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Effects of Age, Gender, Bolus Volume, Bolus Viscosity, and Gustation on Swallowing Apnea
Onset Relative to Lingual Bolus Propulsion Onset in Normal Adults

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Abstract

The purpose of this study was to ascertain the normal relation of swallowing apnea (SA) onset relative to lingual bolus propulsion along with factors that may alter this relation. Forty adults, composed of ten males and ten females in each of two age groups (i.e., 20-30 and 63-79 years) participated. SA onset was assessed during 5- and 20-ml bolus volumes of water and apple juice across three trials. The effects of age, gender, bolus volume, bolus viscosity, and gustation on SA onset relative to lingual bolus propulsion were examined. A significant interaction of age by gender by volume was found. In general, older adults initiated SA onset earlier than young adults and large boluses elicited an earlier SA onset than small boluses regardless of group. Young males demonstrated significantly later SA onset than the older males for large volumes, this difference was not observed for small volumes nor was it found between young and older females. SA onset also was assessed during 5-ml bolus volumes of thin apple juice, thick apple juice, and applesauce across three trials. A significant main effect of viscosity was found revealing that SA onset was initiated later as bolus viscosity increased. Thus, the results of this investigation provided data on the relation of SA onset relative to lingual bolus propulsion in individuals with normal swallowing and how this relation changes as a function of age, gender, bolus volume, bolus viscosity, and gustation.

Key Words: swallowing, dysphagia, swallowing apnea, age, gender, bolus volume, bolus viscosity, gustation

Effects of Age, Gender, Bolus Volume, Bolus Viscosity, and Gustation on Swallowing Apnea Onset Relative to Lingual Bolus Propulsion Onset in Normal Adults

Swallowing apnea (SA) is cessation of respiration that occurs with swallowing. The timing of SA onset relative to lingual bolus propulsion may be an important physiologic event in swallowing. If SA onset is delayed relative to lingual bolus propulsion, the bolus may proceed into the pharynx during inspiration/expiration and subsequent aspiration may occur. Respiration and swallowing coordination may be compromised in individuals with neurological deficits and/or pulmonary problems. Specifically, individuals with pulmonary disease (e.g., chronic obstructive pulmonary disease), who often present with labored breathing and increased respiratory rates, have been identified to be at risk for aspiration with swallowing in light of no identifiable neurological changes (Coelho, 1987). Thus, it is highly plausible that discoordination of respiration and swallowing predisposes the individual with respiratory disease to aspirate. Given that respiration and swallowing must be coordinated, one potential marker of disordered swallowing may be delay of SA onset relative to lingual bolus propulsion. Note that SA only refers to cessation of breathing and may or may not be associated with laryngeal closure.

Delayed SA onset and/or early SA offset in relation to bolus propulsion through the oropharynx could predispose a patient to a misdirected swallow (i.e., laryngeal penetration and/or aspiration). Identification of this normal temporal relation may be utilized for future research comparison to those with dysphagia in order to ascertain one of the potential sources of physiologic breakdown causing disordered swallowing. If SA onset is found to be delayed relative to lingual bolus propulsion, visual respiratory biofeedback could be incorporated into dysphagia therapy, thus retraining the timing of SA onset with subsequent safer swallowing. Therefore, the identification of normal SA onset in regards to bolus propulsion is warranted.

Lingual bolus propulsion is one of the first events that occurs in swallowing and results in emptying of the bolus from the oral cavity into the hypopharyngeal cavity. Cook et al. (1989) reported that “a leading complex of tongue tip and tongue base movement as well as onset of superior hyoid movement and mylohyoid myoelectric activity occurred in a tight temporal relation at the inception of swallowing” (p. 8). Thus, utilizing tongue tip movement data, one may measure the beginning of lingual bolus propulsion as initiating the swallowing sequence. Since lingual bolus propulsion and SA onset presumably occur in close temporal proximity to each other, this relation is a parameter of swallowing physiology that may elucidate a possible area for breakdown in the dysphagic swallow.

The temporal relation between lingual bolus propulsion and SA onset also requires investigation relative to factors that can alter this relation. Factors that may potentially change this relation include age, gender, bolus volume, bolus viscosity, and bolus taste.

SA duration has been demonstrated to increase with increases in bolus volume (Hiss, Treole, & Stuart, 2001). Thus, in order for SA duration to increase, it must begin earlier and/or terminate later. Although changing bolus volume does not alter all temporal and/or durational parameters of swallowing, effects of bolus volume on certain oral and pharyngeal parameters of swallowing have been documented (Cook et al., 1989; Dantas et al., 1990; Kahrilas and Logemann, 1993; Bisch, Logemann, Rademaker, Kahrilas, & Lazarus, 1994; Logemann, Pauloski, Colangelo, Lazarus, Fujii, & Kahrilas, 1995; Rademaker, Pauloski, Colangelo, & Logemann, 1998). Specifically, the Cook et al. (1989) and Dantas et al. (1990) studies indicated that pharyngeal and laryngeal functions began earlier so as to prepare the deglutitive chamber for a larger and subsequently higher velocity bolus. It is plausible, therefore, to expect that SA onset may occur earlier in relation to lingual bolus propulsion with increases in bolus volume.

Deglutition and lingual functioning have been identified to change as a function of aging (Logemann, Pauloski, Rademaker, & Kahrilas, 2002; Dejaeger, Pelemans, Ponette, & Joosten, 1997; Cook et al., 1994; Tracy, Logemann, Kahrilas, Jacob, Kobara, & Krugler, 1989). Specifically, lingual strength decreases with age (Crow & Ship 1996; Robbins, Levine, Wood, Roecker, & Luschei, 1995). Decreased lingual strength reserve results in increased time to generate peak lingual pressures (Nicosia 2000). Pharyngeal swallowing is subject to a similar age effect with older individuals experiencing delayed pharyngeal swallowing onset, prolonged pharyngeal responses, and decreased lingual and hyolaryngeal excursions (Logemann et al., 2002; Logemann, Pauloski, Rademaker, Colangelo, Kahrilas, & Smith, 2000; Rademaker, Paulski, Colangelo, & Logemann, 1998; Cook et al.; Robbins, Hamilton, Lof, & Kempster, 1992; Tracy et al., 1989). While aging has been demonstrated to effect pharyngeal swallowing, many of the physiologic changes with aging are gender specific.

Gender differences in swallowing have been researched although not as extensively as other factors such as age and bolus volume. Women tend to have smaller oropharyngeal chambers than men and may, as a group, demonstrate different temporally related swallowing events when compared to their male counterparts. Beyond anatomic differences, literature is emerging that purports women may maintain neurological and muscular reserves with aging differently than men. Logemann et al. (2000, 2002) compared pharyngeal and laryngeal swallowing physiology in young and older men and women and reported that older men demonstrated significantly decreased range of motion compared to their younger counterparts. In contrast, older women demonstrated the same or greater range of motion compared to their younger counterparts. Specifically to SA, Hiss et al. (2001) reported that women demonstrated significantly longer SA duration than men on saliva swallows. In contrast, men demonstrated

decreased SA durations on saliva swallows with age. Thus, recent reports indicate that swallowing physiology should be investigated with regards to possible gender and aging interactions. SA onset relative to lingual bolus propulsion may change as a function of gender and aging.

Changes in bolus viscosity and/or consistency may require greater oropharyngeal pressures and velocity to move the bolus through the pharynx. Increased oropharyngeal parameter durations of swallowing such as stage-transition, pharyngeal transit, velar excursion, and upper esophageal opening have been reported (Miller & Watkins, 1996; Pouderoux and Kahrilas, 1995; Bisch et al., 1994; Robbins et al., 1992; Dantas et al., 1990). These studies indicated that as the bolus viscosity increased, oropharyngeal responses required more time and/or increased pressure to move the bolus from the oral cavity into the esophagus. Thus, SA onset requires investigation relative to changes in viscosity.

Studies establishing swallowing physiology changes as a function of gustation are limited. However, swallowing initiation has been reported to change as a function of sour boluses in individual with neurologic impairment (Logemann, Pauloski, Colangelo, Lazarus, Fujii, & Kahrilas, 1995). In Logemann et al.'s study, the sour bolus elicited a significantly reduced swallow onset time, oral transit time, pharyngeal delay time, pharyngeal transit time, and increased swallow efficiency. Although this study demonstrated swallowing physiology changed as a function of gustation in individuals with dysphagia, it is plausible that individuals with normal swallowing also experience similar change in swallowing physiology with a bolus that stimulates chemoreceptors as well as mechanoreceptors. Likewise the temporal relation between lingual bolus propulsion and SA onset may change as a function of gustation. However, sour boluses do not occur in everyday oral diets. Thus, boluses (i.e., apple juice and applesauce)

that are frequently consumed were utilized in this study to compare with a less sweet and acidic bolus (i.e., water). Water is more of a neutral bolus and would be less likely to stimulate chemoreceptors compared to apple juice. Thus, although not scientifically demonstrated, water is theorized to stimulate mostly mechanoreceptors as opposed to both mechanoreceptors and chemoreceptors with apple-flavored boluses. Increased recruitment of sensory receptors may alter motor responses such as SA onset.

Participants' "perception of taste" was not controlled for in this study. Temporal measures of swallowing have been demonstrated to change as a function of gustation (i.e., sour boluses) in the absence of any perceptual measures (i.e., they are operationally defined by the experimenter and not by participant's perception). Accordingly, using a bolus type that occurs in many oral diets was utilized in this study.

The temporal relation between lingual bolus propulsion and SA onset may be one of the parameters that should be assessed during swallowing evaluations. Lingual bolus propulsion results in emptying of the bolus out of the oral cavity and into the hypopharynx. Premature lingual bolus propulsion or delayed SA onset would create a longer time that the airway is predisposed to the bolus, thus increasing the risk of aspiration. This temporal relation between SA onset and lingual bolus propulsion as well as the variables that may affect this relation requires identification. Thus, the purpose of this investigation was to identify the temporal relation between lingual bolus propulsion onset and SA onset and to identify factors that affect this relation. Factors examined were the effects of aging, gender, bolus size, bolus viscosity, and bolus taste.

Method

Participants

Forty normal adults served as participants. Twenty individuals comprised each of two age groups: 20 - 30 years ($M = 26.1$ years, $SD = 3.0$), and 63 – 79 years ($M = 70.9$ years, $SD = 5.8$). Ten young males ($M = 25.1$ years, $SD = 3.1$), 10 young females ($M = 26.9$ years, $SD = 2.92$), 10 older males ($M = 69.5$ years, $SD = 6.2$), and 10 older females ($M = 72.3$ years, $SD = 5.4$) were represented in each group. Participants were volunteers and reported, via questionnaire, no history of pulmonary disease, neurological disease, structural disorders, language disorders, speech disorders, swallowing disorders, and/or voice problems. In addition, participants were dentate or utilized partials that did not cover any part of the hard or soft palate. Participants were not probed as to medications they were taking at the time of the study. All participants were ambulatory and in good health.

Apparatus

A Kay Elemetrics Swallowing Signals Lab (Kay Elemetrics, Lincoln Park, NJ) was utilized to obtain concurrent respiratory data and lingual data. The respiratory information was obtained via a nasal cannula (Hospitak Model 302-E) 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 a Bi-Link portable computer (Pentium Model MMX 166). Digital 12-bit samples were obtained with a sampling frequency of 250 Hz. Lingual bolus propulsion onset was measured using the anterior bulb of two small air-filled bulbs (Kay Elemetrics, Lincoln Park, NJ) mounted on a silica strip which was attached longitudinally with stoma adhesive strips (ConvaTec, Princeton, NJ) anteriorly to posteriorly along the midline of the hard palate of each participant. The anterior bulb was the primary bulb used for data collection in this study as tongue tip to alveolar ridge is

the typical first contact point to initiate a swallow. However, if a participant was observed to utilize the second bulb as their first contact point to initiate a swallow, the second bulb onset data was utilized to determine lingual bolus propulsion onset. The bulbs were 13 mm in diameter and spaced 8 mm apart. The anterior edge of the strip was placed immediately posterior to the alveolar ridge. The bulb data were interfaced with the same computer used to acquire the respiratory data. Digital 12-bit samples were obtained with a sampling frequency of 250 Hz and displayed in a 0 – 500 mmHg display window. The system software generated concurrent airflow and lingual bolus propulsion waveforms as a function of time.

Procedure

Respiratory tracings via nasal cannula and lingual bolus propulsion tracings were recorded concurrently for each participant for six bolus conditions: room-temperature water (5 and 20 ml; viscosity of 1 cp), room-temperature apple juice (5 and 20 ml), thickened apple juice (5 ml; Diamond Crystal Medical Food, Wilmington, MA; viscosity of 1100 – 1900 cp at 70 – 80 degrees), and applesauce (5 ml; Lucky Leaf, Peach Glen, PA). Three repetitions of each condition were offered to the participants. The order of presentation of conditions was counterbalanced. Participants contributed 18 swallows each for a study total of 720 swallows. Participants were seated upright, instructed to breathe through their nose, and allowed five minutes to familiarize themselves with the setting and equipment before trials began. The liquid measured boluses were placed in a cup and the puree measured boluses were placed on a spoon. The participants were instructed to swallow the amount placed in the cup or on the spoon when they were ready.

SA onsets in relation to lingual bolus propulsion relations were extracted from the airflow and lingual pressure waveforms off-line. During data collection, each swallow was tagged on-

line by the examiner before proceeding to the next trial. The onset of the apneic pause was defined as a flat line on the display with no positive or negative polarities that occurred in conjunction with a swallow. The onset of lingual bolus propulsion was defined as a positive polarity movement away from the zero baseline on the display that was associated with the tagged swallow. As seen in Figure 1, some participants demonstrated pre-swallow lingual movements. Pre-swallow lingual movements were excluded from analyses and defined as waveform pressures that returned to baseline before a maximum peak pressure associated with the tagged swallow. For all analyses, SA onset was measured in seconds relative to lingual bolus propulsion. That is, if SA onset started before lingual bolus propulsion onset, a negative value was given. If SA onset started after lingual bolus propulsion onset, a positive value was assigned. If SA onset and lingual bolus propulsion onset occurred at the same point in time, a 0.00 s value was assigned.

Five independent variables (i.e., gender, age, bolus volume, gustation, and viscosity) with respect to SA as a dependent variable needed to be investigated. Two of the variables were between factors (i.e., gender and age) while the remaining three were repeated/within. A five-factor mixed ANOVA was not appropriate, as bolus volume was not repeated with respect to viscosity (e.g., a 20-ml one-bolus swallow of applesauce is not plausible). Hence two separate analyses were needed. That is, a four factor mixed ANOVA to investigate SA as a function of gender (male and female), age (young and older adults), bolus volume (5 and 20 ml) gustation (water and apple) was conducted. A three factor mixed ANOVA to investigate SA as a function of gender, age, and viscosity (5-ml apple juice, 5-ml thick apple juice, and 5-ml apple sauce) was conducted.

Results

Swallowing Apnea Onset as a Function of Age, Gender, Bolus Volume, and Gustation

Mean SA onsets relative to lingual bolus propulsion as a function of age, gender, volume, and gustation are presented in Table 1. An α level of .05 was adopted. Relative treatment effect size (i.e., proportion of variance accounted for) and statistical power are indexed by η^2 (Keppel, 1991; Keppel & Zedeck, 1989) and ϕ (Cohen, 1989), respectively in this and subsequent analyses. A four-factor mixed ANOVA was performed to investigate SA onset as a function of age, gender, bolus volume, and gustation. The results of the four-factor mixed ANOVA investigating SA onset as a function of age, gender, bolus volume, and gustation are presented in Table 2. Significant main effects for volume and age were found ($p < 0.05$). A significant volume by age group by gender interaction was found ($p = 0.0012$). The interaction is illustrated in Figure 2. In general, older individuals demonstrated earlier SA onset relative to lingual bolus propulsion, and SA onset occurred earlier with increasing bolus volume.

Post-hoc analyses in the form of Tukey tests examined the age by gender interaction at each volume level. No statistical significance was found for the 5-ml bolus volume condition. For the 20-ml bolus volume condition, statistical significance was found between young and older males ($p = .017$). That is, SA onset relative to lingual bolus propulsion occurred significantly earlier in older males compared to younger males. This significant temporal relation did not exist for the other groups. Single-*df* comparisons examined the performance between each volume level for each age group and gender. Statistical significance was found between 5- and 20-ml bolus volume conditions for young females ($p < .0001$), older females ($p = .017$), young males ($p = .005$), and older males ($p < .0001$). Thus, the 20-ml bolus volume condition elicited an earlier SA onset than the 5-ml bolus volume condition for each age and gender group.

Swallowing Apnea Onset as a Function of Age, Gender, and Viscosity

Mean SA onsets relative to lingual bolus propulsion as a function of age, gender, and viscosity are presented in Table 3. A three-factor mixed ANOVA was performed to investigate SA onset as a function of age, gender, and viscosity. The results of the ANOVA are presented in Table 4. A significant main effect for viscosity was found ($p < 0.0001$) while all other main effects and interactions were not significant. That is, SA onset relative to lingual bolus propulsion occurred later with increasing viscosity (See Figure 3) irrespective of age and gender. Orthogonal single-*df* comparisons were undertaken to assess the main effect of bolus viscosity. Mean SA onset for thin liquid ($M = .08$ s) was significantly earlier ($p < 0.001$) than the mean SA onset for thick liquid ($M = .27$ s) and puree ($M = .35$ s). There was no significant difference between the mean SA onset for thick liquid and puree ($p > 0.05$).

Discussion

The purpose of this study was to identify the temporal relation between lingual bolus propulsion onset and SA onset and to identify factors that affect this relation. Factors examined were the effects of aging, gender, bolus size, bolus viscosity, and bolus taste. In the study's first analysis, SA onset was investigated as a function of age, gender, bolus volume and gustation. The omnibus analysis revealed a significant interaction of age, gender, and bolus volume on SA onset relative to lingual bolus propulsion. In general, older adults initiated SA onset earlier than young adults. Furthermore, large boluses elicited an earlier SA onset than small boluses. *Post-hoc* analysis of the significant interaction revealed that the young males demonstrated significantly later SA onset than the older males for large bolus volumes but this statistically significant difference was not observed for small bolus volumes nor was it found for young and older females on either bolus volume. All groups demonstrated significantly earlier SA onsets on

large bolus volumes compared to small bolus volumes. No significant differences were observed for SA onset as a function of gustation.

In the study's second analysis, SA onset was also investigated as a function of age, gender, and bolus viscosity. A significant effect of viscosity on SA onset was found. SA onset started earlier with thinner viscosities and started later as bolus viscosities increased. No significant differences existed for SA onset as a function of age and gender relative to viscosity.

As the adult pharynx is unfunctional, it can allow for deglutition or respiration, but not both functions simultaneously. One may pose that SA onset must occur before lingual bolus propulsion because airflow must terminate to allow for passage of food through the pharynx. If SA onset did not occur before lingual bolus propulsion, then it presumably should occur simultaneously to or immediately after bolus propulsion. The results of this study revealed that factors such as age, gender, bolus volume, and bolus viscosity determine whether SA onset begins before or after onset of lingual bolus propulsion.

In the present study SA onset relative to lingual bolus propulsion changed as a function of bolus volume. Mean bolus volumes of 28.1 \pm 9.1 ml and 21.6 \pm 5.5 ml for males and females, respectively have been reported (Nilsson, Ekberg, Olsson, Kjellin, & Hindfelt, 1996). Thus, 5-ml was a bolus volume chosen for this study which is a small volume and will also allow for comparison in future research of individuals with dysphagia. Twenty-ml was chosen which is a relatively large bolus and an appropriate volume for individuals with normal swallowing. SA onset started earlier with the larger 20-ml compared to the small 5-ml bolus volumes for all groups. Similarly, Hiss et al. (2001) reported that SA duration increased with increasing bolus volumes in 60 healthy participants who swallowed water in the amounts of 10-, 15-, 20-, and 25-ml. Earlier SA onset likely contributes to the increased SA duration with increased bolus

volumes reported in previous research. It should be noted that while some research has reported that SA duration increased as a function of bolus volume (Issa & Porostocky, 1994; Preiksaitis & Mills, 1996; Hiss et al., 2001; Hirst, Ford, Gibson, & Wilson, 2002), other research has reported that SA duration was not influenced by bolus volume (Preiksaitis, Mayrand, Robbins, & Diamant, 1992; Martin, Logemann, Shaker, & Dodds, 1994). The most recent studies investigating SA duration that have employed a larger number of participants, advanced technology, and normal eating/drinking simulation coupled with the findings of the current study (i.e., onset of SA started earlier with increases in bolus volume) provide strong evidence that SA duration does increase with increases in bolus volume. Similarly, SA offset may occur later accounting for the increased SA duration with increased bolus volumes, yet this was not probed in this study.

As illustrated in Figure 2, young females and males both demonstrated SA onset after onset of lingual bolus propulsion on five-ml bolus volumes, whereas older females and males demonstrated SA onset before lingual bolus propulsion on five-ml bolus volumes. This finding of older adults initiating earlier SA onset suggests a possible decrease in neural reserves in timing. Older adults may compensate for slowing of swallowing sequencing of events by initiating SA onset earlier to assure respiration and swallow coordination. It is plausible that an earlier SA onset likely compensates for age-induced neural and structural changes.

The exception to older adults initiating earlier SA onset compared to young adults is seen in the 20-ml bolus condition where young females demonstrated the earlier SA onset compared to older females. This difference is slight and not significantly different but accounts for part of the significant interaction. The explanation is likely found in the bolus volume itself. A 20-ml bolus volume is a more challenging bolus size for females than males. Gender differences are

documented with respect to SA duration (Hiss et al., 2001) with females demonstrating longer SA duration than males as bolus volume increased. The increased bolus size may have necessitated that the young females initiated an earlier SA onset in an attempt to prepare for the more challenging bolus size thus negating the age effect seen in males.

Another part of the interaction is seen in the markedly earlier SA onset for older males compared to all the groups for the 20-ml condition. The mean ages of the older groups were 72 and 70 years for females and males, respectively. Thus, under the premise that SA onset occurs earlier with increased age, one may assume an earlier SA onset would exist for the older females, yet the opposite was observed in this study. It is possible that older males experience age-induced neural and structural changes relative to SA onset before older females thus requiring an earlier age-induced accommodation. An age by gender interaction has been previously reported in SA research. Men demonstrated a decrease in SA duration and women demonstrated an increase in SA duration with increases in age (Hiss et al., 2001). Similarly, Logemann et al. (2002) reported temporal and range of motion differences in swallowing physiology as a function of gender-specific aging. They reported several swallowing differences between gender; however, of interest to this study, women demonstrated increased hyolaryngeal movement with age whereas men demonstrated decreased movement with age. The authors discuss that the gender-specific aging differences in swallowing physiology “indicate that women maintain muscular reserve better than men” (p. 440).

Furthermore, Lushei, Ramig, Baker, and Smith (1999) investigated single motor unit discharges during phonation in 13 young adults and six older adults. They reported an aging difference between the two sexes as evidenced in motor unit firing characteristics. There was no significant difference between thyroarytenoid and cricothyroid interspike intervals for young and

older females. However, thyroarytenoid interspike intervals was greater in older than younger males. Thus, it is plausible that in one of the few studies that have specifically investigated laryngeal motor firing units, the older males exhibited greater vulnerability to these types of measurements than females with increases in age. Likewise, the findings of our current study support our hypothesis that earlier SA onset relative to tongue propulsion in older males is a gender-specific aging difference. That is, the current study demonstrated that older males demonstrated a statistically significant earlier SA onset than did young males whereas the older females did not demonstrate this same relation with young females.

The current study revealed that SA onset relative to lingual bolus propulsion did not change as a function of gustation. Using apple juice, as opposed to water should theoretically increase the sensory loading of the oral cavity and subsequently “lower the swallow threshold” (Logemann et al., 1995, p. 37). Logemann and colleagues reported that sour boluses decreased the oral transit times and swallowing initiation delays in 19 patients who had experienced at least one cerebrovascular accident. Their findings indicated that the dysphagia measures that were improved were the sensory characteristics of dysphagia.

There are two possible reasons as to why SA onset did not change as a function of gustation in the present study. First, this study employed sweet not sour boluses (i.e., apple juice vs. lemon juice). It is probable that sweet boluses do not have the same degree of sensory loading as sour boluses. The second plausible reason that the present study did not find SA onset changes as a function of gustation, is that this study employed the use of normal participants whereas Logemann and colleagues (1995) studied individuals with neurogenic dysphagia. Participants in the current study were swallowing at a normal threshold, whereas those with dysphagia may be at a higher swallowing threshold. Enhanced sensory stimulation may be needed and utilized to

produce improved swallowing in dysphagia swallowing as compared to non-impaired swallowing. This study, if replicated on a group with dysphagia from a cerebrovascular accident (like those by Logemann et al.), may reveal changes in SA onset as a function of gustation. In other words, individuals with dysphagia may utilize the increased sensory loading for a change in SA onset although no difference was found in individuals with normal swallowing.

The results of the current study revealed that SA onset relative to lingual bolus propulsion changed as a function of bolus viscosity. SA onset occurred earliest with thin liquids, followed by thick liquids and then puree. Intuitively, and as previously documented (Miller & Watkins, 1996; Poudroux and Kahrilas, 1995; Bisch et al., 1994; Robbins et al., 1992; Dantas et al., 1990), the mechanics of a swallow occur more slowly when a bolus has increased viscosity. Thus, pharyngeal and laryngeal physiologic events do not need to occur as quickly as with a thinner, faster moving bolus.

Seemingly contrary to the findings of the current study, Perlman, Ettema, and Barkmeier (2000) reported that no significant temporal differences of seven different respiration and swallowing variables were observed as a function of viscosity in 15 young adults. The difference in findings relative to viscosity between the present study and that of Perlman and colleagues is that they were not specifically investigating SA onset relative to lingual bolus propulsion via lingual manometry. They found no significant differences as a function of viscosity for surface electromyography onset or peaks, acoustic onsets or peaks and apnea offsets for their swallowing and respiration measures. Surface electromyography measured suprahyoid musculature and the acoustical information reflected different physiologic (e.g., epiglottic movement) and bolus flow sounds (e.g., bolus flow through the upper esophageal sphincter). Both surface electromyography

and acoustical analyses measured physiologic parameters other than SA which did not reflect changes with increases in viscosity.

Perlman et al. (2000) did measure SA offset and reported it also did not change with changes in viscosity. Thus, the current study demonstrated that SA onset is vulnerable to changes in viscosity whereas other swallowing parameters and SA offset, as identified by Perlman et al., may not change as a function of viscosity. Hypothetically, it may be necessary to begin SA earlier to accommodate for thinner viscosities as they may move from the oral cavity into the hypopharynx earlier compared to increased viscosities. Given the differences found in SA relative to viscosity, the role of viscosity on SA needs replication and further investigation.

It should also be noted that a nasal cannula was utilized for SA measures in this study. Of concern in the interpretation of SA onset via nasal cannula is that velopharyngeal closure stops airflow through the nasal cavities with swallowing. Perlman et al. (2000) addressed the timing of velopharyngeal closure relative to SA onset via simultaneous videofluoroscopic and respiratory analyses and reported “for a significant number of swallows, respiratory flow ceased before the velum was fully elevated” (p. 89). In their study, complete velopharyngeal closure preceded SA 43% of the time. Although 100% exclusivity of velopharyngeal closure affecting SA measures does not exist, the nasal cannula has been recommended as the optimal way to acquire respiratory data. Plethysmography is vulnerable to limb movement artifact during self-administration of boluses. Thermistors are susceptible to an increase in temperature secondary to warming to body temperature during periods of no nasal airflow (SA). Finally, facemasks are not feasible given the necessity of placing boluses in an individual’s mouth and subsequently losing respiratory information. Given the advantages and disadvantages of the various techniques for

recording respiratory events, the nasal cannula is currently the hardware of choice for nasal airflow and SA onset acquisition.

A potential limitation of this study was the use of oral manometric bulbs to infer lingual bolus propulsion. Videofluoroscopy would have provided optimal visualization of lingual movements associated with bolus propulsion. Although healthy individuals could have been subjected to radiation to acquire this swallowing parameter, it was not deemed necessary as much research has reported characteristic lingual pressure movements associated with swallowing. Specifically, anterior tongue tip to hard palate approximation has been designated as the leading complex of the swallow (Logemann, 1983; Cook et al., 1989). Furthermore, Nicosia et al., (2000) combined videofluoroscopy with the same method of lingual movement acquisition used in the current study and reported that the lingual measurements from the bulb data was consistent to the lingual timing measures acquired with videofluoroscopy. Thus, lingual bolus propulsion onset acquired via manometric bulbs placed along the midline of the hard palate was deemed to provide reliable and efficacious measurements.

In the current study, normal temporal relations of SA onset relative to lingual bolus propulsion have been elucidated with respect to age, gender, bolus volume, gustation, and viscosity. Likewise, similar relations should be investigated in different patient populations. For example, timely SA onset may be more vulnerable in patients with chronic obstructive pulmonary disease. This population's stressed need for oxygen and release of carbon dioxide may translate into prolonged respiration during bolus transfer with subsequent delayed SA onset predisposing them to aspiration. Additionally, individuals post cerebrovascular accidents may exhibit delayed SA onset similar to their well-documented delay in swallowing initiation. Through future research, SA onset measures of disordered swallows that have been specifically correlated with aspiration events may offer insight into respiration and swallow coordination. If

delayed SA onset were deemed to be a consistent predictor of disordered swallowing, then SA onset measures would offer a further parameter of swallowing that could be assessed along with current instrumental swallowing evaluations, increasing interpretation of physiologic breakdown in disordered swallowing.

Summary

In conclusion, data from individuals with normal swallowing have been obtained relative to SA duration in the Hiss et al. (2001) study and relative to SA onset in the current investigation. Factors such as bolus volume, bolus viscosity, age, and gender that affect SA duration and its onset have also been identified. In general, older adults initiated SA onset earlier than young adults and large boluses elicited an earlier SA onset than small boluses regardless of group. A significant interaction revealed gender-specific aging differences related to SA; older men demonstrated significantly earlier SA onset than older women in what is perceived to be an age-induced accommodation for decreased muscular and neural reserves. This gender-specific aging difference is consistent with literature in SA and various other parameters of swallowing and voice physiology.

Once further investigated, SA is a parameter of swallowing that may prove useful in swallowing diagnostics. The data acquired in this study provide a basis for future research for SA to be compared to that observed in different populations with dysphagia. It is hypothesized that SA duration and onset measures that deviate from the established means may offer the clinician more comprehensive information when combined with an instrumental examination as to the cause of a patient's dysphagia. If SA duration and/or SA onset are found to be deficient in any given patient, respiratory waveforms may be utilized as visual biofeedback in rehabilitation efforts toward restoring normal swallowing and respiration coordination.

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Table 1.

Mean Swallowing Apnea Onsets Relative To Lingual Bolus Propulsion As A Function Of Age, Gender, Bolus Volume And Gustation.

Group	Gustation			
	Water Bolus Volume		Apple Juice Bolus Volume	
	5 ml	20 ml	5 ml	20 ml
Young				
Female	0.18	-0.12	0.14	-0.14
	(0.057)	(0.056)	(0.039)	(0.056)
Male	0.14	-0.003	0.08	0.03
	(0.047)	(0.036)	(0.032)	(0.031)
Older				
Female	0.01	-0.14	0.06	-0.09
	(0.067)	(0.083)	(0.092)	(0.040)
Male	0.05	-0.20	0.04	-0.20
	(0.052)	(0.062)	(0.050)	(0.048)

Note. Standard errors of the means are presented in parentheses. A positive value was assigned if SA onset started after lingual bolus propulsion. A negative value was assigned if SA onset started before lingual bolus propulsion. If SA onset and lingual bolus propulsion onset occurred at the same point in time, a 0.00 s value was assigned.

Table 2.

Summary Table For The Four-Factor Mixed Analysis Of Variance Investigating Swallowing Apnea Onset Relative To Lingual Bolus Propulsion As A Function Of Age, Gender, Bolus Volume, And Gustation.

Source	Sum of Squares	df	Mean Square	F	p	η^2	ϕ
Age	.37	1	.37	4.25	.047*	.11	
Gender	.0011	1	.0011	.013	.91	.00	.051
Age X Gender	.072	1	.072	.83	.37	.022	.14
Error	3.1	36	.087				
Volume	1.6	1	1.6	89.4	<.0001*	.71	
Volume X Age	.0031	1	.00031	.018	.89	.00	.052
Volume X Gender	.028	1	.028	1.6	.21	.043	.24
Volume X Age X Gender	.22	1	.22	12.4	.0012*	.26	
Error	.63	36	.017				
Gustation	.0000042	1	.0000042	.00048	.98	.00	.050
Gustation X Age	.020	1	.020	2.3	.14	.06	.32
Gustation X Gender	.0040	1	.0040	.51	.48	.014	.11
Gustation X Age X Gender	.014	1	.014	1.6	.22		
Error	.31	36	.0090				
Volume X Gustation	.011	1	.011	1.0	.32	.028	.17
Volume X Gustation X Age	.0084	1	.0081	.82	.37		
Volume X Gustation X Gender	.0030	1	.0030	.32	.57		
Volume X Gustation X Age X Gender	.0040	1	.0040	.37	.55		
Error	.37	36			.54		

Note. Repeated measures *p* values following Geisser-Greenhouse correction; *considered significant at $\alpha = 0.05$.

Table 3.

Mean Swallowing Apnea Onset Relative To Lingual Bolus Propulsion As A Function Of Age, Gender, And Bolus Viscosity.

Group	Bolus Viscosity		
	Thin Liquid	Thick Liquid	Puree
Female	0.14	0.28	0.36
	(0.039)	(0.061)	(0.067)
Male	0.077	0.16	0.26
	(0.032)	(0.019)	(0.039)
Older			
Female	0.06	0.40	0.47
	(0.092)	(0.13)	(0.088)
Male	0.04	0.26	0.31
	(0.05)	(0.12)	(0.056)

Note. Standard errors of the means are presented in parentheses.

Table 4.

Summary Table For The Three-Factor Mixed Analysis Of Variance Investigating Swallowing Apnea Onset Relative To Lingual Bolus Propulsion As A Function Of Age, Gender, And Bolus Viscosity.

Source	Sum of Squares	df	Mean Square	F	p	η^2	ϕ
Age	.056	1	.056	.54	.47	.015	.11
Gender	.30	1	.30	2.9	.099	.074	.38
Age X Gender	.0012	1	.0012	.012	.91	.000	.051
Error	3.75	36	.10				
Viscosity	1.5	2	.77	25.5	<.0001*	.42	
Viscosity X Age	.15	2	.076	2.5	.088	.065	.49
Viscosity X Gender	.052	2	.026	.86	.43	.023	.19
Viscosity X Age X Gender	.014	2	.0070	.23	.63	.006	.076
Error	2.17	36	.060				

Note. * considered significant at $\alpha = 0.05$.

Figure Captions

Figure 1. Waveforms depicting onset of swallowing apnea relative to onset of lingual bolus propulsion.

Figure 2. Mean swallowing apnea onset relative to lingual bolus propulsion as a function of age, gender, and bolus volume.

Figure 3. Mean swallowing apnea onset relative to lingual bolus propulsion as a function of viscosity.





