absence of specific cues to swallow impart variability to these patterns. For example, a study using an investigator-delivered, 3- or 10-mL bolus via syringe resulted in 94%–100% of swallows following the Ex-Ex pattern (Martin et al., 1994).
However, when Martin-Harris and colleagues (2005) instructed participants to self-administer single liquid bolus (5 mL) swallows via graded medicine cup, they found the presence of the Ex-Ex pattern in only 71%–75% of swallows. The presentation of the bolus in the latter study represented a more natural bolus presentation and possibly a more physiologically realistic description of the respiratory phase surrounding single liquid bolus swallows. Ultimately, the expiratory phase of respiration is preferentially interrupted by single liquid swallows; however, the exact significance of that relationship remains unclear.

It has been hypothesized that the observed interaction of the respiratory system with deglutition may be related to the role of sensory receptors responsive to subglottal pressure during airway closure for swallow (Gross, Mahlmann, & Grayhack, 2003; Kijima, Isono, & Nishino, 2000; Miller, 1993). During a swallow, the laryngeal vestibule closes and the vocal folds adduct, allowing subglottal pressure to increase immediately prior to the swallow. This is purportedly related to temporal aspects of the pharyngeal swallow (Gross, Mahlmann, et al., 2003; Logemann, Pauloski, & Colangelo, 1998; Shin, Maeyama, Morikawa, & Umezaki, 1988; Suiter, McCullough, & Powell, 2003). For example, results from investigations of tracheostomized patients with and without occlusion of the tracheostomy tube have shown faster bolus transit times and lower incidence of penetration or aspiration with the tube occluded (e.g., Gross, Mahlmann, et al., 2003; Logemann et al., 1998; Suiter et al., 2003). As well, volitional manipulation of lung volume (which is related to subglottal pressure, discussed in the next paragraph) results in differences in the timing of swallow; specifically, swallows initiated at very low lung volumes (near residual volume) are significantly slower compared with swallows initiated at or near functional residual capacity or total lung capacity (Gross, Atwood, Grayhack, & Shaiman, 2003). Hence, subglottal pressure occurring during laryngeal closure and airflow through the glottis have been hypothesized to improve laryngeal sensation (Suiter et al., 2003) and stimulation of subglottal pressure receptors (Gross, Atwood, et al., 2003), leading to observed temporal adjustments in the swallow. Gross and colleagues (Gross, Steinhauser, Zajac, & Weissler, 2006) empirically demonstrated the presence of positive subglottal pressure during swallowing perfomed above functional residual capacity in one healthy, nontracheostomized participant.

The generation of subglottal pressure (positive or negative) is, in part, dependent on lung volume given the relationship between lung volume and relaxation pressure. The elastic recoil properties of the lung–thorax unit enables the generation of higher subglottal pressure at higher lung volumes (Hixon, Mead, & Goldman, 1976; Hoit, Plassman, Lansing, & Hixon, 1988; Otis, Fenn, & Rahn, 1950). It is well documented in the speech-breathing literature that the coordination of respiration with speech utilizes the elastic recoil properties of the lung–thorax unit by targeting lung volumes that most efficiently complete a given speech task (e.g., Hoit & Hixon, 1987). Collectively, evidence suggests that respiratory patterns associated with speech and phonation may be centrally coordinated (e.g., Dromey & Ramig, 1998; Huber, 2007; Huber & Stathopoulos, 2003; Huber, Chandrasekaran, & Wolstencroft, 2005; Sapienza, Stathopoulos, & Brown, 1997; Winkworth, Davis, Ellis, & Adams, 1994; Winkworth, Davis, Adams, & Ellis, 1995; Winkworth & Davis, 1997). Extrapolating on this body of evidence, along with existing knowledge regarding the relationship between respiration and deglutition, leads to the hypothesis that perhaps there is also a range of lung volumes that enables the most efficient, and safest, execution of a swallow task. Similar to changes in lung volume initiation during speech that are dependent upon phrase length and loudness parameters, bolus parameters—including the consistency and volume of the material—may influence the lung volume attained prior to swallow initiation.

In this study, we examined respiratory behavior associated with swallows of different bolus consistencies and volumes in healthy adults. The first hypothesis was that significant differences in lung volume initiation (LVI) would exist between single-swallow boluses of thin liquid and paste consistencies and between different bolus volumes of thin liquid (10 mL and 20 mL). The second hypothesis was that differences in LVI would exist across observed respiratory-swallow phase relationships (e.g., whether expiratory-apnea-expiratory, inspiratory-apnea-expiratory, inspiratory-apnea-inspiratory, or expiratory-apnea-inspiratory) for the different bolus consistencies.

**Method**

**Participants**

Twenty young adults (9 male \(M = 23\) years, 11 female \(M = 21\) years) between 19 and 28 years of age served as participants. A certified speech-language pathologist judged all participants as having normal oral anatomy upon visual inspection. No participant reported a history of voice or respiratory problems (including asthma), neurological disease, or head or neck surgery. All were nonsmokers for the past 5 years. The Institutional Review Board at the University of Florida approved the study.

**Procedures**

During data collection, participants were seated with their feet flat on the floor and arms resting on armrests. For instrument calibration purposes, respiratory...
maneuvers including three trials of rest breathing, speech-like breathing, swallow-like breathing (described in the Measurements section), vital capacity maneuvers, and isovolume maneuvers (at resting end expiratory level) were completed. These tasks (excluding swallow-like breathing) were completed in a manner previously described (Hoit & Hixon, 1987; Hoit, Hixon, Altman, & Morgan, 1989; Huber & Stathopoulos, 2003; Huber et al., 2005), in the order presented here. Following calibration procedures, participants were asked to swallow the following bolus types five times (for a total of 20 swallows): (a) 10 ml thin liquid (water) by cup; (b) 20 ml thin liquid (water) by cup; (c) 3 ml thin paste (applesauce or pudding) by spoon; and (d) 3 ml thick paste (peanut butter or cheese spread) by spoon.

The order of trial presentation was randomized for each participant; participants were not told what bolus size or type was being given. Participants self-fed each bolus, with the cup or spoon being placed in the participant’s hand during the expiratory phase of a rest breath, and the cue to “swallow when you are ready” was given at end expiratory level (EEL). The participants were given no further instructions regarding the timing of the swallow and were free to initiate swallowing at any time after the cue. To minimize movement artifact, participants were instructed to keep their feet flat on the floor and restrict self-feeding arm movements to those from the armrest to the mouth and back again, with no extraneous reaching during the trial.

**Equipment**

Respiratory inductive plethysmography via the Respitrace system (Ambulatory Monitoring, Inc., Ardsley, NY) was used to transduce respiratory movements. Elastic bands were placed around the rib cage under the axilla to track rib cage (RC) movement and around the abdomen (AB) with the top of the band at the level of the umbilicus, below the last rib to track AB movement (see Figure 1). Respiratory data including three trials each of rest breathing, speech-like breathing, swallow-like breathing, vital capacity maneuvers, and isovolume maneuvers were used to ensure sampling of relevant lung volumes (due to potential nonlinearity in the transducers) in our calibration of the Respitrace system. These data were collected using a spirometer (ML141, ADInstruments, Inc., Colorado Springs, CO) coupled to a respiratory flowhead (MLT 1000, ADInstruments, Inc.).

An acoustic signal was transduced via a contact microphone (Piezo-electric signal transducer, MLT1010, ADInstruments, Inc.), which was placed on the neck lateral and inferior to the thyroid lamina, with placement adjustment to minimize the artifact of the carotid pulse signal. A Bagnoli-8 EMG System (Delsys, Inc., Boston, MA) using a DE-2.1 surface EMG electrode recorded the submental muscle group activity. The electrode consisted of two silver-chloride bars, which were positioned perpendicular to the muscle fibers for maximal signal detection. Each participant’s skin was first

Figure 1. Participant setup with surface electromyography electrode (A), throat microphone (B), and Respitrace bands (C [rib cage] and D [abdomen]).
cleansed with an alcohol swab, and the surface electrode was taped to the skin beneath the chin lateral to midline (see Figure 1). The ground electrode was placed on the clavicle. Respiratory, acoustic, and surface electromyographic (sEMG) data were input to a Power lab (ML870/P), were they were digitized and then recorded at 2 kHz to a Dell Optiplex desktop computer using Chart 5 software (ADInstruments, Inc).

**Measurements**

Because lung volume change reflects combined changes in RC and AB volumes (Konno & Mead, 1967), the sum of the RC and AB signals, corrected for the respective RC and AB contributions to lung volume (LV) change, were computed. Rib cage and AB contributions to LV change were determined using three nonspeech tasks: rest breathing, speech-like breathing, and swallow-like breathing. To collect speech-like breathing, participants were instructed to say a short sentence (12 syllables) to themselves silently, one time per exhalation. To collect swallow-like breathing, participants were instructed to pretend they were preparing to drink a large glass of water one time per exhalation, without actually swallowing. LV during each swallow was estimated by calculating the corrected sum of the RC and AB signals, calibrated for change in LV during the nonspeech tasks using a least-squares technique (Huber et al., 2005). The participants performed three vital capacity tasks with the Respitrace bands in place to acquire an estimate of the maximal capacity of the lungs.

Lung volume initiation (LVI) was measured at the onset of breathing cessation associated with the swallow. The identification of the swallow onset was determined from the acoustic signal sampled from the contact throat microphone and increased submental muscle activity from the sEMG recording (see Figure 2). Of note, the sEMG and acoustic data were not dependent variables in this study; they simply served as guides in the identification of the swallows of interest, and therefore their values are not reported. The acoustic signal, identified by a biphasic deviation in the signal from baseline, helped to differentiate the onset of oropharyngeal swallow from other submental muscle activity (such as activity related to bolus manipulation and tongue movement). Swallow identification was then based on increased amplitude in the sEMG signal, which coincided with acoustic signal. Once the swallow event was located, the swallow-related apneic period was identified as points in the respiratory signal during the swallow when it was flat relative to cycles of tidal breathing (see Figure 2). LVI was then measured at the onset of swallow-related apnea and was expressed as a percent of vital capacity (%VC; see Figure 3). Lung volume termination (LVT) was measured at the offset of swallow-related apnea. LVTs and excursions (LVI – LVT = lung volume excursion [LVE]) were

![Figure 2. Example of microphone (top), surface electromyography (sEMG; middle), and respiratory (bottom) signals collected simultaneously. A = preswallow expiration; B = apnea onset; C = apnea duration; D = apnea offset; E = postswallow expiration.](image-url)
checked to ensure that little to no volume was expended during the swallow, as would be expected due to the apneic period. However, LVT and LVE were not dependent variables in the current study. The respiratory phase (inspiratory or expiratory) in which the swallow occurred was determined by visual inspection of the lung volume signal. Pre- and postswallow inspiration and expiration were identified as upward or downward movement of the respiratory signal prior to and following the apneic period, respectively (see Figure 2) and were then expressed as one of four possible respiratory patterns: (a) expiratory-apnea-expiratory (Ex-Ex); (b) inspiratory-apnea-expiratory (In-Ex); (c) inspiratory-apnea-inspiratory (In-In); or (d) expiratory-apnea-inspiratory (Ex-In).

Statistics

Intermeasurer reliability was completed on 20% of the data, which included random selection of 2 male and 2 female participants. Means for LVI across the five trials were computed for each participant for each bolus volume and consistency. Respiratory pattern was computed as a percentage of the total number of swallows—for example, where 34 swallows out of 414 total swallows were Ex-In, 8% (34/414 × 100) were Ex-In. Paired samples t tests and Pearson’s r correlations were used to assess intermeasurer reliability. A one-sample t test was used to test the null hypothesis that LVE = 0 (indicating lack of air expended during the apneic period). The differences for mean LVI across the bolus types (thin small, thin large, thin paste, and thick paste) were assessed in a two-factor multivariate analysis of variance (MANOVA), with significance set at p = .05. The within-subject factor was bolus type, and the between-subjects factor was sex. Post hoc testing was completed using Tukey’s honestly significant difference (HSD) test. The alpha level for the Tukey’s HSD tests was set at p = .05. The Kruskal–Wallis test, a nonparametric alternative to one-way analysis of variance (ANOVA) for cases that violated the assumption of homogeneity of variance (Levine’s test = 4.436, df = 3, p = .004; Agresti & Finlay, 1986), was used to assess differences in respiratory pattern according to bolus type and in LVI according to the respiratory pattern observed.

Results

Tests of intermeasurer reliability indicated nonsignificant differences between measurers (t = 1.907, df = 5, p = .220) and strong positive correlations (r = .999, p = .001). Results of the one-sample t tests indicated that LVE was not significantly different from 0 (t = 0.613, df = 412, p = .540).

Table 1 shows the means and standard deviations for LVI according to bolus type. Results of the MANOVA indicated a nonsignificant effect of sex, F(1) = 0.032, p = .895; therefore, data were collapsed across sex, and the tests were re-run. A significant effect of bolus type, F(3) = 6.159, p < .001, was found. Results of post hoc testing for the effect of bolus type are in Table 2; the large thin liquid swallows were initiated at higher LVIs versus the thin paste and thick paste boluses; small thin liquid swallows were initiated at higher LVIs versus the thick paste boluses.

For the majority of swallows analyzed in this study, the respiratory pattern was Ex-Ex (79% of total swallows). The occurrence of other patterns was: In-Ex (8%); In-In (3%); and Ex-In (10%). All study participants exhibited the Ex-Ex pattern in at least one swallow, 11 of 20 exhibited the In-Ex pattern, 7 of 20 exhibited the In-In pattern, and 16 of 20 exhibited the Ex-In pattern. The Kruskal–Wallis tests revealed a nonsignificant effect for bolus type on respiratory pattern, χ²(2) = 5.06, p = .080, Figure 3.

Table 1. Means (M) and standard deviations (SD) for the lung volume initiation (LVI) according to bolus type.

<table>
<thead>
<tr>
<th>Bolus type</th>
<th>LVI M (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thin small</td>
<td>55.26 (9.80)</td>
</tr>
<tr>
<td>Thin large</td>
<td>56.27 (10.11)</td>
</tr>
<tr>
<td>Thin paste</td>
<td>51.47 (11.50)</td>
</tr>
<tr>
<td>Thick paste</td>
<td>51.16 (10.91)</td>
</tr>
</tbody>
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Note. Values are reported as a percent of vital capacity.
These results indicate that the respiratory pattern observed was not different according to the type of bolus swallowed (see Figure 4), and LVI was not significantly different according to the respiratory pattern (see Figure 5).

**Discussion**

This project studied how different bolus consistencies and bolus volumes during swallow affected LVI in healthy adults. The study’s first hypothesis was that significant differences in LVI would exist (a) between single-swallow boluses of thin liquid and paste consistencies and (b) between different bolus volumes of thin liquid (10 mL and 20 mL). Results supported this hypothesis, with significant differences found for LVI based on consistency. Swallows were initiated at significantly higher LVIs for large, thin liquid boluses versus the thin-paste and thick-paste boluses. The LVI values for the small, thin liquid swallows were significantly higher than the thick paste consistency only. No significant differences in LVI existed between small and large volumes of thin liquid or between thin- and thick-paste consistencies. The study’s second hypothesis was that differences in LVI would exist relative to observed respiratory-swallow phase relationships (e.g., whether Ex-Ex, In-Ex, etc.). This hypothesis was not supported, as no significant differences were found for respiratory pattern on LVI. Additionally, the respiratory pattern did not differ significantly according to bolus types (see Figure 5).

Swallows of the large (20 mL), thin liquid boluses occurred at significantly higher lung volumes versus thin- and thick-paste consistency swallows. The LVIs for the small, thin liquid boluses were significantly higher than the thin-paste consistency but not the thin-paste consistency (see Tables 1 and 2). Because thin liquids are more likely to penetrate the laryngeal aditus or be aspirated, even in healthy adult swallwers (Daggett, Logemann, Rademaker, & Pauloski, 2006), the participants in the current study may have initiated the swallows of thin liquid with a larger volume of air in the lungs to enhance expiratory pressure on the chance that penetration or aspiration were to occur.

Surprisingly, no differences in LVI were found between small and large volumes of thin liquids. The 10-mL (small) and 20-mL (large) sizes used in this study were chosen because they could be consistently swallowed as one bolus and because they more closely approximated the “typical” size bolus, which ranges between 16 and 26 mL for healthy adults (Adnerhill, Ekberg, & Groher, 1989). The data regarding differences between these two volumes in terms of the duration of swallow-related apnea and changes to the respiratory cycle surrounding the swallow are equivocal. Differences have been identified between these two volumes both in duration of apnea and respiratory-swallow patterns (Hiss, Treole, & Stuart, 2001; Preiksaitis, Mayrand, Robins, & Diamant, 1992). However, some studies have failed to identify differences related to the duration of swallow apnea and the respiratory phase surrounding the swallow for the 10-mL and 20-mL volumes. For example, a recent study by Butler and colleagues failed to identify a significant difference in terms of the total apnea duration between 10- and 20-mL boluses (Butler, Postma, & Fischer, 2004). Martin and colleagues (1994) found no effect of bolus volumes ranging between 3 and 20 mL on the respiratory phase before and after a swallow. Thus, although the data did not support the original hypothesis related to bolus volume, it is not in disagreement with several published studies which indicate that the bolus volumes included in this study do not have a significant effect in changing the integration of respiration and swallow.
Measurement of the pre- and postswallow respiratory pattern in the current study was based on upward or downward deflection in the respitrace signal surrounding swallow-related apnea. Because the current study did not employ direct swallow visualization, marking the onset and offset of the actual swallow as markers for pre- and postrespiratory phase identification would have been a more ambiguous method of quantifying the respiratory phase pattern associated with the swallow. Nonetheless, the current methodology is different from studies that used onset and offset of the actual swallow as markers for pre- and postswallow respiratory phase, and this necessitates the use of caution when comparing results. However, the current findings are in agreement with several previous works which utilized similar bolus delivery methods (Hiss et al., 2001; Klahn & Perlman, 1999; Martin et al., 1994). Seventy-nine percent of swallows analyzed in this study followed the Ex-Ex respiratory pattern; overall, 8% of swallows analyzed followed the In-Ex pattern, yielding 87% of swallows followed by expiration. Following a swallow with expiration may serve as an airway protection mechanism. For example, if residual bolus material remains in the hypopharyngeal area following a swallow, expiratory airflow would decrease the likelihood of that material being sucked into the larynx or lower airways.

Interestingly, no differences were identified in LVI based on differences in respiratory pattern surrounding a swallow, independent of bolus type. This indicates that the amount of air present in the lungs as a swallow is initiated remains consistent across the four respiratory pattern possibilities surrounding a swallow. One implication of this finding is that various strategies may be employed in terms of respiratory phase to meet lung volume requirements for successful swallow execution. Although Ex-Ex is the respiratory pattern employed for the majority of single-swallow boluses, other patterns may also function to achieve equivalent lung volumes.

Gross, Atwood, and colleagues (2003) demonstrated that volitional lung volume manipulation affected the duration of a swallow (see Figure 5). Swallows performed at or near residual volume were executed more slowly compared with swallows performed at or above functional residual capacity or swallows performed at total lung capacity. The present study elaborates on these previous findings by identifying typical lung volumes associated with single bolus swallows. The mean values for LVI across bolus types ranged from 51.16% to 56.27% vital capacity (VC), with 95% of all data points falling between 42.71% and 64.31% VC. A summary of these findings, along with the findings of Gross, Atwood et al. (2003), appears in Figure 5.
single bolus swallows occurred at mid-range lung volumes, above the 35%–38% VC range typically associated with functional residual capacity (FRC). The advantage of a swallow performed above FRC may be related to the recoil forces generated by the lungs–thorax unit. In the slightly expanded state of the lungs–thorax unit in which study participants initiated swallow apnea, the natural tendency of the lungs–thorax unit is to compress back to a rest position.

The presence of positive recoil forces enhances subglottal pressure generated by expiratory muscle activity, ensuring expiratory airflow and a strong expulsion of any bolus material, if necessary. Thus, in the case where airway compromise is encountered during the swallow, slightly higher lung volumes would position the swallower to quickly initiate a more effective laryngeal cough expiration reflex (ER) response and expel the material. The ER response is similar to a reflexive cough; the fundamental difference between the two is that the ER lacks the inspiratory phase of a cough (i.e., an ER is characterized by forced expiratory effort without a preceding inspiration; Bolser, Poliacek, Jakus, Fuller, & Davenport, 2006; Widdicombe & Fontana, 2006). Like a cough, the ER response is accompanied by glottal closure followed by glottal opening and an expulsive phase. Consequently, expiratory effort for an ER is related to both the recoil forces of the lungs–thorax unit (dependent upon existing volume of air in the lungs) and the strength of the expiratory muscles. The contribution of recoil forces to expiratory pressure at a range of 41%–61% VC is between 1.5 and 9.7 cm H2O; below 40% VC recoil pressures may fall into negative values (mean value = $-1.8$ cm H2O; Rahn, Otis, Chadwick, & Fenn, 1946). However, with expiratory muscle contribution, maximum expiratory pressures generated at similar lung volumes may be upwards of 122 cm H2O (at 40%–60% VC), which is at least approximately 30 cm H2O higher than maximum pressures at lower lung volumes (below 40% VC). Therefore, breathing to slightly higher lung volumes prior to a swallow would greatly enhance the strength of an ER in the case of aspiration via the combined contribution of both recoil and muscular forces.

The current study suggests that in addition to the phase of respiration that a swallow interrupts, there are lung volumes that may be incorporated into the motor plan for swallowing and breathing. Evidence to date tells us that the primary integration of respiration and swallowing occurs at the level of the brainstem, specifically within and between the respiratory and swallow groups of neurons in the ventrolateral medulla (Broussard & Altschuler, 2000; Jean, 1984). Various inputs project information to those structures and ultimately impact the swallow–respiratory integration. One projection may originate cortically—for example, from external cues to increase or decrease the volume of air in the lungs prior to swallowing (Gross, Atwood, et al., 2003). A second projection might be from the periphery—for example, a mechanoreceptor signaling the presence of a bolus at specific locations in the oro- or hypo-pharynx (Jean, 1984). Gross, Atwood, and colleagues’ (2003) study of external cues to manipulate lung volume prior to swallowing suggests a peripheral input to the swallowing neurons in the brainstem. These researchers hypothesized that the observed changes in the duration of the swallow as starting lung volume was manipulated resulted from mechanoreceptors in the laryngeal area that are sensitive to subglottal pressure differences resulting from the change in lung volume. Consequently, afferents traveling via the recurrent laryngeal nerve, which provides sensory innervation to the inferior glottal area, provide feedback to the swallow and/or respiratory central pattern generator (CPG), thereby modulating the swallow output (Gross, Atwood, et al., 2003).

Paydarfar and Buerkel (1995) found that under normal physiologic conditions, swallowing reset the phase of the respiratory cycle, including the swallow, and shifted the phase and time of the one or two subsequent respiratory cycles. This is in agreement with McFarland and Lund (1995), who also found an effect of the swallow on the respiratory rhythm in the form of increased cycle duration for the 1–2 cycles following the swallow. These findings were consistent, regardless of whether the swallow occurred during late inspiration, expiration, and so forth. It was subsequently hypothesized that the respiratory phase following the swallow was the result of sensory integration and motor output organization at the level of the swallow and respiratory CPGs rather than being dependent solely on biomechanical events.

Therefore, lung volumes achieved during swallowing may result from two possible mechanisms. It may be that input from mechanoreceptors sensitive to subglottal pressure (which is partly dependent upon lung volume)—or perhaps other afferent input from the lungs or chest cavity, which is delivered to the swallowing and respiratory central pattern generators—plays a significant role in development of the swallow output plan. This hypothesis can account for the observed differences in the duration of a swallow relative to differences in the volume of air in the lungs reported by Gross, Atwood, and colleagues (2003) and the relationship between the respiratory pattern surrounding a swallow and the LVI. However, it fails to account for differences found based on bolus characteristics. The majority of swallows do not occur specifically at the top of inspiration or bottom of expiration but, rather, during expiration (Ex-Ex swallows), and there is variability within those swallows dependent upon the bolus type as to the LVI observed. If detection of a particular subglottal pressure were necessary a priori to the swallow in order to effectively generate a swallow–respiratory plan, differences based on
characteristics of the bolus would not likely be seen. However, the current study demonstrated that large thin liquid boluses were swallowed at higher lung volumes than paste consistencies. Therefore, the motor output plan for a swallow is partially determined by bolus characteristics, which would be sensed at a point earlier than would the detection of specific subglottal pressures occurring with glottal closure. In the case of the swallow variability based on lung volume in the Gross, Atwood, et al. (2003) study, modulation of the plan may have occurred prior to and independent of the peripheral detection of subglottal pressure differences at the level of the brainstem, as the volitional intent to maximally deplete the air in the lungs prior to swallowing was received by the CPGs from supramedullary structures, thus resulting in durational differences observed. Further study is needed regarding the neural pathways underlying the swallow–respiratory coordination in order to confirm or reject these hypotheses.

This study adds to the knowledge base regarding the relationship between the swallow and respiratory subsystems and suggests that consideration of a patient’s ability to initiate a swallow with adequate air in the lungs may be an important consideration along with other swallowing events, such as oral–pharyngeal bolus propulsion and hyolaryngeal motion. Because disease and age-related differences exist in these other aspects of the swallowing mechanism, repeating this study in patient populations and in a cohort of older adults is warranted. Small bolus sizes, which could be ingested in one swallow, are reported here; it is known that the swallow–respiratory integration is different with chewing and/or sequential swallowing, and these conditions should be investigated as well. Additionally, all swallows in the current study were cued at the bottom of expiration (although participants were free to “swallow when ready” after being given the cue); it may be that staggering the cue to swallow at random points in the respiratory cycle may have impacted the respiratory pattern surrounding breathing cessation. Lastly, it would be interesting and relevant to investigate how commonly utilized swallowing therapy maneuvers, such as the effortful swallow and Mendelsohn maneuver, would impact the swallow–respiratory relationship.

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