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Dysphagia

The Influence of Orolingual Pressure on the Timing of Pharyngeal Pressure Events

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Abstract. This study explored the influence of two methods of effortful swallow execution on the timing of pharyngeal pressure events. Participants were asked to either emphasize or minimize tongue-to-palate contact during performance of the maneuver. Twenty healthy participants were evaluated using concurrent submental surface electromyography (sEMG), orolingual manometry, and pharyngeal manometry. Each subject performed three repetitions of three counterbalanced tasks (noneffortful dry swallows, effortful dry swallows with tongue-to-palate emphasis, and effortful dry swallows with tongue-to-palate de-emphasis). Four variables were measured: Onset Lag vs. sEMG Peak, Peak Lag vs. sEMG Peak, Total Duration, and Percent Rise Time to Peak. Compared to noneffortful swallows, the effortful swallow task elicited significantly earlier onsets and peaks of pharyngeal pressures relative to the submental sEMG peak. Total pressure event durations were greater and rise times were significantly shorter. When comparing the two methods of effortful swallow execution, a longer latency to peak proximal pharyngeal pressure was found in the tongue-to-palate emphasis condition. These results support the interpretation that the effortful swallow maneuver involves generation of higher velocity bolus driving forces that propel the bolus into and through the pharynx with greater efficiency and that pressure is then sustained to facilitate more complete bolus clearance.

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Management of the patient with swallowing impairment has rapidly progressed over the past 15 years, evidenced by a remarkable increase in publications related to this area of clinical practice [1]. A number of interventions for dysphagia have been proposed, and these can be subclassified as techniques with goals of achieving either an immediate but transient improvement in swallowing safety and/or efficiency, or long-term rehabilitation of underlying physiology through neuromuscular re-education [2,3]. These interventions are regularly applied in clinical practice based on either anecdotal evidence or preliminary research. However, our understanding of the physiologic effects of therapeutic maneuvers remains incomplete. A more thorough investigation of these techniques is needed to enable a clearer understanding of the biomechanical changes that occur in response to volitionally altered swallowing behaviors.

One example of a maneuver whose effects are not fully understood is the effortful swallow. This maneuver was first introduced by Kahrilas and colleagues [4–6] as a compensatory technique. Early videomanometric studies suggested that increased effort in swallowing resulted in increased bolus pressure and subsequently decreased pharyngeal residue. Based on this work, clinicians have readily prescribed the technique as a compensatory strategy and more recently as a rehabilitation exercise [7–9], with the end goal of improving pharyngoesophageal bolus clearance through the generation of increased pharyngeal pressure.

Subsequent research on both oral (tongue-to-palate) and pharyngeal pressures generated during the effortful swallow has raised questions regarding the specific biomechanical influence of this technique. Although several publications have documented increased pressure generation, [4–6,10–13], other publications report conflicting results [14–16]. In addition, published research has documented that the effortful swallow influences pressure generation differentially, depending on where measurements are recorded within the pharynx [12,13,17] and on how individuals are instructed to perform the technique [13]. In a study of ten healthy research participants, Olsson and colleagues [17] reported greater pharyngeal pressure amplitudes at the level of the inferior pharyngeal constrictor compared with a measurement site at the base of the tongue. This finding was confirmed in a more recent study of 22 healthy research participants by Huckabee and colleagues [12]. Huckabee and Steele [13] recently reported that emphasizing tongue-to-palate contact pressure during performance of the maneuver yields greater increases in the magnitude of pharyngeal pressure than performance of the technique with an intentional focus on effortful pharyngeal muscle contraction while limiting tongue-to-palate contact. Collectively, this research suggests that the effects of the effortful swallow are not as straightforward as originally presumed, namely, that simply ''swallowing hard'' generates increased pharyngeal pressure.

The effortful swallow influences not only the magnitude of orolingual and pharyngeal pressure events, but also the timing of biomechanical events during the pharyngeal swallow [12]. Several studies have begun to explore these temporal influences. Hiss and Huckabee [12] have recently reported that the duration of pharyngeal pressure events was significantly longer in effortful saliva swallows compared with noneffortful saliva swallows. As with pressure amplitude effects, the magnitude of these temporal effects varied across different locations within the pharynx, with greater prolongation of the pressure wave observed in the proximal pharynx compared with the distal pharynx. This observation was in agreement with Olsson et al.'s [17] finding that the duration of pressure generation in the lower pharynx was shorter than that measured at the base of the tongue during the effortful swallow.

Hiss and Huckabee [12] also reported that the temporal locations of the onsets of pharyngeal pressures and upper esophageal sphincter (UES) relaxation were delayed relative to the onset of submental sEMG contraction during performance of the effortful swallow. They suggest that this finding of exaggerated delay in pharyngeal pressure onsets may provide evidence to contraindicate the use of the effortful swallow maneuver in patients who already display delays in pharyngeal swallow initiation. It may, however, be argued that the functional benefits (i.e., enhanced pressure amplitudes) of the effortful swallow are likely to be most strongly experienced at the time of pressure peaks (rather than at the time of pressure onsets), or indeed in the relative speed with which peak pressures are achieved. Additional research is therefore needed to elucidate the effects of the maneuver on the temporal characteristics of pharyngeal pressure generation.

Hiss and Huckabee's [12] data do not, however, take into account the potential temporal effects of the effortful swallow on oral events that typically precede the beginning of pressure generation in the proximal pharynx. Data reported by Hind et al. [11] showed evidence of increased orolingual pressure amplitudes during performance of the effortful swallow, suggesting that the exaggeration of tongue-to-palate contact occurs during execution of the maneuver. Huckabee and Steele [13] recently confirmed that volitional emphasis on orolingual pressure enhances the pharyngeal pressure amplitude influences of the maneuver. Therefore, it is important that our understanding of the temporal effects of the maneuver include oral as well as pharyngeal events.

The purpose of this study was to evaluate the influence of the effortful swallow on the temporal characteristics of pressure generation in both the mouth (tongue-to-palate pressures) and the upper (proximal) and lower (distal) pharynx. Differences in the temporal characteristics of pharyngeal pressure events were explored under two conditions of maneuver execution: In one condition, tongue-to-palate contact was intentionally emphasized; in the other, orolingual pressure was intentionally limited in favor of emphasis on pharyngeal muscle effort. In contrast to the methods used previously by Hiss and Huckabee [12], the timing of pressure peaks (rather than onsets) was used as the event of interest. It was hypothesized that effortful swallows would elicit pressure events of longer duration in both the mouth and the pharynx but that the temporal location of pressure peaks would be advanced (rather than delayed) relative to the timing of peak submental sEMG contraction. This hypothesis was considered to be consistent with the idea that the increased driving forces of the effortful swallow would generate faster movement of a bolus through the oropharynx. With specific reference to the role played by tongue-to-palate pressures, it was expected that any strategy-related differences in temporal events would be evident only in pharyngeal pressure data because the expressed instruction in the de-emphasis condition was to limit tongue-to-palate pressure. No specific hypotheses were formulated regarding the nature of any temporal effects associated with the manner of maneuver execution.

Methods

Twenty healthy research participants (RP) between the ages of 20 and 35 years volunteered for this project. A questionnaire confirmed that the RPs had no history of swallowing disorder, pulmonary disease, neurologic illness, or structural disorder of the head and neck. Informed consent was obtained from all RPs before initiating data collection; ethics approval was obtained by the appropriate regional health ethics review board. Each RP attended two data collection sessions (approximately 90 min long) within a one-week period. Data collection sessions were conducted in a Swallowing Rehabilitation Research Laboratory located in a medical facility. Identical methods were used for both sessions, except for the instruction regarding the performance of swallowing maneuvers. All data [surface electromyography (sEMG), orolingual manometry, and pharyngeal manometry] were collected concurrently and analyzed using the integrated Kay Elemetrics Digital Swallowing Workstation (Kay Elemetrics, Lincoln Park, NJ). Triode surface electrodes (5.4-cm diameter) were positioned lengthwise under the chin (between the spine of the mandible and the superior palpable edge of the thyroid cartilage) to measure collective sEMG activity of the floor of the mouth and anterior suprahyoid muscles during swallowing. The ground electrode was positioned laterally.

Before proceeding with further sensor placement or data collection, the subjects were instructed in the performance of a noneffortful saliva swallow and maneuvers (the effortful swallow and the Mendelsohn maneuver). Two methods of maneuver execution were taught, with the order of instruction counterbalanced across consecutive sessions for each RP. In the first condition, RPs were asked to restrict tongue-to-palate contact when performing maneuvers, so that they were using the floor of the mouth and pharyngeal muscles to generate forces for swallowing (“As you swallow, I want you to squeeze hard with the muscles of your throat, but NOT use your tongue to generate extra force”). In the alternative condition, RPs were asked to exaggerate tongue-to-palate contact during performance of maneuvers (“As you swallow, push really hard with your tongue”). RPs were allowed to practice these tasks while viewing a computer-displayed output of the rectified and averaged submental sEMG signal to guide performance and mastery.

Following practice in the experimental tasks, a 100-cm solid-state manometry catheter containing three 2-mm × 5-mm, unidirectional, posteriorly oriented pressure transducers and a pair of bipolar sEMG electrodes (Medical Measurements Inc., Hackensack, NJ; Model CT/S3 + emg, 2.1 mm in diameter) was placed transnasally for the purpose of measuring intraluminal pharyngeal pressures. This catheter is similar to that described previously [12,18,19]. When resistance at the posterior pharyngeal wall indicated that the catheter had reached the upper pharynx, the RPs were provided with a glass of water and instructed to drink rapidly through a straw to facilitate swallowing of the catheter into the proximal esophagus. When approximately 40 cm of the catheter, as measured from the tip of the nose, had been swallowed, a pull-through technique was used to position all sensors appropriately. Correct placement was confirmed by observation of an “M” wave in the third sensor during swallowing and high pressure in the third sensor at rest. With this placement the uppermost manometric sensor was positioned approximately even with the tip of the epiglottis, the second manometric sensor was placed 13 mm below in the midpharynx, and the third sensor was positioned within the tonically contracted UES. The catheter was then taped securely to the external nose. Catheter calibration was conducted according to manufacturer’s specifications before data collection in each participant. Finally, a strip of soft plastic that housed three orolingual pressure sensors was secured to the palate using a small amount of polymer tissue adhesive (isobutyl cyanoacrylate). The most anterior sensor was placed at the junction of the central incisors and the alveolar ridge. The middle sensor was approximately midpalate and the most posterior sensor was approximately at the junction of the hard and soft palates. Data from the most anterior sensor were not analyzed for this study.

Data Collection

During data collection each subject performed three repetitions of the three research tasks as instructed during the training period: noneffortful (saliva) swallows, effortful (saliva) swallows, and the Mendelsohn maneuver. Data were collected in sets, comprising a series of five reiterated tokens of the selected task. Data from the Mendelsohn maneuver are not reported in this article. The order of tasks was randomized for each RP. Digital 12-bit samples of the manometric (both orolingual and pharyngeal) and the submental sEMG data were obtained concurrently at a sampling rate of 500 Hz, producing waveforms showing amplitude over time. These data were displayed to the researcher but not to the participant throughout data collection and were stored on the swallowing workstation for subsequent analysis. Confidentiality was assured by assigning each RP a coded identification number.

Operational Definitions

Data from this study were collected over two sessions per participant, counterbalanced for the strategy used to perform the effortful swallow task (with or without tongue-to-palate emphasis). To permit comparison of temporal events across channels, the time of peak submental sEMG amplitude served as time zero, i.e., the point from which all durational variables were measured (in milliseconds). Three temporal events were indexed for each of the four pressure sensors (mid orolingual pressure, posterior orolingual pressure, proximal pharyngeal pressure, and distal pharyngeal pressure): departure from baseline (onset), peak amplitude, and return to baseline (offset) (Fig. 1). Peak pressure was defined as the time point of maximal pressure generation during swallowing. Based on these procedures, the following temporal variables were derived for each sensor location:

1. Onset Lag (Advance) vs. sEMG Peak (in ms)
2. Peak Lag (Advance) vs. sEMG Peak (in ms)
3. Total Duration (i.e., offset time minus onset time, in ms)
4. Percent Rise Time (i.e., peak time minus onset time, divided by total duration)

Mean values for each variable were calculated across each set of five reiterated swallows and subjected to statistical analysis using SPSS v13.0 (SPSS, Inc., Chicago, IL). A Bonferroni-corrected alpha level of $p < 0.0125$ was used to adjust for expected

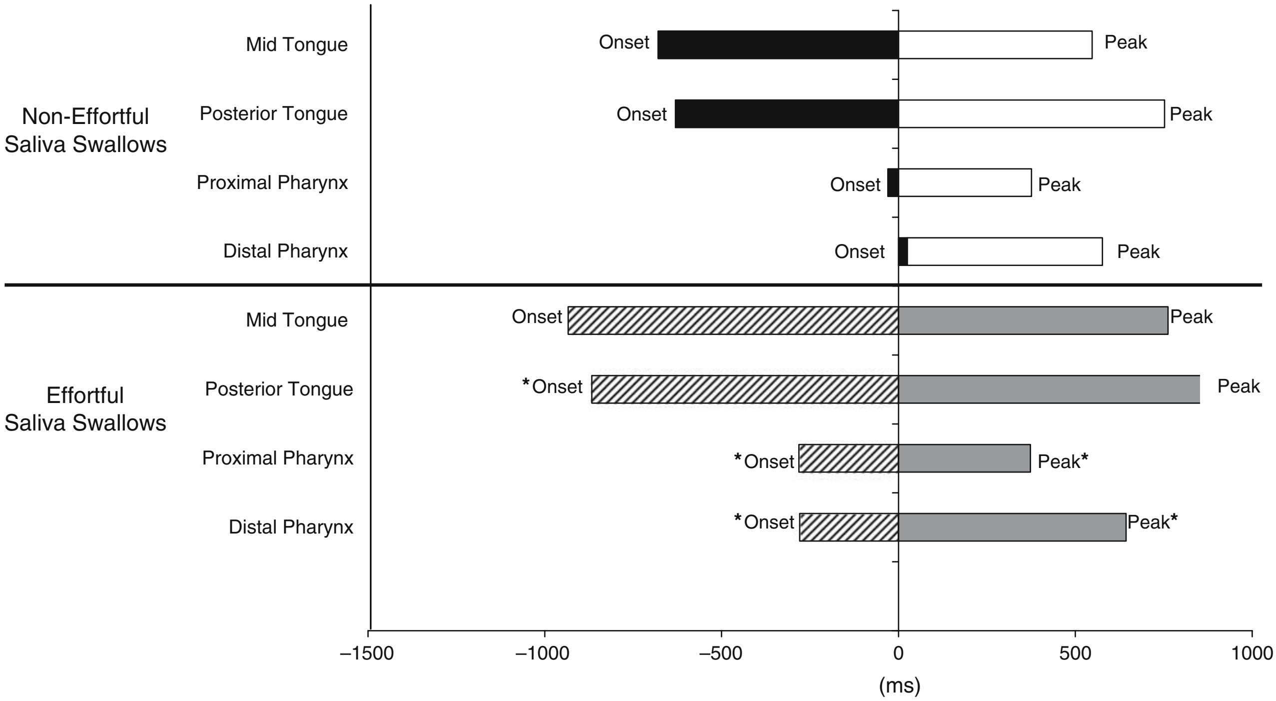

Fig. 1. Temporal locations of pressure event onsets and peaks relative to peak submental sEMG during noneffortful and effortful saliva swallows. The temporal locations of pressure onsets and peaks are shown relative to peak submental sEMG (time = 0 ms) for noneffortful and effortful saliva swallows. Statistically significant differences ($p < 0.0125$) between noneffortful and effortful swallows are indicated by the asterisks for onset lags and peak lags.

relationships across the four variables (0.05/4) [20]. Effect sizes are reported for statistically significant findings using Cohen's d standardized effect size, which is calculated as the difference in group means divided by the pooled standard deviation [21]. Effect size can be interpreted as strong for d values of 0.8 or higher, moderate for $d = 0.5$–0.79, and weak for $d = 0.2$–0.5 [21,22].

Results

Noneffortful vs. Effortful Swallows

Noneffortful saliva swallows were the reference task in this investigation and were performed in the same manner on both data collection days. For the comparison of noneffortful and effortful swallowing conditions, temporal data from both conditions of effortful swallow execution were collapsed into a single data file. Repeated-measures analysis of variance (ANOVAs), with factors of TASK (noneffortful vs. effortful) and SET (6 task repetitions), were performed. The effortful swallow task elicited significantly earlier onsets of pressures relative to the peak of submental sEMG contraction in the posterior tongue [$F(1, 18) = 12.02$, $p = 0.003$, $d = 0.41$] and in both the proximal [$F(1, 19) = 10.41$, $p = 0.004$, $d = 0.68$] and distal pharynx [$F(1, 19) = 23.00$, $p = 0.000$, $d = 0.58$]. Peak pressures were achieved significantly sooner relative to the peak of submental sEMG contraction in the proximal [$F(1, 19) = 11.21$, $p = 0.003$, $d = 0.76$] and distal pharynx [$F(1\ 19) = 7.93$, $p = 0.011$, $d = 0.62$]. Figure 1 provides a graphic illustration of the temporal locations of pressure event onsets and peaks relative to the peak of submental sEMG contraction (time zero) in both task conditions. Although the absolute duration of pressure generation (in milliseconds from onset to peak) increased for all sensors in the effortful task, when these differences were examined as a percentage of the total pressure duration (as illustrated in Fig. 2), only the midtongue sensor showed a statistically significant increase in this phase of the pressure event [$F(1, 14) = 20.27$, $p = 0.000$, $d = 0.81$]. Interestingly, an opposite significant effect of proportionally shorter rise times (i.e., relatively faster achievement of peak pressure) was observed at both pharyngeal pressure sensor locations during the effortful swallow [proximal pharynx: $F(1, 18) = 26.72$, $p = 0.000$, $d = 0.73$; distal pharynx: $F(1, 18) = 8.27$, $p = 0.010$, $d = 0.57$]. Total pressure event durations were significantly longer in the effortful swallowing task for three of the four manometry sensor locations [midtongue: $F(1, 16) = 11.46$, $p = 0.004$, $d = 0.34$; proximal pharynx: $F(1, 16) = 96.04$, $p = 0.000$, $d = 0.83$; distal pharynx: $F(1, 18) = 14.22$, $p = 0.001$, $d = 0.34$].

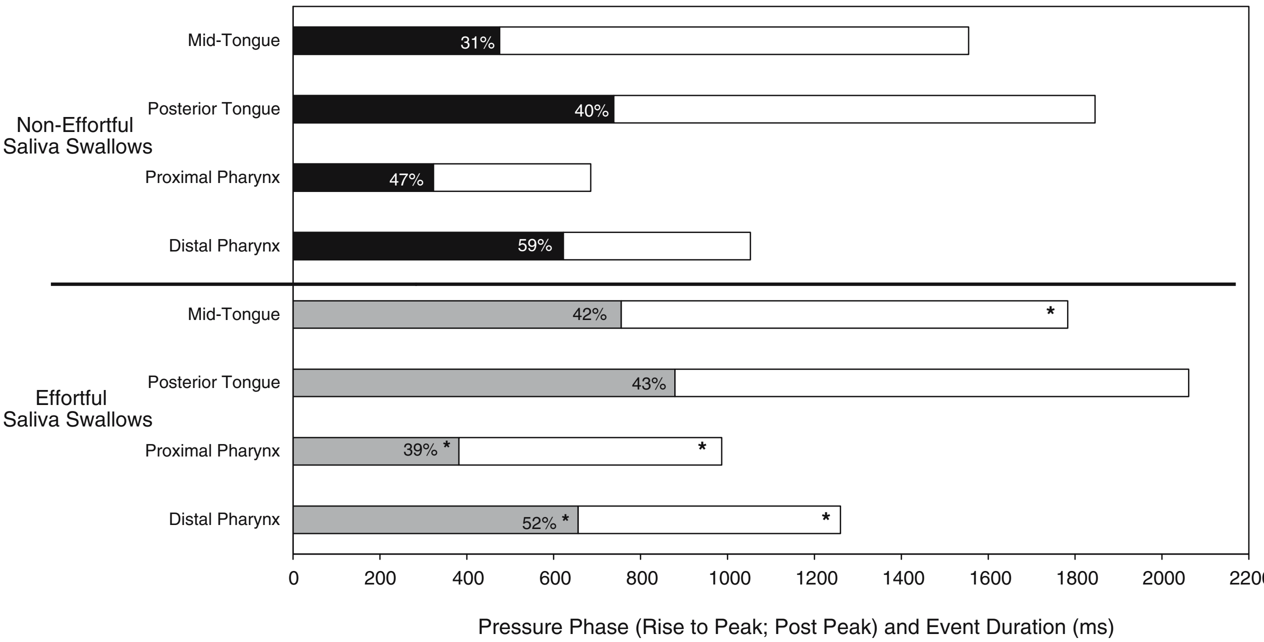

Fig. 2. Durations of the generation (onset to peak) and postpeak phases of pressure events during noneffortful and effortful saliva swallows. The duration and relative event percentage of the pressure generation phase are shown by the shaded sections of each bar. Statistically significant differences ($p < 0.0125$) between noneffortful and effortful swallows are indicated by the asterisks for percent rise time and total event durations.

Prolongation of the posterior tongue pressure event was also observed in the effortful swallow, but this finding failed to meet the Bonferroni-adjusted criterion for statistical significance [$F(1, 18) = 5.84$, $p = 0.027$, $d = 0.26$]. A single statistically significant SET effect was observed in the data set (for posterior tongue pressure peak lag vs. peak sEMG, [$F(5, 14) = 4.88$, $p = 0.009$, $d = 0.36$]); closer inspection of the data revealed that this finding differentiated two subgroups of data, which corresponded to the sets performed using either the tongue-to-palate emphasis or the tongue-to-palate de-emphasis strategies, which is discussed below. No significant TASK × SET interactions were observed.

Effortful Swallow by Strategy

Descriptive statistics for the effects of the effortful swallow technique on temporal characteristics of pharyngeal pressure events are shown in Table 1. Repeated-measures ANOVAs with factors of STRATEGY (tongue emphasis vs. no tongue emphasis) and SET (3 task repetitions) were performed. As suggested by the SET effect noted previously in the pooled data, a single significant STRATEGY effect in the form of a longer interval between peak submental sEMG and the peak of proximal pharyngeal pressure was observed in the tongue-emphasis condition [$F(1, 19) = 8.72$, $p = 0.008$, $d = 0.71$]. No statistically significant differences were noted in onset lag times, total pressure event durations, or the percent rise time to peak pressure for any of the four manometric sensors.

Discussion

The results of this investigation shed new light on the temporal effects of the effortful swallow maneuver. Previous investigations [12] have reported a prolonged latency to pressure onset in both the upper and lower pharynx during execution of the effortful swallow (compared with a noneffortful saliva swallow) relative to the onset of submental sEMG activity. In this study a different temporal reference point (i.e., the peak rather than onset of submental sEMG contraction) was used, revealing a new finding, namely, that pressure onsets are advanced during the effortful swallow (Fig. 1). Thus, one must surmise that the interval between submental sEMG onset and peak contraction (sEMG rise time) is prolonged during effortful swallowing. Furthermore, when the latencies from peak submental sEMG contraction to pharyngeal pressure peaks are considered, the current data again demonstrate shorter (rather than prolonged) latencies during performance of an effortful swallowing maneuver (Fig. 1). These data are consistent with the hypothesis that effortful swallowing generates forces that drive a bolus through the

Table 1. Descriptive statistics for temporal characteristics of pharyngeal pressure events during effortful saliva swallows performed with and without tongue-to-palate contact emphasis

Variable	Strategy	Mean	SE
Proximal Pharynx Pressure Onset Lag from sEMG Peak (ms)	No Tongue Emphasis	−342.07	41.39
	Tongue Emphasis	−216.95	86.71
Proximal Pharynx Pressure Onset Lag from sEMG Peak (ms)	No Tongue Emphasis	−350.49	81.30
	Tongue Emphasis	−212.54	83.06
Proximal Pharynx Pressure Onset Lag from sEMG Peak (ms)	No Tongue Emphasis	−17.47	50.53
	Tongue Emphasis[a]	200.87	64.77
Proximal Pharynx Pressure Onset Lag from sEMG Peak (ms)	No Tongue Emphasis	267.02	53.46
	Tongue Emphasis	460.38	70.36
Proximal Pharynx Pressure Rise Time (% of Total Duration)	No Tongue Emphasis	0.37	0.02
	Tongue Emphasis	0.40	0.02
Distal Pharynx Pressure Rise Time (% of Total Duration)	No Tongue Emphasis	0.51	0.02
	Tongue Emphasis	0.52	0.03
Proximal Pharynx Pressure Duration (ms)	No Tongue Emphasis	929.99	62.70
	Tongue Emphasis	1043.30	94.13
Distal Pharynx Pressure Duration (ms)	No Tongue Emphasis	1221.37	136.63
	Tongue Emphasis	1275.90	120.22

[a]Statistically significant ($p < 0.0125$).

pharynx with greater speed. Interestingly, as shown in Figure 2, the current data also concur with previous literature in demonstrating the lengthening of the overall duration of pressure events in the oral cavity (tongue-to-palate pressures) and in the pharynx during effortful swallowing. The combination of these findings supports the interpretation that the effortful swallow maneuver involves the generation of higher-velocity bolus driving forces that propel the bolus into and through the pharynx with greater efficiency and that pressure is then sustained to facilitate more complete bolus clearance. It should, of course, be noted that the present finding arises from research conducted with young, healthy research participants. Whether older individuals or those with dysphagia would be able to generate equivalent enhancements to swallowing efficiency with the effortful swallow remains a question for future study.

Huckabee and Steele [13] have recently shown that volitional emphasis of tongue-to-palate contact is beneficial for enhancing elevated amplitudes of pharyngeal pressure during the effortful swallow. The current data do not provide any evidence to suggest that tongue-to-palate emphasis significantly influences the temporal characteristics of pharyngeal pressure generation in effortful swallowing. As with the findings regarding effortful swallows in general, it must be remembered that the present data reflect effortful swallow performance in young, healthy individuals and cannot be generalized to seniors with age-related changes in tongue strength, nor to individuals with oropharyngeal dysphagia. Nonetheless, these data provide strong preliminary evidence to suggest that enhanced temporal efficiency of the pharyngeal swallow can be achieved using an effortful swallow maneuver, performed either with or without emphasis on tongue-to-palate contact.

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