Effects of Age, Gender, Bolus Volume, and Trial on Swallowing Apnea Duration and Swallow/Respiratory Phase Relationships of Normal Adults

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Abstract. The effects of age, gender, bolus volume, and trial on swallowing apnea duration (SAD) and swallow/respiratory phase relationships were examined. Sixty adults, composed of ten males and ten females in each of three age groups (i.e., 20–39, 40–59, and 60–83 years), participated. SAD was assessed via nasal airflow during saliva swallows and 10-, 15-, 20-, 25-mL bolus volumes across three trials. Results revealed SAD is consistent across trial ($p > 0.05$). Significant main effects of age, gender, and bolus volume were found ($p < 0.05$), i.e., elderly adults had longer SAD than young and middle-aged adults; women had longer SAD than men; and SAD increased as bolus volume increased. With respect to saliva swallows, a significant interaction of age by gender was found ($p < 0.05$), i.e., males exhibited a decrease in SAD with increasing age while females exhibited an increase in SAD with increasing age. Concerning swallow/respiratory phase relationships, the pattern of exhale–swallow–exhale was evident during 62% of participants' swallows. Furthermore, age, gender, or bolus volume did not predict the pattern of exhale–swallow–exhale ($p > 0.05$).

Key words: Normal swallowing — Respiration — Apnea — Deglutition — Duration — Deglutition disorders.

Airway closure occurs during deglutition, as the pharynx is a shared pathway for breathing and transit of food from the oral cavity into the esophagus. Airway closure occurs secondary to true vocal fold closure, ventricular vocal fold medial movement, arytenoid to base of epiglottis approximation, epiglottic inversion, and aryepiglottic fold stiffening [1]. Subsequently, complete airway closure, which occurs in normal swallowing, requires a cessation in respiration, i.e., swallowing apnea (SA).

Clearly, SA may occur secondary to airway closure providing a mechanical obstructive-type apnea. One may suggest that SA is a central phenomenon. For example, Martin et al. [2] reported that participants continued to maintain respiration even after initial oral transit of a liquid bolus, supporting a fine coordination between the neuromuscular integration of oral swallowing dynamics and respiration. Moreover, an apneic reflex is believed to exist in humans as demonstrated by stimulating the pharyngeal region in sheep with water inducing apnea with a subsequent swallow [3]. However, this apneic reflex demonstrated in sheep can only be generalized to humans with caution as the apneic reflex was found in a nonhuman species and varying reflex mechanisms may exist. To further support a central cause, SA has been found in unconscious intubated patients who are unable to achieve airway closure and initiate an obstructive-type apnea because of the presence of the endotracheal tube between the vocal folds [4]. In his neurophysiological investigations of swallowing, Miller [5,6] concluded that neutral control is involved in the central inhibition of respiration during swallowing.

Even with an appreciation for the highly coordinated swallow and respiration phenomenon, apneic reflexes, and obstructive forces, SA and its

sources are not entirely understood. At any rate, researchers and clinicians have proposed that swallowing apnea duration (SAD) may be one physiologic swallowing parameter that can be utilized to determine if an individual with dysphagia is maintaining adequate airway protection during swallowing. Thus, a goal of SA research is to establish data so that normal SA can be compared with abnormal swallowing physiology and potential aspiration. In addition, SAD may potentially be identified as an invariant that if decreased or increased in duration is correlated with aspiration. Researchers have investigated SA as a function of duration, timing with other swallowing events, bolus volumes, bolus types, age, gender, and the respiratory phase SA interrupts.

Systematic changes in various parameters of normal swallowing (e.g., oral pressure, oral transit time, pharyngeal response time, etc.) with increasing bolus volumes have been repeatedly documented [2,7–17]. Unfortunately, the effect of bolus size on SAD is inexplicit. Martin et al. [2] reported SAD was not a function of bolus volume (i.e., 3, 10, or 20 mL) among 13 healthy adults. In 1992, Preiksaitis et al. [13] similarly failed to find a definitive relationship between bolus volume and SAD in a small sample of 12 participants. Preiksaitis et al. reported that a bolus volume effect was present for some but not all participants. Issa and Porostocky [18] reported a bolus volume effect on SAD but this was obtained via oral infusion of water into participants' oral cavities. They reported an increase in SAD with increasing bolus volume. However, in 1996, Preiksaitis and Mills [14] reported again on the effect of bolus volume and concluded that bolus volume had no significant effect on SAD. Thus, further studies investigating SAD as a function of bolus volume are warranted considering the equivocal findings of the limited available data with small sample sizes.

In addition to small sample sizes that limit the interpretation of existing SAD data, so too does the restrictive range of bolus volumes. That is, the majority of studies have used 1-, 5-, and 10-mL boluses. Only a few studies have used a bolus size as large as 20 mL [2,13,14], and even that bolus size does not reflect a normal bolus volume swallow for most adults. Consider, for example, the Nilsson et al. [19] report of a mean bolus volume of 25.6 mL during single swallows for 292 healthy adults. When gender was taken into account, they reported a mean bolus volume of 28.1 ± 9.1 mL and 21.6 ± 5.5 mL for males and females, respectively. Thus, a study that uses a wide range of bolus sizes is needed. Small bolus sizes are needed to simulate conservatism when initially testing dysphagic swallows which minimize aspiration risk, and normal bolus sizes are needed to simulate a realistic eating environment. This bolus volume range can easily be tested in normals and would provide data at many bolus volumes for later comparison to data acquired from disordered swallows.

Studies of age effects on SAD and swallow/respiratory coordination have been limited, yet studies done support changing SAD and swallow/respiratory coordination with aging. Elderly adults initiated swallowing more frequently in the inspiratory phase compared with young adults [7]. Furthermore, SAD was reported to be significantly longer in 18 elderly adults compared with 21 young adults (cf. 1.0 s vs. 0.6 s, $p < 0.05$) [20]. Both studies support an age effect on SA but both studies utilized small bolus volumes (i.e., 5 mL and saliva swallows) and small samples which consequently limited data generalization. A comprehensive study investigating the effect of age on various swallowing parameters of 167 normal females was undertaken by Rademaker et al. [8]. There was a significant age effect on pharyngeal transit time, with older groups demonstrating longer times than younger groups. No SAD measures were reported, yet longer pharyngeal transit times might correlate with long SAD as a result of the pharyngeal shared pathway. However, such a correlation has not been systematically investigated.

Swallow/respiratory coordination with regard to respiratory phases before and after the swallow has been investigated, and again the findings are equivocal. Martin et al. [2] reported apneic onset occurred during expiration 94%–100% of the time and was succeeded by expiration 100% of the time with the use of 3-, 10-, and 20-mL bolus volumes. Klahn and Perlman [21] reported similar percentages where apneic onset occurred during expiration 93% of the time and was succeeded by expiration 100% of the time across 5-mL water and applesauce boluses. In contrast, however, Preiksaitis et al. [13] reported that a marked smaller percentage of 71.4% of swallows exhibited an exhale–swallow–exhale pattern. Moreover, Preiksaitis and Mills [14] reported that the pattern of exhale–swallow–exhale was present in 77% of 100 swallows, yet this pattern decreased during 200-mL straw drinking and during a sandwich meal. Thus, the current literature offers a relatively large percentage range (i.e., 71%–100%) associated with SA respiratory phase relationships. This disparity may be secondary to different methods of bolus delivery used in the different studies. Both Martin et al. [2] and Klahn and Perlman [21] delivered boluses to participants via syringe and spoon, respectively, whereas Preiksaitis et al. [13] allowed the participants to self-administer boluses simulating a more realistic eating environment. Thus,

because of the ambiguity that exists regarding respiratory phase SA percentages, replication and more encompassing studies are warranted to offer clarification. However, in replication, SA respiratory phase relationships obtained from delivery method that allows participants to self-administer the bolus would be preferable in order to increase generalization of findings as representative of what occurs in an individual's natural eating environment.

Klahn and Perlman [21] acknowledged the disparity in the reported data relating to SA and called for a larger body of normative data from a larger number of participants to confirm their findings. Additional normative data is paramount for a better understanding of SAD and to serve as a comparison to disordered swallows. Furthermore, SAD data across various types of patients with specific swallowing disorders is also needed to determine if differences exist across types of dysphagia as well. The purpose of this study was to determine the effects of age, gender, bolus volume, and trial on SAD measurements, a study that to the best of our knowledge has yet to be undertaken. A second purpose of this study was to examine swallow/respiration coordination by determining if the pattern of exhale–swallow–exhale was predicted as a function of age, gender, or bolus volume.

Method

Participants

Sixty adults served as participants. There were 20 individuals in each of three age groups: 20–39 years ($M = 27.9$ years, $SD = 3.1$), 49–59 years ($M = 52.6$ years, $SD = 3.8$), and 60–83 years ($M = 67.0$ years, $SD = 6.6$). Ten males and 10 females were in each group. Participants were volunteers and reported no history of pulmonary disease, neurological disease, structural disorders, language disorders, speech disorders, voice problems, and/or swallowing problems. All participants were Caucasians, ambulatory, and in good health.

Apparatus

A Swallowing Signals Lab (Kay Elemetrics, Lincoln Park, NJ) was used to obtain concurrent surface electromyography (SEMG) and respiratory signals. Single-channel SEMG was acquired with 5.4-cm silver chloride electrode triode patches (Uni-Patch, Wabasha, MN). Digital 12-bit samples were obtained with a sampling frequency of 500 Hz via a Bi-Link portable computer (Pentium Model MMX 166). The respiratory information was obtained via nasal cannula (Hospitak, Farmingdale, NY), identical to that used to deliver supplemental oxygen. The proximal end of the nasal cannula was placed at the entrance of each nare. The distal end of the nasal cannula was coupled to an analog-to-digital airflow sensor thermistor transducer (Honeywell Microswitch Model

AWM2200V) and interfaced with the same computer used for SEMG acquisition. In addition, digital 12-bit samples were obtained with a sampling frequency of 250 Hz. The system software generated concurrent airflow and SEMG waveforms as a function of time.

Procedure

Submental SEMG and respiratory tracings via nasal cannula were recorded concurrently for each participant. SEMG was obtained via electrodes placed over the mylohyoid–geniohyoid muscle complex in order to provide a marker of the swallow. Previous studies have utilized SEMG to mark the event of the swallow to assure the apneic event observed was in fact associated with the swallow [2,7,21].

Five conditions were studied: 10-, 15-, 20-, and 25-mL bolus volumes and a saliva swallow. Three repetitions of each condition were offered to the participants in random order. Thus, participants contributed 15 swallows each, which afforded a total of 900 swallows for analyses. Participants were seated upright, instructed to breathe through their nose, and allowed five minutes to get familiar with the setting and the equipment before the trials began. The measured boluses were placed in cups (saliva swallows were not), and the participants were instructed to swallow the entire bolus when ready.

SAD and swallow/respiratory phase relationships were extracted from the airflow waveforms offline. A positive polarity indicated expiration and a negative polarity indicated inspiration. The apneic pause was defined as a flat line on the display with no positive or negative polarity occurring in conjunction with swallowing SEMG activity. A consistent SEMG pattern was observed with the swallowing activity and served as a marker that the respiratory flat line on channel 2 was in fact an apneic pause associated with swallowing. SAD was measured in seconds. In addition, the phase of respiration that was interrupted by the swallow was judged. A positive or negative polarity preceding the apneic pause was recorded as swallowing interrupting expiration or inspiration, respectively. Similarly, a positive or negative polarity succeeding the apneic pause was deemed expiration or inspiration, respectively, after the swallow.

Data Analysis

It was of interest at first to determine the effect of trial on SAD. Accordingly, a general linear model, repeated-measures variance of analysis (ANOVA) was undertaken to investigate SAD as a function of trial. An α level of 0.05 was adopted, and relative treatment effect sizes (i.e., proportion of variance accounted for) and statistical power are indexed by ω^2 [22,23] and ϕ [24], respectively, in this and subsequent analyses. A three-factor mixed ANOVA was performed to investigate SAD as a function of age, gender, and bolus volume. Tukey pairwise comparisons [22,23] were done if the main effect of age was significant. Single-df comparisons were done if the main effect of bolus volume was significant.

Results

There was no significant effect of trial on SAD [$F(2,299) = 0.59$, $p = 0.55$, $\omega^2 = 0.002$, $\phi = 0.15$ at

$\alpha = 0.05$]. In other words, SAD was stable across three measures in the relatively short sampling session. These findings justified collapsing SAD data across trials for the remaining analyses. Mean SADs as a function of age, gender, and bolus volume collapsed across trial are presented in Table 1.

Table 1. Mean swallowing apnea duration(s) as a function of age, gender, and bolus volume[a]

| Group | Bonus Volume | | | | |
	10 mL	15 mL	20 mL	25 mL	Saliva
Young					
females	0.77	0.83	0.83	1.11	0.86
	(0.18)	(0.19)	(0.19)	(0.42)	(0.27)
males	0.74	0.79	0.80	0.88	1.05
	(0.14)	(0.16)	(0.17)	(0.19)	(0.51)
Middle age					
females	0.90	0.90	1.01	1.11	1.11
	(0.26)	(0.18)	(0.25)	(0.40)	(0.44)
males	0.79	0.80	0.90	0.98	1.05
	(0.13)	(0.16)	(0.28)	(0.32)	(0.43)
Elderly					
females	1.05	1.13	1.14	1.32	1.41
	(0.26)	(0.32)	(0.28)	(0.55)	(0.57)
males	0.96	1.00	1.00	1.12	0.91
	(0.25)	(0.24)	(0.22)	(0.28)	(0.27)

[a]Standard errors of the means are presented in parentheses.

Table 2. Summary table for the three-factor mixed analysis of variance investigating swallowing apnea duration as a function of age, gender, and bolus volume

Source	df	F	p[a]	ω^2	ϕ
Age	2	23.40	<0.0001[*]	0.21	1.00
Gender	1	13.82	<0.0001[*]	0.07	0.96
Age × Gender	2	0.31	0.73	0.00	0.10
Bolus	3	38.99	<0.0001[*]	0.18	1.00
Bolus × Age	6	0.88	0.49	0.01	0.29
Bolus × Gender	3	2.62	0.07	0.02	0.55
Bolus × Age × Gender	6	0.74	0.58	0.01	0.25

[a]p values following Geisser–Greenhouse correction; [*]considered significant at $\alpha = 0.05$.

Table 3. Tukey pairwise comparison of swallowing apnea duration as a function of age

Mean	Age	Young	Middle aged	Elderly[a]
0.84	Young			*
0.92	Middle aged			*
1.10	Elderly			

[a]* denotes pairs of means significantly different at $p < 0.05$ (two-tailed).

The results of the three-factor mixed ANOVA investigating SAD as a function of age, gender, and bolus volume are presented in Table 2. Significant main effects for age, gender, and bolus volume were found ($p < 0.05$). All interactions were nonsignificant ($p > 0.05$). In general, older participants had longer SADs, females had longer SADs, and SADs increased with increasing bolus size. Numerous *post hoc* analyses were undertaken to examine the significant main effects as noted above. Tukey pairwise comparisons were used to assess the main effect of age. The results of those pairwise comparisons are given in Table 3. The SADs of young and middle-aged adults, though not significantly different from each other, were significantly shorter than SAD of elderly adults. Single-*df* comparisons were undertaken to assess the main effect of bolus volume. It was found that the mean SAD for 10 mL ($M = 0.87$ s) and 15 mL ($M = 0.91$ s) was significantly shorter than the mean SAD for 20 mL ($M = 0.95$ s) [$F(1,162) = 6.52$, Geisser–Greenhouse $p = 0.03$]. Also 10-, 15-, and 20-mL bolus volumes were significantly shorter than the mean SAD for 25 mL ($M = 1.09$ s) [$F = (1,162) = 64.92$, Geisser–Greenhouse $p = 0.0$]. However, the mean SAD for 10 mL was not significantly shorter than the mean SAD for 15 mL [$F(1,162) = 2.12$, Geisser–Greenhouse $p = 0.15$].

A two-factor ANOVA was performed to investigate saliva SAD as a function of age and gender. Saliva swallows were analyzed separately since they did not qualify as a controlled bolus volume condition. No significant effects of group [$F(2,54) = 1.75$, $p = 0.18$] or gender [$F(1,54) = 1.76$, $p = 0.19$] were observed for the saliva SAD condition. However, a significant group by gender interaction was present [$F(2, 54) = 5.05$, $p = 0.01$]. This interaction, displayed in Figure. 1, is explained by the fact that males exhibited a decrease in SAD with increasing age while females exhibited an increase in SAD with increasing age.

With regard to swallow/respiratory phase relationships, the pattern of exhale–swallow–exhale was evident during 62% of participants' swallows. Of the 900 swallows acquired, 75% were preceded by expiration and 86% were succeeded by expiration. A logistic regression analysis was undertaken to ascertain if any independent variables were significant predictors of the exhale–swallow–exhale pattern. The analysis was performed using SPSS Logistic Regression (Chicago, Illinois) (SPSS Release 8.0). Predictor variables of age, gender, and bolus volume were fit in the logistic regression model. The analysis revealed that age [*Wald statistic* (1) = 2.20, $p = 0.14$], gender [*Wald statistic* (1) = 0.13, $p = 0.72$], and bolus
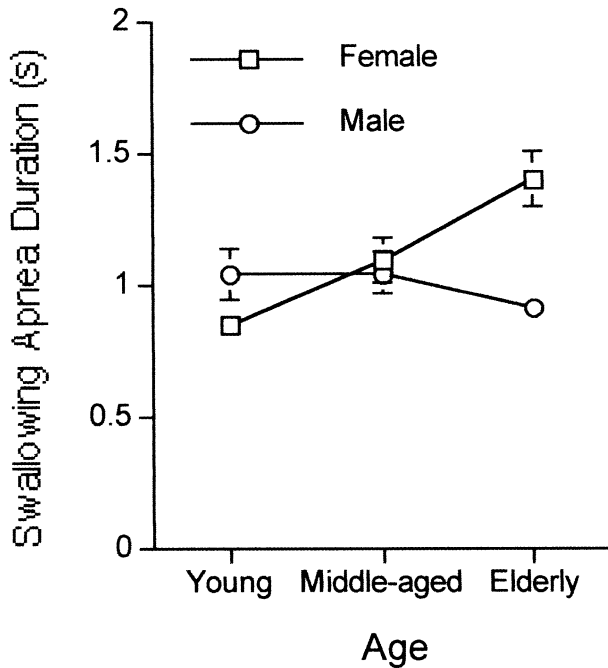
Fig. 1. Saliva swallowing apnea duration as a function of age and gender. Error bars represent plus/minus one standard error.

volume [*Wald statistic* $(1) = 0.81$, $p = 0.37$] were not statistically significant predictors of an exhale–swallow–exhale pattern (versus any other possible pattern). In other words, the likelihood of an exhale–swallow–exhale pattern was not dependent on age group, gender, or bolus volume.

Intrajudge Reliability

Ten percent of the data were reanalyzed in an effort to provide an index of intrajudge agreement. The SAD mean difference between first and second analyses was 0.01 s.

Discussion

This study revealed significant effects of age, gender, and bolus volumes on SAD. Specifically, SAD increased with age, females exhibited longer SADs than males, and SAD increased with increasing bolus volume. No significant differences existed for SAD as a function of trial, i.e., SAD measurements remained relatively consistent within each bolus volume condition in a relatively short sampling session. In the saliva swallow condition, an interaction was present in that males exhibited a decrease in SAD with increasing age while females exhibited an increase in

SAD with increasing age. The pattern of exhale–swallow–exhale was evidenced in 62% of participants' swallows. Expiration preceded and succeeded SA 75% and 86%, respectively. Furthermore, age, gender, and bolus volume were not significant predictors of the exhale–swallow–exhale pattern. This study provides normative data from a larger number of participants from whom SAD was acquired via nasal cannula and a thermistor airflow transducer with concurrent surface electromyography, a respiratory recording technique that can be easily implemented clinically and in further research.

The finding that SAD increased with age is in agreement with well-documented age effects on other parameters of swallowing function. Sonies et al. [25] reported slower elderly adult swallows compared with young adult swallows. In addition, older individuals demonstrated increased oropharyngeal pressure duration [15] and increased hypopharyngeal pressure in amplitude and duration compared with young adults [26]. The age effect of change in respiratory phase and swallow coordination [7], however, was not supported in this study. The exhale–swallow–exhale pattern did not change as a function of age. However, an increase in elderly adult SAD as compared with SAD of young adults [20] is consistent with the findings of this study. Subsequently, an increase in SAD as a function of increased age further supports previous age-related findings of anatomic and physiologic changes in aged swallowing.

Gender effects on normal swallowing physiology has not been investigated as thoroughly as that of age effects. However, the finding of increased SAD in females compared with males is consistent with a longer upper esophageal sphincter opening in females than males [26]. Correlation of SAD with upper esophageal sphincter opening duration across genders has not been investigated, yet a closed laryngeal vestibule would seem necessary if active bolus transport were occurring from pharynx into the esophagus. "Given the smaller potential area of upper esophageal sphincter opening in the oropharynx in women than in men, women might require a more prolonged duration of upper esophageal sphincter opening to accommodate passage of equivalent bolus size" [26, p. 828] and subsequently induce a longer SAD.

Previous reports have provided an overall SAD mean without an appreciation for various ages, gender, or bolus volumes. This study's SAD measurements were roughly similar to the mean SAD of approximately 1 reported by Martin et al. [2], Klahn and Perlman [21], and Preiksaitis and Mills [14]. However, reporting an overall mean SAD may not be

appropriate given age, gender, and bolus volume effects found in this study (see Table 1). The findings of this study demonstrated that normal elderly female mean SAD on a 25-mL bolus was 1.32 s whereas normal young female mean SAD on a 10-mL bolus was 0.77 s. Thus, if a researcher or a clinician obtains a SAD value from a participant/patient without respect to age or bolus volume, an incorrect assumption may be made as to the increased or decreased nature of its duration. The lack of a significant bolus volume effect on SAD reported by Martin et al. [2] and Preiksaitis et al. [13] may be a consequence of employing a small sample size and limited bolus volumes. Also, power analysis and effect sizes were not reported in their studies. Rademaker et al. [8] reported increased laryngeal closure duration as a significant function of increasing bolus volume as visualized fluoroscopically, lending support to the fact that pharyngeal dynamics change with increasing volume loads on the system. Moreover, laryngeal closure has been shown to begin significantly earlier on 5-mL bolus volumes compared with 1-mL bolus volumes [17], thus, analogously modifying SAD. Of interest in this study are the significant differences in SAD between the 10-, 15-, and 20-mL bolus volume conditions and between the 10-, 15-, 20-, and 25-mL bolus volume conditions with no significant difference between the 10- and 15-mL bolus volume condition SADs. Even though the difference in SAD between 10- and 15-mL bolus volumes did not have statistical significance, there was a clear trend in the SAD increase across the 10- and 15-mL bolus volumes as seen in Table 1. The difference may not have been as large given the smaller bolus volumes and decreased sensory loading on the system. However, given the findings of this study, SAD measurements should be interpreted with a distinct regard for bolus volume.

Of concern in the interpretation of SAD data is the use of respiratory data acquisition. Researchers have used a variety of respiratory acquisition hardware including respiratory inductive plethysmography [2,7,27–29], nose/facemasks [18], nasal cannulas [13,14,20,21], and nasal thermistors [2]. In addition, the normative data established should be clinically useful. The method of SAD data collection should be accurate, easy and expeditious to acquire, and minimize the physiologic load imposed by the apparatus on the subject.

Respiratory inductive plethysmography allows assessment of respiratory phase and duration, but the plethysmography belt is cumbersome and it is time consuming to position it correctly, especially if the patient is bedridden. The advantage of respiratory plethysmography is that the patient can breathe through the mouth or nose without any loss of information and the belt typically worn does not interfere with bolus placement. However, to acquire artifact-free tracings, the bolus is usually placed in the participant's mouth by the examiner (usually via syringe) so that no limb movement artifact is present in the tracings. This is problematic since it removes a natural element of normal swallowing and respiration coordination from the test.

Facemasks, which cover the mouth and nose, have also been used in respiratory data acquisition allowing for respiratory phase and duration measurements. A facemask, however, is not feasible for our test given the necessity of placing boluses in an individual's mouth and subsequently losing respiratory information.

A third option is the nasal cannula which acquires nasal airflow and is easy and comfortable to wear and does not interfere with bolus placement in the mouth. Nasal cannulas are present in most medical settings since they are used to deliver supplemental oxygen and are disposable, thus eliminating cross-patient contamination. One disadvantage of the nasal cannula is that it depends on the individual to breathe through the nose so no respiratory information is lost.

Nasal thermistors, a fourth option for respiratory data acquisition, typically measure the amount of resistance subsequent to an increase or decrease in temperature corresponding to warm exhaled air and cool inspired air, respectively. The nasal thermistor has similar advantages and disadvantages to those of the nasal cannula since it is typically placed at the nares entrance. The temperature-mode thermistor-transduced tracing, however, may demonstrate an increase in temperature during a period of no nasal airflow secondary to warming to body temperature [30].

In addition to the various forms of equipment that can be used to acquire respiratory information, sensitivity to flow, response time, and sampling are all crucial in obtaining an accurate reflection of the durational respiratory events. Given the advantages and disadvantages of the various techniques for recording respiratory events, the nasal cannula has been recommended and was used to record nasal airflow and SAD in this study [30].

The effects of age and gender on SAD were not the same in the saliva swallow versus the bolus volume conditions. Recall that in the bolus volume condition, SAD increased with increasing age and with increasing bolus volume and females exhibited longer SADs than males. In contrast, during saliva swallows males exhibited a decrease in SAD with increasing age while females exhibited an increase in SAD with increasing

age. The difference in SAD findings between the bolus volume and the saliva swallow conditions indicates that the saliva SA may be physiologically different from a bolus volume SA and/or more susceptible to measurement acquisition biases. A typical saliva swallow is approximately 1 mL. According to our bolus volume condition data, one may expect the saliva swallow to exhibit the shortest SAD of the five conditions. Surprisingly, four of the subgroups demonstrated saliva SADs longer than the 20-mL bolus volume condition. Preiksaitis et al. [13] reported a similar phenomenon regarding the saliva swallow. In fact, they divided the participants into two groups retrospectively for analyses, those that exhibited the longest SAD and those that exhibited the shortest SAD on the saliva swallow of the 5-, 10-, and 20-mL bolus volume conditions ($n = 7$ and $n = 5$, respectively). They also did not find a significant difference between age and gender; however, they also included bolus volume conditions in their data analysis. Conversely, to support a long saliva SAD, SA during pharyngeal pressure activation seems logical secondary to the closed pharynx acting as an obstructive force to airflow. Saliva swallows have been shown to elicit longer pharyngeal pressure durations compared with that elicited by 5- and 10-mL bolus volumes [15]. Given the findings of Klahn and Perlman [21], Preiksaitis et al. [13], and this study, evidence is building that perhaps one may expect longer SAD on the saliva swallow. The fact that Preiksaitis et al. found that some participants exhibited shorter saliva SAD and this study found that elderly males and young females exhibit shorter saliva SAD suggests that the saliva SAD measurement may be more susceptible to sampling or recording biases, since conclusions drawn from similarities between young females and elderly males is difficult at best. The fact that one cannot control saliva volume may preclude acquiring reliable saliva SADs.

The respiratory phase most frequently interrupted by swallowing was also previously uncertain given the large range of percentages reported for expiration before and after the swallow. This study found that expiration preceded SA 75% of the time and was succeeded by expiration 86% of the time. This is lower than that previously reported where 95%–100% of swallows were preceded and succeeded by expiration [2,21]. A plausible explanation for the difference is in the bolus delivery. This study simulated a more natural eating environment by allowing the participants to self-administer and drink from a cup at their own pace. Most previous studies created an artificial eating environment with the examiner administering the bolus into the participant's mouth via syringe or spoon. Preiksaitis and Mills [14] reported that the pattern of exhale–swallow–exhale decreased significantly with a 200-mL drink and during a sandwich meal which incorporated self-feeding. The previously reported high percentages of exhale–swallow–exhale are probably secondary to manipulated bolus administration and limited sample sizes used. Thus, a lower expectation of the exhale–swallow–exhale pattern frequency may be more realistic.

In summary, the results of this study document SAD as a function of age, gender, and bolus volume and extend previous research which incorporated much smaller sample sizes and limited bolus volumes. In addition, this study provides comprehensive normative SAD and SA respiratory phase data that may now be used for comparison with disordered swallows. SAD values of disordered swallows that have been specifically correlated with aspiration events may offer insight into airway protection. If SAD were deemed to be a consistent predictor of disordered swallowing, then SAD would offer a further parameter of swallowing that could be assessed as part of the clinical swallowing evaluation. This objective information obtained at bedside would facilitate decisions to pursue endoscopic or videofluoroscopic swallowing studies.

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