

THE EFFECT OF BOLUS CONSISTENCY AND AGE
ON MEASUREMENTS OF HYOLARYNGEAL
MUSCULAR ACTIVITY DURING
SWALLOWING

by

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Submitted in partial fulfillment of the
requirements for Departmental Honors in
the Department of Speech-Language Pathology
Texas Christian University
Fort Worth, Texas

December 15, 2014

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ABSTRACT

The objective of this study was to measure the effect of Age and Bolus Consistency on Hyolaryngeal Muscular Activity in older healthy adult males (ages 60-90) as compared to younger healthy males (ages 18-25) using Surface Electromyography (sEMG). Ten young healthy adult male participants (ages 18-25) and ten older healthy adult male participants (ages 60-90) were recruited for this study. The dependent variables for this study were Amplitude and Duration measurements that were obtained from sEMG signals. The sEMG signals were acquired using the Swallowing Signals Lab workstation model (Kaypentax, Montvale NJ). Disposable self-adhesive electrode patches containing three electrodes were placed 1 cm below the inferior rim of the mental protuberance of the mandible. This electrode placement ensured that the electrodes were over the laryngeal elevator muscles. Each participant swallowed each bolus consistency (based on the National Dysphagia Diet levels 1 & 3) five times.

The study found that bolus consistency significantly influenced measurements. As bolus consistency became more solid, the amplitude and duration in of sEMG increased. Results also indicated that older males exhibited greater durations during swallows as bolus consistency increased as compared to younger males. No significant effect of age group on amplitude was found.

The significant effects of Amplitude and Duration based on different bolus consistency likely resulted from the participants using greater muscular contraction force when swallowing solid boluses. This study contributes to the current knowledge and research that helps us understand how Age and Bolus Consistency effect the Amplitude and Duration of hyolaryngeal muscle activity in healthy younger and older males.

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INTRODUCTION

Swallowing Physiology

Swallowing involves the passage of a given substance via the mouth into the body. Swallowing is divided into four distinct phases that are referred to as the Oral Preparatory, Oral, Pharyngeal, and Esophageal stages (Murry and Carrau). There are several anatomical structures and muscles that are involved during each stage of a swallow, and complex neural circuitry, which facilitates safe and effective delivery of food from the mouth to the stomach.

Oral Preparatory Phase

The Oral Preparatory phase marks the beginning of the swallowing process. During this stage food is ground and positioned through the coordination of the lips, tongue, mandible, soft palate, and muscles of the buccal cavity. In this stage there is a transfer phase in which the tongue positions the food to a posterior position in the oral cavity where it can be chewed (Murry and Carrau). Once this positioning occurs the reduction phase takes over and the food is chewed, ground, and combined with saliva to form a bolus that is eventually swallowed. Saliva acts as a triggering stimulus for a swallow to occur. Liquids are held in the mouth briefly before swallowing whereas a solid bolus takes several seconds to become masticated and transported to the next phase of swallowing.

Oral Phase

The next phase in the swallowing process is the oral phase, where the bolus is delivered from the anterior oral cavity to the posterior oral cavity. In this phase the bolus is moved anterior to posterior by the tongue and its interaction with the palate. During the

oral stage the tongue acts as the main manipulator of food. Contact of the posterior tongue to the soft palate keeps the bolus in place and prevents spillage into the pharynx from occurring. As the tongue strips the bolus posteriorly along the hard palate, the bolus ends up being positioned on the posterior portion of the tongue (Murry and Carrau). The velum (soft palate) is pushed upward by the bolus while the lips and buccal muscles contract to create pressure and reduce the volume of the oral cavity. Near the end of the oral stage, the most posterior portion of the tongue becomes depressed while the front and middle sections of the tongue elevate to continue propulsion of the bolus into the oropharynx.

Pharyngeal Phase

The third phase of the swallowing process is the pharyngeal phase. It is classified as involuntary because the muscular events, which occur, are not under conscious voluntary control. This stage begins when the bolus reaches the anterior tonsillar pillars where sensory receptors are stimulated by the bolus (Murry and Carrau). These receptors send signals into the brainstem, where a swallowing pattern generator responds by activating motor nerves which go out to the muscles of the pharynx and larynx. There are many receptors that are sensitive to light touch, discriminative touch, movement, pressure, temperature, and taste. All of these receptors are located in overlapping areas of the mouth, pharynx and larynx.

Physiology of Pharyngeal Phase

Swallowing occurs most effectively when a large amount of receptive fields are stimulated. The supraglottic mucosa of the larynx, especially on the laryngeal surface of the epiglottis, the arytenoid cartilages, and the true vocal folds are where the highest

densities of receptors are located (Langmore). The consistency of a bolus determines the way in which the anatomical structures involved in the swallow responds to it. For example, if a bolus is too acidic, it will be received as a threat when reaching the hyopharynx or larynx and a cough will occur rather than a swallow. The structures and physiology that are influenced by these sensory receptors during the pharyngeal stage include tongue elevation, velopharyngeal closure, elevation of the larynx, and relaxation of cricopharyngeus musculature. All of these movements occur in sequence as the bolus moves through the pharynx and into the esophagus.

Esophageal Phase

The fourth and final phase in the swallowing process is the Esophageal phase. The esophagus is a muscular tube where the primary function is the passage of food from the pharynx to the stomach. The esophageal stage begins when the head of the bolus passes the upper esophageal sphincter (UES), entering the esophagus. The esophagus shortens by ten percent during swallowing due to longitudinal muscle contraction. Peristalsis, or wave-like muscle contractions, of the esophagus occur to move the bolus down the esophagus, followed by relaxation of the lower esophageal sphincter (LES). As the bolus passes the LES it enters the stomach, where digestion begins.

Swallowing and Aging

The process of swallowing requires many different anatomical mechanisms to work in a precise and ordered manner. The structures involved with swallowing are equipped to recognize and process different shapes, sizes, and forms of a bolus. For example, the structures involved in a liquid swallow might not react to the same degree as that of a thick bolus swallow. A number of studies have investigated the form and

consistency of a bolus in relation to swallowing. In addition, studies have investigated age as a factor that has potential to contribute to swallowing physiology. Logemann et al. (2000) conducted a study which looked at both age and bolus consistency in relation to the swallowing process. In this study eight healthy males between the ages of 21 and 29 and eight healthy men between the ages of 90 and 94 were analyzed during two swallows one with 1 ml of liquid and the other with 10 ml of liquid. Videofluoroscopic studies of these groups were assessed as well as a biochemical analysis of each swallow. During the biochemical analysis data was collected on temporal, range of motion, and coordination characteristics of the oropharyngeal swallow. In addition to this, position of the larynx at rest, length of neck, and pattern of hyoid movement were compared between the two age groups. The conclusion of this study was that none of the participants, both young and old had a characterized swallowing disorder. However the data collected did vary between the two age groups. This supported the hypothesis of reduced muscular reserve in the swallows of older men compared to younger men. Age effects indicated older men had a shorter C2 to C4 distance compared to that of younger men, as well as a laryngeal position at rest that was lower. In addition, older men had a significantly longer pharyngeal delay and faster onset of posterior pharyngeal wall movement in regards to the first cricopharyngeal opening. Hyoid movement, both vertical and anterior, in the older men was significantly reduced. In regards to the volume of liquid during the swallow, older men had smaller widths at the cricopharyngeal opening at the 10 mL volume, which is indicative of less upper esophageal sphincter flexibility. Significant changes of the extent of hyoid elevation and duration of the cricopharyngeal opening were seen when the liquid bolus volume increased.

Logemann et al. (2002) investigated the swallowing process in regards to bolus consistency and age in women. Similar to the previously discussed study, two age groups were compared which included eight healthy women ages 21 through 29 and eight healthy older women ages 90 to 93. Two swallows were conducted with volumes at 1 ml and one at 10 ml. The swallows were analyzed using videofluoroscopic equipment. Kinematic analysis of both of the swallows was also used, and from this analysis data on range of motion of the pharyngeal structure as well as coordination of oropharyngeal structures was retrieved. The videofluorographic results were analyzed in slow motion to see if any swallowing disorder existed. What was concluded from this study in regards to age was that the maximal extent of structural movement was significantly reduced in tongue base movement at mid C2. Anterior movement of the arytenoid and vertical laryngeal significantly increased. While both of the studies indicated that there were no swallowing disorders present in the studied samples of participants, it did give information on how swallowing differs with age and bolus size.

In a recent study, Ekberg and Feinberg (1991) studied swallowing patterns in 56 elderly participants with no history of swallowing impairment. The study consisted of 22 men and 34 women ranging from 72-93 giving a mean age of 83 years. The patients were given liquid barium while sitting or standing upright during videofluoroscopic swallow examinations. The results indicated that both oral stage and pharyngeal stage abnormalities were evident during swallowing. Oral stage abnormalities were evident in 63% of participants, and included difficulty ingesting a bolus, controlling a bolus, or moving a bolus posteriorly to initiate a swallow reflex. Pharyngeal stage abnormalities were evident in 64% of swallows and included bolus retention, lingual propulsion

difficulties, pharyngeal constrictor paresis, and cricopharyngeal dysfunction. The authors noted that participants with a history of neurological disease had greater dysfunction than other patients. When comparing the data against swallows of younger persons without dysphagia it can be said that the elderly persons had a higher amount of abnormalities. Reaction time during a swallow was seen as decreasing in elderly persons, suggesting that older persons require more time to process neurological signals in regards to swallowing. The study points out that muscle strength has been seen to decline with age, which is related to a change in muscle fiber composition.

Swallowing and Respiration

Respiration is an important aspect to be analyzed when looking at the swallow because both processes involve similar anatomical mechanism. In addition, airway protection must be maintained when a bolus is passing through the pharynx, so the two processes are again correlated with one another. Leslie, Drinna, Ford, and Wilson (2005) recently investigated respiration patterns during swallowing as a function of age. These authors studied 50 healthy volunteers between the ages of 20 and 78, who were asked to swallow different bolus volumes and consistencies while respiratory patterns were measured by a computer system. Bolus consistencies included water and yogurt, while bolus volumes included 5mL and 10mL of the water bolus. From recorded swallows the authors measured multiple dependent variables, including resting breathing pattern, the number of measureable swallows, the duration of apnea during a swallow, the post-swallow breath direction (inspiration or expiration), the frequency of multiple swallows for clearing a bolus, and the frequency of normal vs. abnormal breathing reset pattern after swallowing. Results found that at age effected two dependent variables: (a) the

number of measureable swallows, which decreased with age, and (b) the duration of swallow apnea, which increased with age. Based on the results of the study the authors concluded that subtle changes occur in respiration patterns during swallowing as an individual ages. It is not certain whether these changes are due to compensatory mechanisms to protect the airway, the result of decreased muscle mobility, or altered reaction times.

Bolus Characteristics and Swallowing Physiology

One of the most important physiological events that occur during the pharyngeal stage of the swallow is hyolaryngeal elevation. The hyoid and larynx elevate during this stage to protect the airway and to help open the UES. This hyolaryngeal elevation occurs due to contraction of at least three submental muscles, which include the mylohyoid, geniohyoid, and anterior digastric. If these muscles are impaired in any way it can impact the swallowing process and put the person at risk for penetration and or aspiration of bolus material. As a group the mylohyoid, geniohyoid, and digastric muscles pull the hyoid up in an anterosuperior position, which causes the larynx to move up and forward. This movement protects the airway as well as pulls open the esophageal sphincter. The degree to which these muscles are affected by aging and/or bolus characteristics, such as texture or viscosity, is somewhat unclear based on current literature.

Van den Engel et al. (2012) investigated the activity of the submental hyolaryngeal muscles in a group of healthy participants between the ages of 5 to 65 years of age. Swallowing biomechanics were analyzed during swallows of saliva, water, and varying bolus consistencies. This study measured the duration and mean amplitude value (MAV) of surface electromyography (sEMG) in the submental muscle group (mylohyoid,

geniohyoid, digastric). In addition to this, the study also measured the maximum anterior tongue pressure and the rise and release slopes of the anterior tongue pressure while participant's swallowed different consistencies. Head and neck movements were also analyzed via videotape. Data was collected using a Digital Swallowing Workstation. Each of the participants was able to swallow the 5 mL of water in one swallow. Throughout the study sixteen swallows were analyzed for each of the participants. Outcome results varied with the consistency of the liquid or bolus that was swallowed. The rise and slope of the overall mean anterior tongue position was significantly different for each of the sampled consistencies. The ATP data showed a large inter-subject variation but the intra-subject differences were not deemed statistically significant. In the discussion it was noted that duration and MAV of sEMG activity and ATP during swallowing were impacted more by bolus consistency than by gender or age. Age influenced the duration of SMG activity when solid food was swallowed longer than water with the younger subjects having a longer SMG duration.

Im et al. investigated the effects of bolus consistency, age, and gender in healthy individuals by using temporal measurements of Pharyngeal Transit Duration (PTD). PTD represents the amount of time it takes for a bolus to move from the ramus of the mandible to the UES. 40 Videofluoroscopic Swallowing Examinations (VFSEs) of healthy individuals were randomly selected. All of the swallows were said to be within the normal range with no penetration or aspiration occurring. However, significant differences between the independent variables were present. For each consistency the younger aged subjects yielded shorter PTDs but there was no interaction between age and consistency. The male individuals had shorter PTD's than the female individuals and the

two groups showed significant differences from on another. There was no interaction between age, gender and consistency, but there were significant differences between the actual consistencies (puree, thin, and thick liquids). Over all the study concluded that PTD differences occur by age, gender, and bolus consistency across healthy populations.

In a study by Ruark et al. bolus consistency and swallowing were analyzed in both children and adults. In this study bipolar surface EMG recordings were taken from four placement sites including the submental muscles (SM). Participants completed five tasks with each task involving three trials of swallowing of a given liquid or food consistency, which included water, thickened liquid, pudding, cheese spread, and a gummy bear. The duration of muscle activity revealed that there was no significant effect for age but that there was significant interaction between muscle activity and consistency Ruark et al. The duration of submental muscle and laryngeal strap muscle activity was increased when comparing thicker consistencies e.g., cheese spread to thinner consistencies, such as water. The average EMG amplitude of muscle activity indicated significant effects in regards to bolus consistency but no other effects e.g., age. The amplitude results indicated the greatest magnitude to be with the cheese spread bolus, and the smallest to be with water.

PURPOSE

This study will seek to determine if older males (60-90 years) exhibit different swallowing patterns from measures of sEMG amplitude and duration when swallowing boluses of different consistencies, specifically thin liquids, thick liquids, a pudding bolus, and a cookie bolus. Additionally, this study will seek to determine if older males exhibit

sEMG swallowing amplitude and duration characteristics, which are different from younger adult males (18-25 years) as a function of bolus consistency.

The following research questions will be addressed during the study:

1. Does bolus consistency effect the amplitude and duration of hyolaryngeal muscle contraction during swallowing in older males?
2. Does age effect the amplitude and duration of hyolaryngeal muscle contraction during swallowing when swallowing different bolus consistencies?

METHODOLOGY

Participants

Participants in this study were older healthy males between the ages of 60-90 years. Data from younger healthy males between the ages of 18-25 years were also used in this study. These younger males were previously recruited from a study conducted at TCU, from which the procedures of this investigation were replicated. Demographic information for participants in older and younger groups is shown in Table 1. All participants were recruited via a convenience sample from the local community. Ten older and ten younger males were recruited based on the following criteria:

- Male between 60-90 or 18- 25 years
- No history of a swallowing disorder
- No history of neurological disease or injury that effect the muscles of the head or neck
- No complaints of swallowing impairment
- No complaints of laryngeal or throat irritation at the time of participation
- No allergies to the foods being used as part of the study protocol

Equipment

Data was collected from the participants in the Vocal Function Laboratory in the Miller Speech and Hearing Clinic on the campus of Texas Christian University. There were two dependent variables for this study including Amplitude and Duration measurements that were obtained from sEMG signals. The sEMG signals were acquired through the use of components of the Swallowing Signals Lab workstation (Kaypentax, Montvale, NJ). The materials used included disposable self- adhesive electrode patches, which were approximately 2.25 in. in diameter. The patches consisted of three electrodes organized in a triangle configuration approximately 0.25 in. from each other. Two of the electrodes served as a recording electrode and a third served as the ground. Signals from the electrodes were processed by the Swallowing Signals Lab, which was connected to a desktop PC. Signal processing consisted of digital sampling at 500Hz followed by band-pass filtering between 50-250Hz. Signals were then integrated with a time constant of 50ms and then rectified. The resulting signal was a smoothed sEMG waveform displayed as amplitude x time.

TABLE 1. Demographic information (gender & age) for each participant

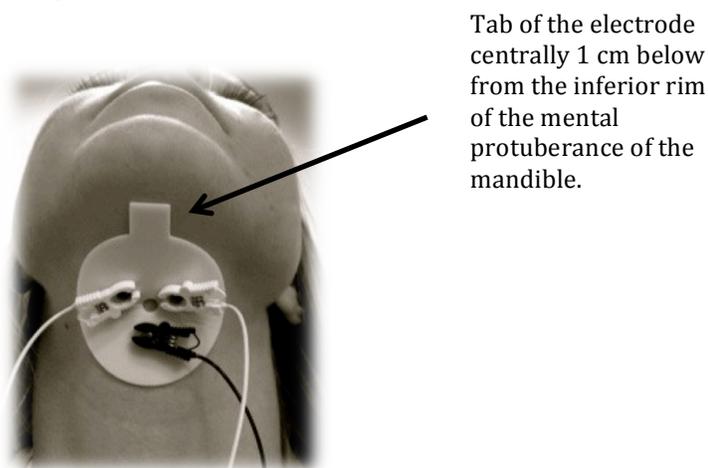
Group/Participant	Gender	Age	Group/Participant	Gender	Age
Older 1	M	66	Younger 1	M	22
Older 2	M	63	Younger 2	M	23
Older 3	M	70	Younger 3	M	21
Older 4	M	74	Younger 4	M	22
Older 5	M	79	Younger 5	M	21
Older 6	M	76	Younger 6	M	22
Older 7	M	68	Younger 7	M	21
Older 8	M	81	Younger 8	M	21
Older 9	M	67	Younger 9	M	21
Older 10	M	68	Younger 10	M	19
	Mean	71.2		Mean	21.3
	(SD)	(5.98)		(SD)	(1.06)

Procedure

Both older and younger participants were measured using the same procedural methods. Participants first went through a standard consenting procedure where they were asked a set of questions that were specific to the inclusion criteria. Each participant was provided an overview of the study and had the opportunity to ask questions. After the consenting procedures were completed, the skin surface was cleansed with an alcohol wipe (MEDI-PAK 70% Isopropyl Alcohol) to remove skin oils. Electrode heads on the self-adhesive electrode patch were then coated with a light film of electrode gel (Signa

gel, Parker Laboratories, Fairfield, NJ) to improve signal conduction. The tab of each electrode path was then placed centrally 1 cm below the inferior rim of the mental protuberance of the mandible as seen in Figure 1. This placement ensured that electrodes were over the laryngeal elevator muscles. Electrode cables from the Swallowing Signals lab were then attached to the electrode patch.

FIGURE 1. Surface EMG electrode placement



Amplitude and duration from sEMG signals was measured via the electrode cables of the Swallowing Signals Lab. Participants were recorded swallowing different bolus consistencies 5 times per bolus type. Stimuli were based on categories from the National Dysphagia Diet, and consisted of 15ml of thin liquid (water), 15ml of THICK & EASY ® Thickened HYDROLYTE ® Lemon Water (Hormel Health Labs) pre-thickened nectar-thick beverage, 2 tsp. of vanilla pudding, and one (.25oz) Lorna Doone cookie. Each Liquid consistency was measured and placed into disposable cups for consumption. The participants were instructed to hold the liquid in their mouth and

remain still until they were told to swallow. Each liquid bolus was swallowed five times. Each solid bolus consistency was also swallowed on five separate trials. Participants were given time between the trials to adjust and prepare for the next swallow at their personal discretion. After manipulation on the oral cavity, the participants were instructed to hold the bolus in the mouth and remain still until told to swallow. This allowed for a recording of a baseline sEMG signal phase and then a swallow sEMG signal phase, which was followed by a return to baseline.

To control for bolus control effects, the order in which the liquid bolus consistencies and solid bolus consistencies were administered was counterbalanced (5 older received liquid first; five older received food first, and vice-versa for the younger males). To analyze recorded sEMG signals, files were opened and measured using the Swallowing Signals Lab software. sEMG signals were recorded during each swallow and saved as separate files. This resulted in a total of 20 sEMG files for each participant (5 swallows of cookie, 5 swallows of pudding, 5 swallows of thick liquid at 15ml and 5 swallows of thin liquid at 15ml).

Analyses

Two different dependent variables were measured from the recorded sEMG signals. Signal Amplitude corresponded to the peak amplitude of the sEMG tracing within the timeframe of a single swallow. These measurements are associated with the number of motor units recruited during muscle activation, and for the purposes of this study reflected the strength of contraction in the laryngeal elevators during the swallow. Signal Duration corresponded to the duration between the initiation (rise from baseline) of the sEMG swallow signal at the peak contraction point to the termination of the peak

waveform (return to baseline) for a single swallow. This measurement reflected the activation time of the laryngeal elevators during the pharyngeal swallow.

Measures of signal Amplitude and Duration were measured from each participant's swallow. This resulted in a total of 20 measurements from each participant for amplitude and 20 each for duration. The dependent variables for this study are summarized Table 2.

TABLE 2. Independent and Dependent Variables utilized in the study, with the number of swallows recorded for each combination of variable levels.

Dependent Variable	Thin Liquid	Thick Liquid	Pudding	Cookie
Amplitude	20 participants 5 swallows n = 100			
Duration	20 participants 5 swallows n = 100			

Randomly selecting 10% of the recorded files and recalculating Amplitude and Duration measures calculated inter-measurer reliability. These were then applied to a Pearson product-moment correlation analysis to assess the degree of relationship between the initial and second measures. A correlation coefficient of 0.85 was considered acceptable reliability.

For each participant, measurements of Amplitude and Duration were averaged in each bolus condition, so that one data point represented one participant's average sEMG amplitude and duration. To answer the first research question, separate one-way repeated measures ANOVA's were applied to the amplitude and duration data from the older group, with bolus consistency (thin, thick, pudding, cookie) as the independent variable. Post-hoc pairwise comparisons using Fisher's LSD test were used for follow up comparisons. To investigate the second research question, a series of mixed two-way (age group x bolus consistency) ANOVA's were applied to the Amplitude and Duration data, where age was a between-subject variable and bolus consistency was the within-subject variable for the two ANOVA's. Follow-up Pairwise comparisons using Fisher's LSD test were used for post-hoc analysis of significant effects. In addition to these tests, four statistical independent-samples t-tests with group as the independent variable were completed to investigate interaction effects. The level of significance were set at $\alpha = 0.05$ for each test.

RESULTS

Reliability

10% of the signal files were randomly selected and re-measured for each dependent variable (Amplitude & Duration). Pearson Product Moment analyses reported strong correlations for measurements of amplitude (Pearson $r = 1.0$, $p < 0.001$) and duration (Pearson $r = 0.99$, $p < 0.001$). These results suggested very high degrees of measurement reliability.

Older Males

Descriptive data was collected from ten Older Male participants ages 60-90. The means and standard deviations (for raw data) of the dependent variables across the four bolus conditions are displayed in Table 3. Patterns from the descriptive data indicate that as the bolus consistency became more solid, both amplitude and duration increased. The data suggested differences in amplitude with the cookie having the largest amplitude as compared to the pudding, thickened lemonade, and water bolus condition. The pudding bolus also had a higher amplitude when compared to water. These results are consistent with those we found for the duration variable.

TABLE 3. Descriptive data for older males (60-90) in each of the bolus conditions (water, thickened liquid, pudding, and cookie). Amplitude measures are in microvolts (*mV*)

Group	Condition	Amplitude (<i>mV</i>)	Duration (seconds)
Male (60-90)	Water	51.69 (19.75)	.9554 (.19)
Male (60-90)	Thickened Liquid	55.09 (18.71)	1.09 (.28)
Male (60-90)	Pudding	61.48 (21.07)	1.17 (.14)
Male (60-90)	Cookie	81.53 (24.71)	1.39 (.22)

Results from a one-way ANOVA with bolus consistency as the independent variable revealed a significant effect on measures of sEMG amplitude ($F[3,27] = 16.49, p < 0.05$). Follow-up post-hoc Pairwise Comparisons indicated significant differences in amplitude all at the $p < 0.001$ level, as follows:

- Cookie > Water, Thick, Pudding
- Pudding > Water

An additional one-way ANOVA with bolus consistency as the independent variable revealed a significant effect on measures of sEMG duration ($F [3,27] = 9.35, p < 0.05$). Post-hoc Pairwise Comparisons indicated significant differences in duration all at the $p < 0.05$ level:

- Cookie > Water, Thick, Pudding
- Pudding > Water

Older vs. Younger Males

The means and standard deviations of the dependent variables for each age group across the four bolus conditions are displayed in Table 4. Patterns in the data indicated that older males consistently exhibited lower amplitudes than younger males, regardless of the bolus consistency. The descriptive data indicated that older males had longer durations with the exception of the water condition. The amplitude data from Table 4 is graphically represented in Figure 2. Table 4 displays both the younger male and older male age groups as well as bolus consistency and the results for amplitude and duration.

The duration data from Table 4 is graphically represented in Figure 3, which shows the differences in the younger and older male age groups in relation to duration.

TABLE 4. Descriptive data for each age group in each of the bolus conditions
(water, thickened liquid, pudding, and cookie)

Group	Condition	Amplitude (<i>mV</i>)	Duration (seconds)
Male (18-25)	Water	69.20 (66.81)	1.00 (.28)
Male (60-90)		51.69 (19.75)	.9554 (.19)
Male (18-25)	Thickened Liquid	69.11 (75.13)	1.01 (.20)
Male (60-90)		55.09 (18.71)	1.09 (.28)
Male (18-25)	Pudding	90.82 (73.50)	1.00 (.16)
Male (60-90)		61.48 (21.07)	1.17 (.14)
Male (18-25)	Cookie	115.90 (96.93)	1.08 (.19)
Male (60-90)		81.53 (24.71)	1.39 (.22)

FIGURE 2. sEMG Amplitude of each age group across the four bolus consistencies

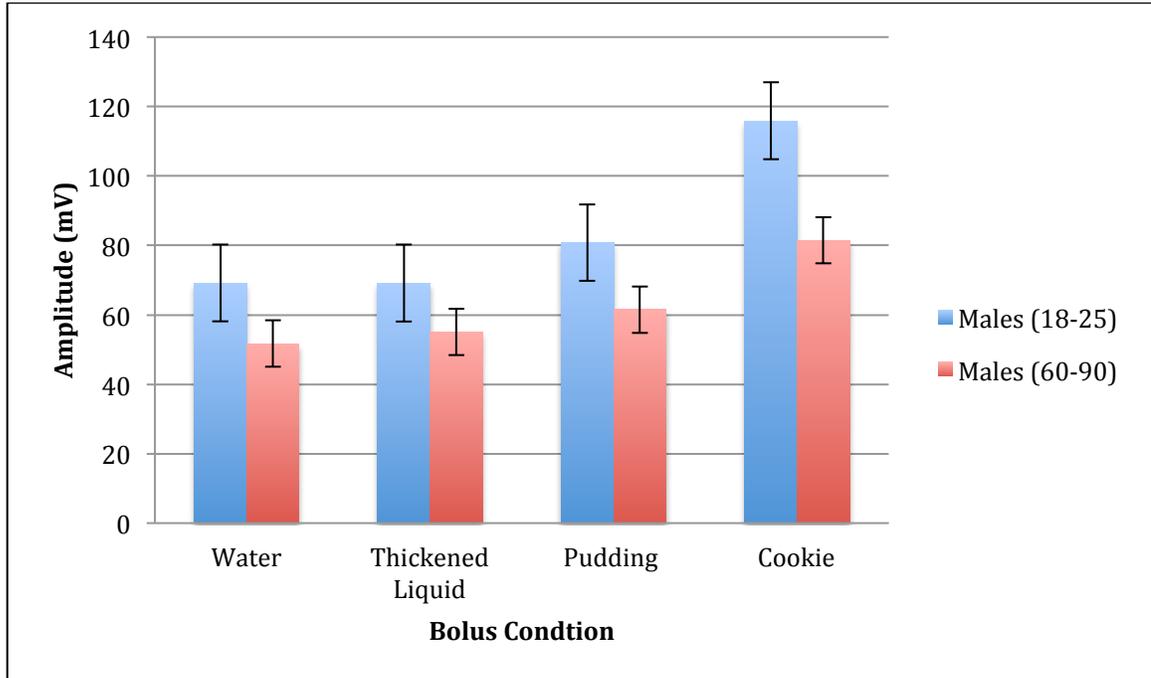
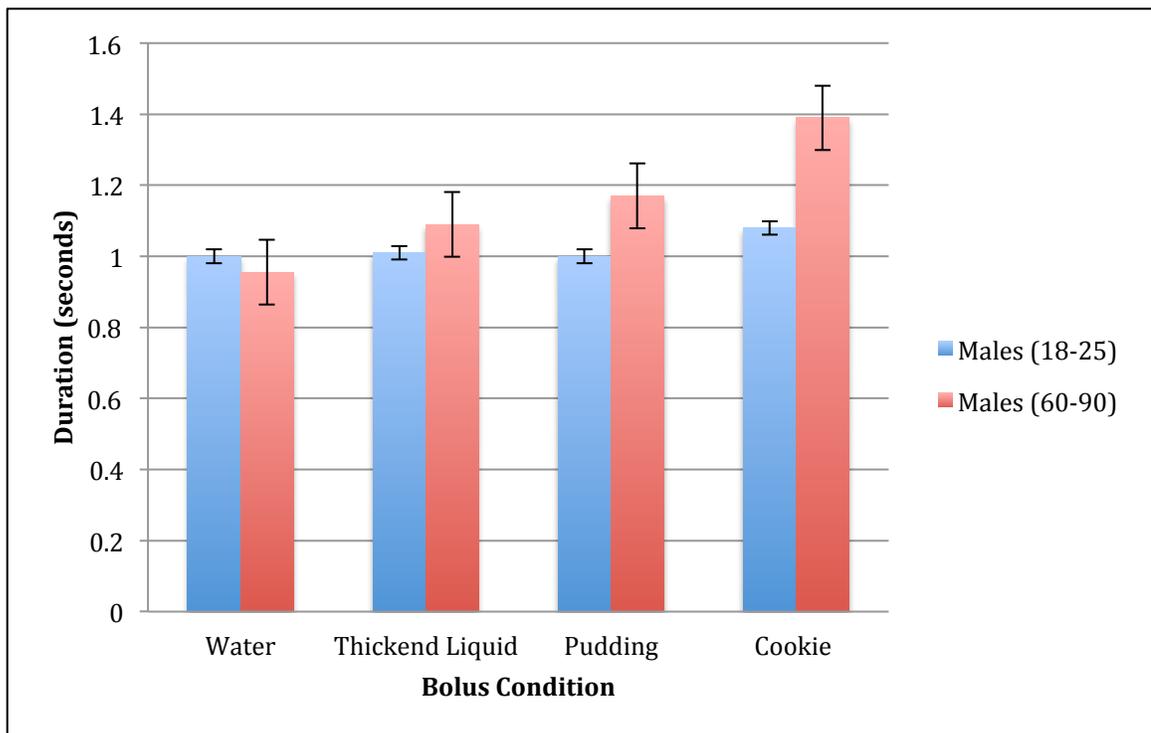


FIGURE 3. sEMG Duration of each age group across the four bolus consistencies.



Statistical analyses using separate two-way mixed ANOVA's (age group x bolus condition) were applied to the Amplitude and Duration data. The first ANOVA in relation to amplitude revealed no significant effect of age group on measures of Amplitude ($F[1,18] = .023$, $p > 0.001$) but a significant effect of bolus consistency ($F[3,54] = 40.89$, $p < 0.001$). There was no significant Age Group x Condition interaction effect ($F[3,54] = .909$, $p > 0.001$). Follow-up pairwise comparisons revealed the following significant differences, all at the $p < 0.05$ level:

- Cookie > Water, Thickened Liquid, Pudding
- Pudding > Water, Thickened Liquid

Based on the data it was interpreted that Amplitude in the cookie bolus consistency was significantly greater than all other bolus conditions, and Amplitude in the Pudding bolus consistency significantly greater than the Water and Thickened Liquid bolus conditions.

A second mixed two-way ANOVA on duration revealed a significant effect of age group on measures of Duration ($F[1,18] = 4.54$, $p < 0.001$). There was a significant effect on bolus condition on duration ($F[3,54] = 7.225$, $p < 0.001$). In addition, there was a significant interaction effect ($F[3,54] = 3.11$, $p < 0.001$). Post-hoc tests were conducted to investigate the interaction effect. An independent-samples t-test was completed to compare the duration of swallows of four different bolus conditions in older and younger males. Results included the following:

- There was not a significant difference in the duration of swallow for the Water bolus in Younger Males and Older Males ; $t(18) = -.451$, $p > 0.05$.

- There was not a significant difference in the duration of swallow for the Thickened Liquid bolus in Younger Males and Older Males; $t(18) = 1.098$, $p > 0.05$.
- There was a significant difference in the duration of swallow for the Pudding bolus in Younger Males and Older Males; $t(18) = 2.148$, $p < 0.05$.
- There was a significant difference in the duration of swallow for the Cookie bolus in Younger Males and Older Males; $t(18) = 3.263$, $p < 0.05$.

Based on this data it was concluded that liquid bolus consistencies whether thin or nectar thick, did not influence the duration of swallowing as a function of age. However, the duration of swallowing solid bolus consistencies were influenced by age, where older male participants exhibited a significantly longer swallowing duration on both pudding and cookie consistencies compared to younger males.

DISCUSSION

Summary of Findings

The purpose of this study was to determine if healthy older adult males exhibit different swallowing patterns through measures of sEMG amplitude and duration from hyolaryngeal muscle activity when swallowing thin liquids, thick liquids, a pudding bolus, and a cookie bolus. In addition, this study sought to determine if age and bolus consistency effected the amplitude and duration of hyolaryngeal muscle activity. Results from this study included the following: 1) When measuring sEMG amplitude in older participants, bolus consistency significantly influenced measurements, such that as bolus consistency became more solid, the amplitude of sEMG increased. 2) When measuring sEMG duration in older participants, bolus consistency significantly influenced

measurements, such that as bolus consistency became more solid, the duration of sEMG increased. 3) When measuring sEMG duration of males of different ages older males exhibited greater duration of swallow as bolus consistency became more solid.

In a similar study to ours, Im et al. (2012) investigated the effects of bolus consistency, age, and gender in healthy individuals. Temporal measurements of Pharyngeal Transit Duration (PTD) were obtained for 40 randomly selected subjects using Videofluoroscopic Swallowing Examinations (VFSEs). As in our study, Im et al. (2012) found significant differences between the independent variables. For each consistency the younger aged subjects yielded shorter PTDs however, unlike our findings, there was no interaction between age and consistency. While Im et al. (2012) found no interaction between age and consistency, there were significant differences between the actual consistencies (puree, thin, and thick liquids), which we also found in our study. The research done by Im et al. (2012) concluded that PTD differences occur by age, gender, and bolus consistency across healthy populations, similar to our findings, however it should be noted that the gender factor was not considered in our study.

In a study by Logemann et al. (2000) both age and bolus consistency were investigated in relation to the swallowing process. In this study males representing both younger and older age groups were analyzed during swallows. Sixteen subjects of different age groups were analyzed during two swallows one with 1 ml of liquid and the other with 10 ml liquid. Videofluoroscopic studies and biochemical analyses were assessed for each swallow. In addition to these measurements, position of the larynx at rest, length of neck, and pattern of hyoid movement were compared between the two age groups. While this study used different amounts of the same bolus to look at the effects of

consistency on swallowing, it did yield similar results to our findings. The data collected varied between the two age groups. This supported the hypothesis that there is reduced muscular reserve in the swallows of older men compared to younger men. Age effects indicated older men had a shorter C2 to C4 distance compared to that of younger males, as well as a laryngeal position at rest that was lower. The study also found that older men had a significantly longer pharyngeal delay and faster onset of posterior pharyngeal wall movement in regards to the first cricopharyngeal opening. Hyoid movement in older men was found to be significantly reduced, which is similar to the results of our study.

L. van den Engel-Hoek et al. (2012) investigated the influence of substance consistency and saliva on the duration and amplitude on sEMG activity during swallows of seventy-eight healthy children and adults. Both males and females were represented in this sample. Results indicated that the mean duration was significantly shorter for swallowing saliva and significantly longer for swallowing both thick and solid food boluses (L.van den Engel-Hoek et al). In regards to duration, the results of this study reflected that of our data. The results for amplitude of sEMG activity indicated that the mean amplitude value was significantly higher for saliva, thick liquid, and solid food when compared to swallowing water. No statistically significant differences in consistencies and amplitude were found across age groups. These results were similar to what was found in our study. However the study by L. van den Engel-Hoek et al. concluded that factors including bolus consistency are more influential on measures of amplitude and duration during swallowing than age and gender. Our study did find bolus consistency to have influence on measures of amplitude and duration but there were also age group effects found when analyzing the duration of sEMG activity.

A study by Ruark et al. (2002) looked at bolus consistency and swallowing in children and adults. The study found that children produce muscle activity that is shorter in duration during swallowing as compared to adults. Findings from this study also suggested that bolus consistency had an effect on amplitude at the different consistency levels. Similar to our study, it was found that thicker consistencies had higher amplitudes of muscle activity than did water. It should be noted that there were some differences between consistencies that were not considered to be significant. Similar to our study, Ruark et al. (2002) found that average EMG amplitude of muscle activity indicated significant effects in regards to bolus consistency but no other effects e.g., age.

Results from previous studies seem to agree that there is a change in muscle function between older and younger age groups depending on the type of bolus consumed. Our study found that as the bolus consistency became more solid, the duration of the swallow took more time. The findings of this study indicate that as males age the muscles involved in the swallowing process change in a way that effects the duration it takes to swallow more solid bolus consistencies. The significant effects of Amplitude and Duration when swallowing different bolus consistencies in older males was most likely due to increased muscle contraction force when swallowing more solid bolus types. The results from this study add to the current knowledge regarding age and bolus consistency in relation to swallowing, which helps us better understand how these variables effect hyolaryngeal muscle activity in younger and older adult males.

CONCLUSION

This study used Surface Electromyography (sEMG) to noninvasively study the effects of age and bolus consistency on measurements of Amplitude and Duration in relation to hyolaryngeal muscle activity during swallowing. Data was collected from 20 participants, 10 younger males (18-25) and 10 older males (60-90). The study concluded that bolus consistency significantly influenced measurements such that as bolus consistency became more solid, the amplitude and duration in of sEMG increased. This study also found that older males exhibited greater durations during swallows as bolus consistency increased as compared to younger males. No significant effect of age group and amplitude was found.

This study helps us understand how Age and Bolus Consistency effect the Amplitude and Duration of hyolaryngeal muscle activity in young adult males as compared to that of older males.

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