THE EFFECT OF GENDER AND BOLUS TYPE ON MEASUREMENTS OF HYOLARYNGEAL MUSCULAR ACTIVITY

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HYOLARYNGEAL MUSCULAR ACTIVITY

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INTRODUCTION

Swallowing impairments can result from numerous etiologies including stroke, chemoradiation, surgery, and aging. Age-related swallowing impairments are often the result of reduced muscular function secondary to typical aging processes. This reduced function manifests itself in slower transit of food and liquid through the oral cavity, delayed initiation of the swallowing reflex, and a reduction in overall structural movement when the food or liquid travels through the pharynx (Logemann, 2007).

Previous research using videofluoroscopy has found that these reduced structural movements can be measured in reduced velocity and reduced extent of excursion during swallowing. Additionally some authors have found that bolus volume and viscosity can influence the structural movements during swallowing, especially movements of the hyoid bone. However, the literature is not consistent in reporting the degree to which bolus volume and viscosity effect the hyoid movement (Dodds, Man, Cook, Kahrilas et al., 1988; Zu, Yang, Perlman, 2011; Ueda, Nohara, Kotani, Tanaka et al., 2013). Although we do know that aging influences hyoid movement, the degree to which bolus volume and viscosity effects hyoid movement in the elderly compared to young and healthy individuals is not clear.

One way to indirectly measure hyoid activity is through surface electromyography (sEMG). sEMG has been used to measure the Duration and Amplitude of muscle contraction specific to muscles which move the hyoid during swallowing (Crary, Carnaby, Groher, 2006). Few studies have used sEMG to measure muscular activity in young adult and elderly populations in the context of different bolus volumes and viscosity. As aging influences hyolaryngeal muscle activity, we first have to understand how normal patterns of muscle activation occur in young healthy individuals so that any impairments in other populations can be validly interpreted. The purpose of this study will be to investigate the effects of different bolus consistencies on measurements of the Duration and Amplitude of hyolaryngeal muscular activity in young healthy males and females.

Swallowing Physiology

Deglutition, more commonly referred to as swallowing, is defined as the semiautomatic motor action of the muscles of the respiratory and gastrointestinal tracts that propels food or other material from the oral cavity or pharynx into the stomach (Arvedson & Brodsky, 2002). Swallowing is a highly complex process that involves multiple muscles and nerves associated with voluntary and involuntary components of the nervous system. The complexity of the swallowing process is evidenced by a requirement for the coordination of 31 muscles, 6 cranial nerves, and multiple levels of the central nervous system, including the brain stem and cerebral cortex, for normal swallowing to properly function (Arvedson, 2002).

Swallowing can be organized into three phases: The Oral, Pharyngeal, and Esophageal Phase (Matsuo & Palmer, 2008; Ertekin & Aydogdu, 2003). Other schemes separate the oral phase into two distinct phases, the Oral Preparatory and Oral phases, so that swallowing is organized into four phases. In the different phases muscle movement is either voluntary or involuntary. The Oral Preparatory and Oral phase (in time, these are the first and second phases that occur during the process of swallowing) are both under voluntary neural control. The Pharyngeal phase (3rd phase) is under involuntary control as is the esophageal phase (4th phase).

Oral Preparatory Phase

The Oral Preparatory phase is the first phase of the swallowing process and its primary action is to prepare the bolus. The movements that occur during this phase are under voluntary control. The phase first begins with sensory recognition of food or drink approaching the mouth, and then quickly moves to the intake of food or drink into the oral cavity. Once food or drink is placed into the mouth, lip closure is needed in order to maintain food or secretions within the mouth (Arvedson, 2002; Logemann, 1998). While the lips are closed and mastication occurs, an open nasal passage is required in order to breathe (Logemann, 1998). Meanwhile, a cyclical movement of the jaw and tongue moves the food towards the molars to be masticated or chewed. While the food is being prepared, saliva is mixed in with the food to produce and form a bolus, which is a small rounded mass of liquid or chewed food. (Logemann, 1998)

Tongue tip movements after mastication aid the bolus in reaching the tongue holding phase. There are two distinct ways of tongue tip movement during this final portion of the oral preparatory phase: tipper-type holding pattern, which is the dominant pattern for most, and the dipper-type holding pattern (Dodds et al., 1988; Gleeson, 1999; Logemann, 1998). The tipper-type pattern is where the bolus held by the tongue is against the teeth and alveolar ridge (Gleeson, 1999). In the dipper- type pattern the bolus is held cupped in the tongue as it sits near the floor of the mouth (Gleeson, 1999). Each individual has their own preference and variation of tongue movement, however it has been found that most geriatrics gravitate towards the dipper-type swallow (Gleeson, 1999). The bolus is held on the tongue until the oral phase begins. During this process, the soft palate is lowered to the base of the tongue, to seal off the oral cavity from the pharynx (Arevedson, 2002). Slight premature spillage into the pharynx during the Oral Preparatory phase is common (Flint, Haughey, Lund, Niparko et al., 2010), although it is uncommon for premature spillage of food or liquid to occur when the tongue is in the holding position before the initiation of the Oral phase. If premature spillage does occur it has the potential to spill into the airway because the larynx is open when at rest. One result of premature spillage entering the airway is for a person to respond by coughing,

Muscles and Nerves of the Oral Preparatory Phase

The brain stem, which is an essential part of the central nervous system, has shown to be necessary for mastication (Van der Bilt, Engelen, Pereira, van der Glas et al., 2006). The pons and medulla contain the motor cell bodies of essential cranial nerves for the deglutition process (Ertekin, 2003; Plant, 1998). Cranial nerves V (Trigeminal), VII (Facial), and XII (Hypoglossal) are involved in activating the muscles that help oral structures prepare a bolus. The act of lowering the soft palate occurs by contraction or the downward and forward pull of the palatoglossus muscle that is controlled by the Vagus (X) nerve (Arvedson, 2002; Khosh & Krepsi, 1997; Crary & Groher, 2003). A number of jaw (controlled by Trigeminal nerve) and facial muscles (controlled by Facial nerve) are coordinated during the process of bolus formation, including the temporalis, masseter, buccinators, and pteryoid muscles (Khosh, 1997; Crary, 2003; Ertekin, 2003). The Hypoglossal (XII) nerve controls tongue movement during the oral preparatory phase (Khosh, 1997). Meanwhile, a central pattern generator in the brainstem controls the rhythmic movements of opening and closing the jaw muscles for mastication (Logemann, 1998; Van der Bilt, 2006). Production of saliva is administered from the parotid, submandibular, and sublingual glands (Crary, 2003; Arvedson, 2002).

Oral Phase

The Oral Phase is the second voluntary phase of the swallowing process and its primary act is the propulsion of the bolus from the oral cavity into the oropharynx (Gleeson, 1999). The oral phase it takes less than 1.5 seconds to complete in healthy adults (Logemann, 1998; Flint, 2010). Once the bolus is prepared and is resting superiorly on the tongue at the end of the oral preparatory phase, the anterior and lateral sides of the tongue elevate to form a groove, which will act as a chute to help the bolus move posteriorly.

The most essential and critical part of the oral phase is when the tongue propels the bolus posteriorly. The tail end of the bolus is progressively pushed and squeezed along the hard palate to the region of the oropharynx (Flint, 2010; Matsuo, 2008). The oral phase is complete when the dorsum of the tongue reaches its maximum posterior point of excursion and the swallowing reflex is triggered.

Muscles and Nerves of the Oral Phase

Tongue elevation and the propulsion of the bolus to the posterior portion of the tongue are controlled by the extrinsic tongue and suprahyoid muscles which include: the digastric and mylohyoid muscles, activated by the trigeminal (V) nerve, genioglossus muscle, and the geniohyoid muscle, activated by the hypoglossal (XII) nerve (Arvedson, 2002; Crary, 2003; Ertekin, 2003).

Pharyngeal Phase

The Pharyngeal Phase is the third phase of the swallowing process. It is under involuntary neural control. This phase begins when the swallowing reflex is triggered. The swallowing reflex is a patterned muscular response controlled by brainstem structures. The Duration of the swallowing reflex differs in individuals, and a decrease in Duration is seen in the elderly (Gleeson, 1999; Aydogdu, Yuceyar, Kiylioglu, Tarlaci et al., 2007; Plant, 1998). A decrease in Duration of the swallowing reflex can lead to swallowing disorders (dysphagia) where part or all of a bolus enters the airway. Some researchers agree that the swallowing reflex is triggered when the dorsal tongue propels the bolus posteriorly to the posterior pharyngeal wall and reaches its maximum excursion as the head of the bolus passes the anterior faucial arches (Logemann, 1998; Matsuo, 2008); others argue that the swallowing reflex is triggered when the bolus crosses the point where the ramus of the mandible meets the plane of the tongue base (Flint, 2010).

Complex muscular activity is a hallmark of the pharyngeal phase. As the bolus head comes into the pharynx, the soft palate elevates, closing the nasopharynx to prevent material from entering the nasal cavity (Matsuo, 2008) and the larynx closes. Laryngeal closure is essential to prevent material from entering the airway. Muscular events occur in a unique order to facilitate successful laryngeal closure (Arvedson, 2002). True vocal fold adduction occurs first. As the vocal folds are closing the tongue base moves posteriorly to aid in closure of the laryngeal vestibule by facilitating inversion of the epiglottis. As the laryngeal vestibule closes, a downward, forward, inward rocking motion of the arytenoids results in their touching the base of the epiglottis in a vertical position (Arvedson, 2002; Logemann, 1998). The larynx will also elevate due to its connection to the hyoid bone (Crary, 2003), which pulls the larynx away from the bolus and also facilitates epiglottic inversion.

Once the bolus is in the pharynx, wave-like muscle contractions called peristalsis begin from superior to inferior on the pharyngeal wall to aid the progression of the bolus downward into the esophagus (Ertekin, 2003). As the upper esophageal sphincter (UES) opens, the bolus will pass into the esophagus which begins the esophageal phase of the swallow.

Muscles and Nerves of the Pharyngeal Phase

The pharyngeal phase is involuntary and it is controlled by the lower portion of the brainstem (medulla) in the reticular formation (Flint, 2010; Khosh, 1997) Sensory receptors in the posterior portion of the oropharynx send messages into the brainstem when they are stimulated by a bolus. A central pattern generator in the brainstem activates the multiple cranial nerves responsible for muscular activity during the swallowing reflex, including the V, VII, IX, X, and XII nerves (Crary, 2003; Ertekin, 2003). These cranial nerves innervate multiple muscles in the pharynx, larynx, and upper esophagus during the pharyngeal phase.

Esophageal Phase

Once the bolus enters the UES the esophageal phase has begun. The esophageal phase is under involuntary neural control. This phase is initiated when relaxation of the UES sphincter occurs and the bolus proceeds down the esophageal tube. There are three factors that aid in abducting the UES, which include: 1) hyolaryngeal elevation produces a traction pulling force on the UES to aid in pulling it open, 2) the force of the bolus superior to the opening of the UES helps to force the UES open, and 3) the central nervous system sends signals of relaxation to the UES to aid in the bolus progressing down into the esophagus tube (Khosh, 1997). The progression of the bolus into the esophagus tube and into the stomach is controlled by an automatic peristaltic wave (Arvedson, 2002). The peristaltic wave, which starts at the top of the esophagus, aids in pushing the bolus down the esophageal tube until the lower esophageal sphincter (LES), also known as the gastroesophageal juncture, opens up and allows the bolus to enter the stomach. The process can last up to 8 seconds.

Muscles and Nerves of the Esophageal Phase

The IX (Glossopharyngeal) and X (Vagus) cranial nerves assist in mediating the muscle tone of the UES through central nervous system control (Crary, 2003). The esophageal peristaltic wave begins in the upper third of the esophagus. This peristaltic wave is controlled by the Vagus (X) cranial nerve (Crary, 2003).

Laryngeal Elevators

The larynx is suspended from the hyoid bone (Logemann, 1998). The hyoid bone is the small bone just inferior to the tongue base and is suspended from muscles above (superiorly) and below (inferiorly) (Som & Curtain, 2011). The superior muscles aid in elevation of the larynx and include the geniohyoid muscle, mylohyoid muscle, stylohyoid muscle, and digastric muscles (Crary, 2003). The geniohyoid, mylohyoid, and anterior portion of the digastric move the larynx up (superiorly) and away (forward) from the bolus during the pharyngeal stage of the swallow. This results in hyoid and laryngeal excursion, which produces a traction pulling force to facilitate opening of the UES.

Effects of Aging on Swallowing

An impairment in swallowing in any of the four stages is referred to as dysphagia. Dysphagia can be caused by neurological injuries or structural abnormalities, among other conditions. In healthy young adults the phases of swallowing occur as described above. However, as humans age, a number of physiological changes occur which can effect swallowing. Muscle mass and connective tissue elasticity is reduced caused by natural age-related changes. This can cause loss of strength in the muscles and reduced speed (velocity) of movement (Crary, 2003). The speed of swallowing alone can distinguish between an old and young person (Crary, 2003). The Duration of the swallow gradually slows after age 45, and by 70 years of age the swallowing process is significantly slower in time than in individuals under 45 years of age (Robbins, Hamilton, Lof, Kempster, 1992; Aydogdu et al., 2007; Gleeson, 1999). Data on speed of swallowing in healthy young adults have come from measurements obtained from visual measurements of videoflouroscopic studies. Limited information on speed of swallowing obtained from sEMG measurements is available from the literature.

An increased (slower) Duration of swallowing can be attributed to two factors: 1) increase threshold and delay in the triggering of the swallowing and 2) prolongation of the muscular movements which during the swallowing reflex (Aydogdu et al., 2007). In the oral stage, according to studies by Shaw et al. (1990), older individuals had a significant increase in Duration during oral transit when tested with liquid barium compared to younger individuals. Several studies confirm that the Duration of the oral stage is slightly longer (slower) in older individuals because the triggering of the pharyngeal swallow is prolonged (Aydogdu et al., 2007; Crary et al., 2003; Gleeson, 1999; & Logemann, 1998).

Muscles that effect hyolaryngeal excursion can especially be affected by age. Sonies et al. (1988) reported that 80% of 19 subjects in an older age group required double or triple hyoid gestures to complete the swallow in comparison to 0% in the middle-age group. In addition, the total time of hyoid activity during dry and wet swallows increased significantly with age (Sonies, Parent, Morrish, Baum, 1988;

Gleeson, 1999). Logemann, Pauloski, Rademaker, and Kahrilas (1996) performed a study which found that after cricopharyngeal opening was attained, hyoid and laryngeal elevation continued in the young men but remained static in the elderly men. The authors suggested these finding were due to elderly men having less muscular "reserve" compared to younger men (Crary et al., 2003).

Hyolaryngeal Activity Measured

Several different methods of measuring hyolaryngeal muscle activity or movement have been used. These different methods include Manofluroscopy, mfMRI, and Surface Electromyography (sEMG). The primary use for Surface Electromyography (sEMG) is as follows: 1) to determine and recognize the presence of swallowing activity, 2) to examine the function of swallowing (Duration and Amplitude) and 3) to provide insight and feedback for ways to treat swallowing disorders (Crary et al., 2006). sEMG is known to be a highly reliable measure of muscles activity that exhibits greater stability across repetitions and testing data and provides valuable information on the muscle activity level (Vaiman et al., 2004). The sEMG, although it does not provide information on specific muscle activity, it is a safe non-invasive way to measure hyolaryngeal muscle activity (Crary et al., 2006; Pearson, Hindson, Langmore, Zumwalt, 2012). Because the sEMG measures large groups of muscle fibers, it is easier to repeat findings (Vaiman, Eviatar, Segal, 2004). Therefore, Surface Electromyography is more valid than the needle EMG because it can assess whole muscle function (Vaiman et al., 2004).

It has been logically concluded that the muscles which move the hyoid bone are most closely linked to the sEMG signal because these muscles are closer to the surface of the skin resulting in an easier measurement from the surface electrodes (Crary et al., 2006). In past studies the sEMG method has been used to measure the hyolaryngeal activity in microvolts by placing electrode sensors on the skin above the mylohyoid, geniohyoid, and digastric muscles (Pearson et al., 2012; Watts, 2013). Crary et al. (2006) found that the mylohyoid, geniohyoid, and anterior digastric muscles provide the most information to the sEMG signal during swallowing. As the laryngeal elevators contract, the surface electrodes detect electrical activity in the muscles, which can provide information about the strength (Amplitude) and Duration of muscular activity. These factors can be altered depending on the volume of the bolus (Crary et al., 2006).

The National Dysphagia Diet

When the muscular actions of swallowing are impaired due to neurological or structural injury (i.e., due to stroke, neurological disease, aging, or surgery), the ability to safely swallow can be compromised due to dysphagia. The National Dysphagia Diet (NDD) was developed in an attempt to standardize diet modification for individuals with dysphagia. A team of registered dietitian's (RD's), SLPs, and food scientists developed the NDD and published it in 2002 through the American Dietetic Association (McCullough, Pelletier, Steele, 2003; McCallum, 2003). The diet is organized into four different levels (McCullough et al., 2003). The levels correspond with a patient's individual needs. Lower levels of the NDD (1 & 2) indicate more severe dysphagia cases and NDD higher levels (3 & 4) indicate almost normal-normal capability of swallowing. NDD level 1 (Dysphagia-Pureed) is pudding- like consistency that is cohesive and requires minimal chewing (McCullough et al., 2003). Food such as, moistened bread, fresh mashed bananas, pureed meat, mashed potatoes, smooth pudding, etc., along with beverages without pulp or seeds are recommended in this level (National Dysphagia Diet

2002). NDD level 2 (Dysphagia- Mechanically Altered), consists of foods that are soft, moist, tender, ground, diced, can easily form into a bolus, and can easily be chewed (McCallum, 2003; McCullough et al., 2003). Appropriate food for the NDD level 2 diet includes soft and moistened bread, meat, potatoes, vegetables and cereals. NDD level 3 (Dysphagia-Advanced Diet) is for patients whose chewing ability is almost normal; therefore, level 3 recommends moistened almost normal textured food and no sticky, crunchy, or very hard foods. Food such as meat, vegetables, and fruit needs to be sliced and cut up into smaller bits for easier chewing are recommended in this level (McCullough et al., 2003; National Dysphagia Diet Task Force, 2002). It is recommended that NDD levels 1-3 avoid dry and hard foods. Dependent on the patient, soups or beverages may need to be thickened at any level (except NDD 4) (McCullough et al., 2003; National Dysphagia Diet Task Force, 2002). NDD level 4 (Normal), allows all types of textured foods (Mcallum, 2003; McCullough et al., 2003). Variations of liquid consistencies, based on viscosity, in the NDD include: Spoon thick liquid (which is the thickest at >17.5 g/cm-s), Honey thick liquid (3.51-17.5 g/cm-s), Nectar thick liquid (0.51-3.50 g/cm-s), and Thin liquid (the thinnest at 0.01-0.5 g/cm-s) (McCullough 2003).

Effects of Bolus Volume and Viscosity on Hyoid Movement

The hyoid bone is a freestanding bone that relies on the movement of surrounding muscles and structures for its position and support (Zu et al., 2011). The hyoid bone's movement is considered to play a critical function in swallowing (Ueda et al., 2013). Airway safety during swallowing can be compromised if the hyoid bone does not move anteriorly and superiorly enough. The movements of the hyoid are influenced by muscles attached to structures above the hyoid and the hyoid itself- they hyolaryngeal elevator muscles, which include the geniohyoid, mylohyoid, and anterior digastric. Contraction of these muscles results in elevating the larynx, which protects the airway by moving the larynx away from the bolus and opens the upper esophageal sphincter for bolus passage (Ueda et al., 2013). However, aging can negatively affect the function of these muscles and put an individual at risk for dysphagia.

One effect of aging on the hyolaryngeal elevator muscles is a reduced velocity of movement in the anterior and superior excursion of the hyoid (Ueda et al., 2013). The risk of aspiration increases in dysphagic and elderly individuals when the velocity of contractions within in the suprahyoid muscles decrease, creating a reduction in hyoid movement speed. The bolus volume can also influence the velocity of movement where larger volumes result in decreased velocity (Ueda et al., 2013).

Dodds et al. (1988) found that there was a significant direct correlation between the volume of the bolus and the magnitude of anterior and superior movements of the hyoid. When individual were presented with bolus volumes between 2-10 ml, they only needed one swallow to clear the bolus. However, when the bolus volume increased to more than 10 ml, secondary swallows were needed (Zu et al., 2011), and the anterior and superior movements were found to increase (Dodds et al., 1988) in these contexts. Contrary to what Dodds et al. (1988) found, Zu et al. (2011) and Ueda et al. (2013) concluded from their results that bolus volume had little to no effect on the extent of hyoid movement (Ueda et al., 2013). These authors utilized different reference points to measure the distance of movement, which could contribute to why there are different outcomes for the studies (Ueda et al., 2013; Zu et al., 2011). Because of this discrepancy in the literature, it is difficult to determine the extent to which bolus volume influences the muscles which influence hyoid movement. It is possible that application of sEMG measurements to swallowing different bolus sizes and viscosities could shed light on this discrepancy.

Ueda et al. (2013) did find that hyoid movement velocity was influenced by bolus volume. Their results indicated that an increase of velocity in hyoid movement occurred with larger bolus volumes in healthy adults. However, it has not been determined if this is the same case with elderly individuals. A study by Vaiman et al. (2004) confirms that a significant increase in swallowing Duration did not occur in any age group except in the elderly (70 +). It can be inferred that when the bolus volume increases the hyoid muscles must contract at a faster rate (Ueda et al., 2013). Therefore, if the suprahyoid muscles must contract at a faster rate and it is already known that muscle strength and speed decrease as adults age, we can postulate that this reflects why elderly individuals are able to swallow a small bolus without issues, but have difficulty swallowing a large bolus (Ueda et al., 2013).

Swallowing complications such as aspiration can arise and result from post-surgery and radiation to the neck. Radiation to the neck can produce a plethora of issues concerning successful swallowing function due to the effect of radiation on muscle tissue. Impairments can include reduced tongue-base contraction, decreased laryngeal elevation, and reduced anterior hyoid movement (Zu et al., 2011). Results of Zu et al.'s (2011) study showed that males post-radiation experienced a significant decrease in the superior movement of the hyoid bone no matter how viscous (thick) or voluminous (big) the bolus was (Zu et al., 2011). The study compared individuals who had surgery to normal swallowing controls and found significant differences on both anterior and superior hyoid displacement (Zu et al., 2011).

When looking at bolus volume vs. bolus viscosity affecting hyoid movement, increased bolus viscosity has been found to increase hyoid movement both anteriorly and superiorly (Zu et al., 2011). This study, unlike Dodds et al.'s (1988) study, did not show a significant difference in hyoid movement from 5 mL to 10 mL liquid boluses (Zu et al., 2011). It can be concluded from this study that liquid viscosity plays a role in hyoid movement and can result in aspiration if the individual has decreased muscle mass or strength. The degree to which viscosity and volume influences hyolaryngeal muscle activity in aging, however, is less clear.

In order to fully begin to understand the degree to which bolus characteristics influence hyolaryngeal muscle activity in the elderly, we first need to understand how these factors effect the Duration and Amplitude of hyolaryngeal muscle activity in young healthy males and females. When evaluating gender and its effects on muscle activity and hyoid movement, Vaiman et al. (2004) found no significant difference in muscle activity Duration amongst men and women. Another study performed by Van den Engel-Hoek, Groot, Esser, Gorissen et al. (2010) looked at the effects of swallowing thin liquid and saliva on Duration and Amplitude and found no significant difference in men and women younger than 70 years of age. However, Duration and Amplitude were found to increase with thicker consistency foods (Van den Engel-Hoek, Groot, Esser, Gorissen et al., 2010).

PURPOSE

Further investigation is needed to determine the extent to which hyoid excursion is effected by bolus characteristics. Therefore, the effects of bolus consistency, based on the National Dysphagia Diet scheme, on hyolaryngeal muscular Duration and Amplitude will be investigated. Additionally, the effects of gender on measurements of Duration and Amplitude of hyolaryngeal muscular activity in young healthy males and females will be investigated. We will evaluate two different questions within this study, which include, 1) Does bolus consistency affect measures of hyolaryngeal muscular Duration and Amplitude and 2) Does gender effect the Duration and Amplitude of hyolarygneal muscular activity differently? Due to information gathered from previous studies, we hypothesize that bolus consistency will have a significant effect on measures of Duration and Amplitude, but gender will not have an effect on those measures.

METHODOLOGY

Participants

Participants in this study were young healthy males and females between the ages of 18-25. Demographic information for each participant is shown in Table 1. Participants were recruited via a convenient sample from the student body of Texas Christian University. 10 males and 10 females were recruited based on the following inclusion criteria:

- Male or female between 18-25
- 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

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

Participant	Gender	Age	Participant	Gender	Age
1	F	21	11	M	22
2	F	22	12	M	23
3	F	21	13	M	21
4	F	22	14	M	22
5	F	21	15	M	21
6	F	22	16	M	22
7	F	22	17	M	21
8	F	22	18	M	21
9	F	23	19	M	21
10	F	22	20	M	19
Mean Age =		21.8	**Mean Age** =		21.3
Standard Deviation =		0.63	**Standard Deviation** =		1.06

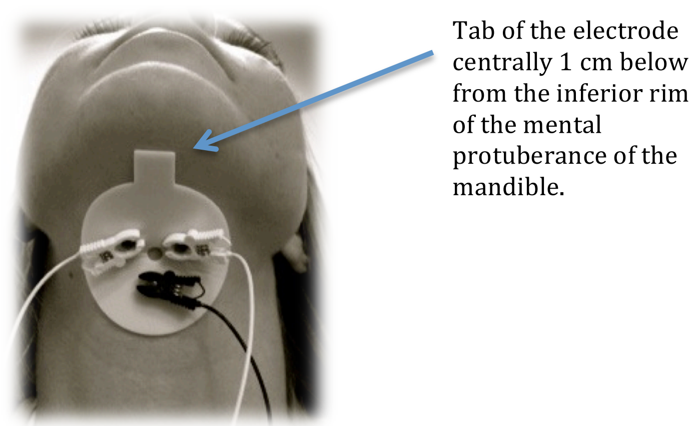
Equipment

The dependent variables for this study consisted of Amplitude and Duration measurements obtained from sEMG signals. To acquire sEMG signals we used components of the Swallowing Signals Lab workstation model (Kaypentax, Montvale, NJ), set up in a similar method as Crary, Carnaby, and Groher (2006). This included disposable self- adhesive electrode patches, which were approximately 2.25 in. in diameter. 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.

Procedure

All participants were asked a set of questions regarding inclusion criteria and provided informed consent prior to participation in the study. Once consent was obtained, participants were recorded in the vocal function laboratory in the Miller Speech and Hearing Clinic on the campus of Texas Christian University. Participants underwent one recording session during which all measurements were obtained. After consenting procedures, electrodes were applied to the surface of the skin beneath the mandible. 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 coated with a light film of electrode gel (Signa gel, Parker Laboratories, Fairfield, NJ) to improve signal conduction. The tab of each electrode patch was placed centrally 1 cm below the inferior rim of the mental protuberance of the mandible. This placement ensured that electrodes were over the laryngeal elevator muscles, as shown in Figure 1. Electrode cables from the Swallowing Signals Lab were then attached to the electrode patch.

Figure 1. Surface EMG electrode placement.



Participants were recorded swallowing different bolus stimuli multiple times. Based on the National Dysphagia Diet, specific foods with different textures were assigned and given to each participant from levels 1 and 3. Among the food samples there were 2 tsp. of pudding for level 1, and one (0.25oz) Lorna Doone Cookie for level 3. Each bolus was swallowed on five separate trials. After manipulation in the oral cavity, the participants were instructed to hold the bolus in the mouth and remain still until told to swallow. This allowed recording of a baseline sEMG signal phase and then a swallow sEMG signal phase, followed by a return to baseline. Additionally, nectar-thick and thin consistency liquid stimuli were provided. The thick liquid provided to the participant consisted of 15oz of THICK & EASY ® Thickened HYDROLYTE ® Lemon Water (Hormel Health Labs) pre-thickened nectar-thick beverage. The thin liquid consisted of 15oz of bottled water. Each liquid consistency was measured into the 15ml volumes and placed in a Dixie cup. The participants were instructed to hold the liquid in their mouth and remain still until cued to swallow. Participants swallowed each liquid bolus five times.

To control for bolus order effects, the presentation of bolus types was counterbalanced across all participants. 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 Level 1 food, 5 swallows of Level 3 food, 5 swallows of Nectar-thick liquid at 15ml, 5 swallows of Thin liquid at 15ml). To analyze recorded sEMG signals, files were opened and measured using the KayPentax Swallowing Signals Lab software.

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. This measurement is 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 time between the initiation (rise from baseline) of the sEMG swallow signal and the termination (return to baseline) of the sEMG swallow signal 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 swallow. This resulted in a total of 20 measurements from each participant for Amplitude and 20 each for Duration, and 800 measurements total (400 for Amplitude and 400 for time). The dependent variables for this study are summarized in Table 2 below:

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

Dependent Variable	**Level 1Food Pudding**	**Level 3 Food Cookie**	**Liquid Nectar-Thick 15ml**	**Liquid Thin 15ml**
Amplitude	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100
Duration	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100	20 subjects 5 swallows n = 100

Inter-measurer reliability was calculated by randomly selecting 10% of the recorded files (40) and recalculating Amplitude and Duration measures. These were then applied to a Pearson product-moment correlation analysis to assess the degree of relationship between the initial and second measures.

For each participant, measurements of Amplitude and Duration were averaged in each bolus condition, so that one data point represented one participant's Amplitude and Duration sEMG average. Because sEMG data is known to vary greatly from individual to individual, the data were normalized to allow for statistical analyses following the methodology of Ruark et al. (2002). The Duration and Amplitude of each participant's water bolus swallows were converted to 100% (representing baseline). Mean Duration and Amplitude measures from the subsequent bolus conditions were then transformed to a percentage of that baseline. These measures then reflected the degree of change from baseline, which has been argued to be a more clinically relevant measure compared to raw sEMG data. A series of mixed two-way ANOVA's were then applied to the data, with gender as a between-subject variable and bolus type as a within-subject variable. The level of significance was set at alpha = 0.05 for each test. Follow-up Pairwise comparisons were then applied to the data to investigate significant main effects.

RESULTS

Reliability

10% of the signal files were randomly selected and re-measured for each dependent variable (Amplitude & Duration). A Pearson-product moment correlation was applied to the 1st and 2nd measurements of each variable. Results revealed a significant and strong correlation between the 1st and 2nd Amplitude measures (Pearson $r = 0.997$, $p < 0.001$).

The relationship between the Duration measures was not as large but was significant and strong (Pearson r = 0.736, $p < 0.001$). These results were interpreted as the measurements for Amplitude and Duration collected in this study being reliable.

Table 3 displays means and standard deviations (for raw data) of the dependent variables for each gender group across the four bolus conditions. Trends in the data indicated that males consistently had lower Amplitudes than females, regardless of condition. Additionally, the descriptive data indicated that males exhibited shorter Duration swallows across the bolus conditions.

Table 3. Descriptive data for each gender group (male, female) in each of the bolus conditions (water, nectar, pudding, and cookie).

Group	Condition	Amplitude (*m*V)	Duration (seconds)
Male	Water	69.20 (66.81)	1.00 (.28)
Female		73.30 (50.21)	1.14 (.35)
Male	Nectar	69.11 (75.13)	1.01 (.20)
Female		83.16 (43.34)	1.25 (.30)
Male	Pudding	80.82 (73.50)	1.00 (.16)
Female		87.33 (51.15)	1.22 (.31)
Male	Cookie	115.90 (96.93)	1.08 (.19)
Female		117.44 (54.30)	1.24 (.24)

Figure 2 shows a box and whisker plot illustrating the data for Amplitude as a function of gender. The graphical pattern indicated that gender did not affect Amplitude to a large extent. It appears the females did exhibit overall higher Amplitude, as indicated by the median within the box. However, the wide range of variability within the female group was large compared to that of the males.

Figure 2.

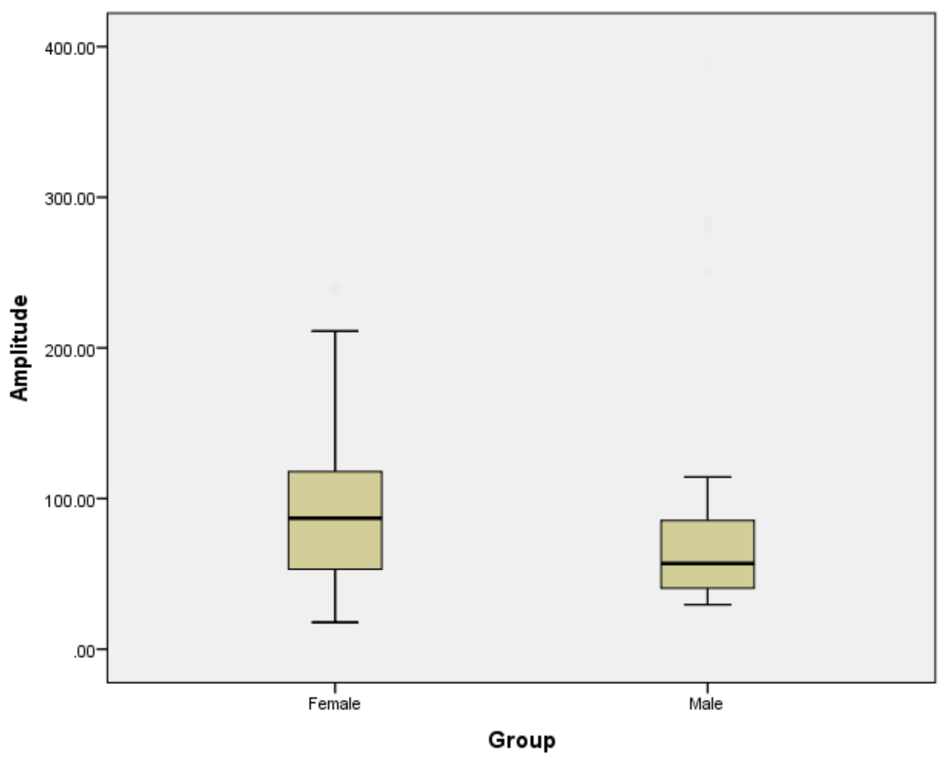


Figure 3 illustrates the data for Duration as a function of gender. The graphical pattern indicated that females exhibited longer Duration swallows compared to the males, as indicated by the median values. However, as with Amplitude measures, the females exhibited a large degree of variability compared to the males.

Figure 3.

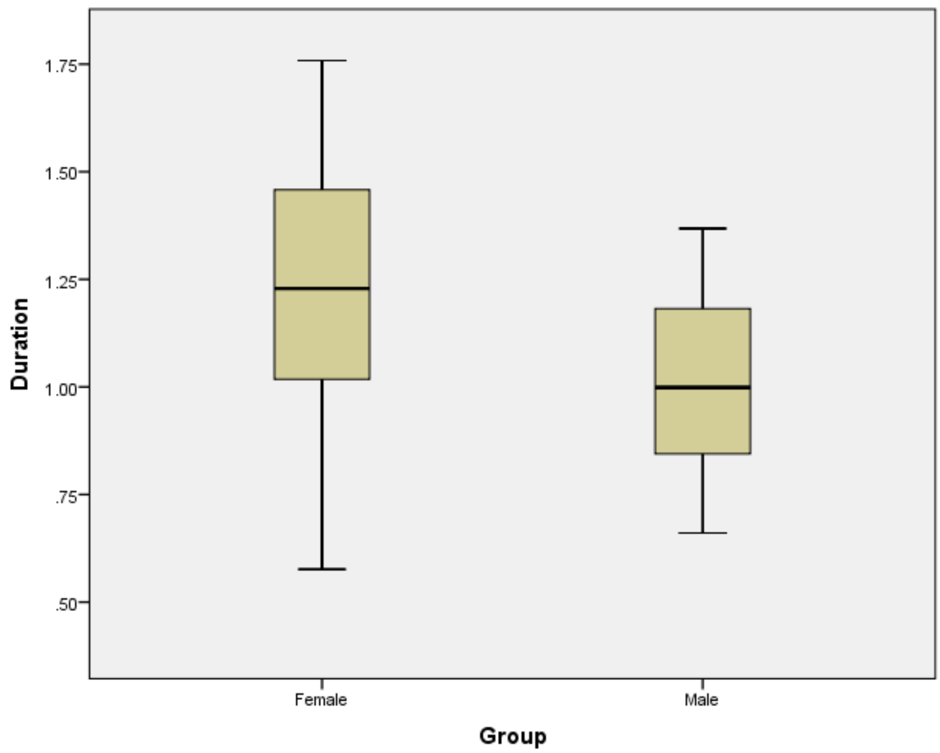


Figure 4 illustrates the data for Amplitude across the four bolus conditions, with data collapsed across gender. Measurements across the four conditions indicated that the consistency of the bolus seemed to affect Amplitude. The graphical pattern suggested that measures of Amplitude for cookie were higher than those of the pudding, water, and nectar bolus conditions. In addition, the pudding bolus had higher Amplitude than that of the water and nectar, while the water and nectar were at an equal level of Amplitude. This data suggested that a thicker or more solid bolus consistency required more activity and muscle contraction to properly swallow, making the Amplitude of the swallow greater due to stronger muscular contractions needed to swallow thicker or more solid foods.

Figure 4.

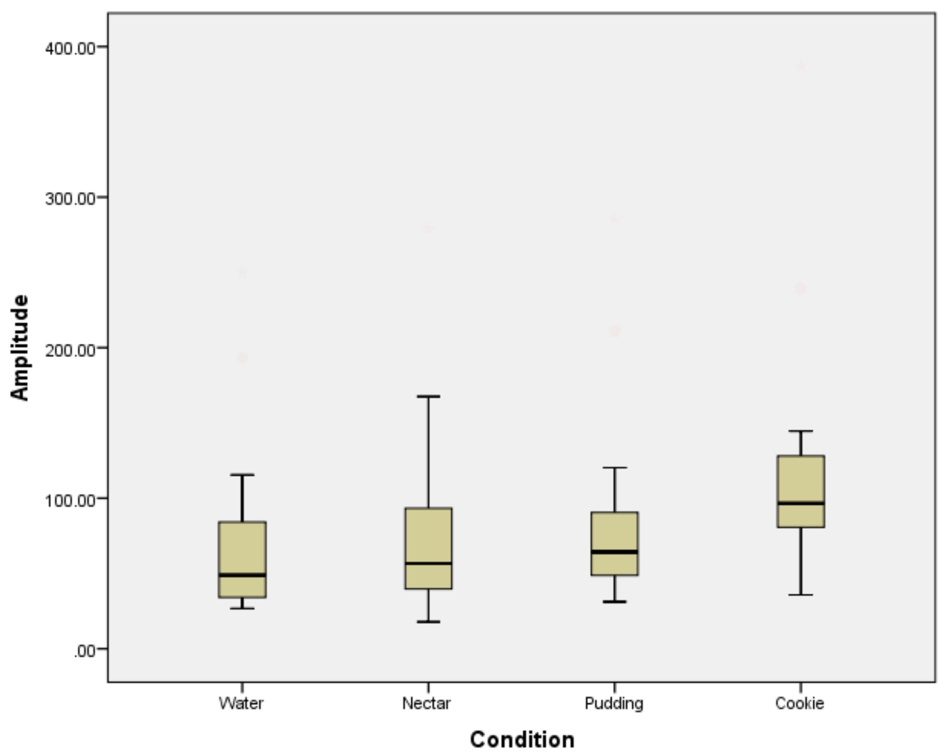
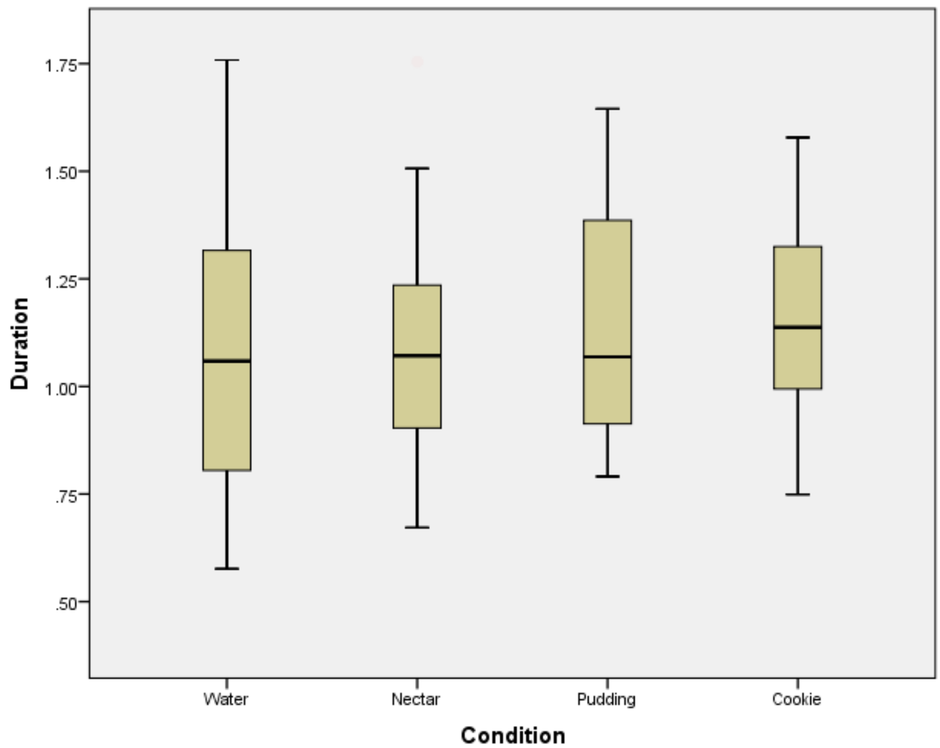


Figure 5 illustrates the data for Duration across the four bolus conditions, with data collapsed across gender. Descriptive data revealed that the consistency of the bolus did not appear to have a large effect on swallow Duration. The median range for each bolus condition was almost level with each other. Because of the wide range of variability with each bolus condition, there was not one condition where Duration was much greater than another.

Figure 5.



Initial statistical analyses using separate two-way mixed ANOVA's (gender group x bolus condition) were applied to the normalized Amplitude and Duration data, respectively. The first ANOVA revealed no significant effect of gender on measures of Amplitude ($F[1,18] = 0.78$, $p > 0.05$), but a significant effect of bolus on Amplitude ($F[3,54] = 29.13$, $p < .001$). There was no significant Gender x Condition interaction effect ($F[3,54] = 0.82$, $p > 0.05$). Follow-up pairwise comparisons revealed the following significant differences, all at the $p < 0.05$ level:

- Cookie > Water, Nectar, Pudding
- Pudding > Water, Nectar

These data were interpreted as Amplitude in the cookie bolus condition being significantly greater than all other bolus conditions, and Amplitude in the Pudding bolus condition significantly greater than the Water and Nectar bolus conditions.

The second ANOVA revealed no significant effect of gender on measures of Duration ($F[1,18] = 0.316$, $p > 0.05$), no significant effect on bolus condition ($F[3,54] = 2.86$, $p > 0.05$) and no significant interaction effect ($F[3,54] = 0.19$, $p > 0.05$). These results were interpreted as the Duration of swallow not being affected by gender or bolus condition.

DISCUSSION

Summary of Findings

The purpose of this study was to measure the effects of gender and bolus type on Duration and Amplitude in young healthy adults. We first needed to understand how these factors effect the Duration and Amplitude of hyolaryngeal muscle activity in young healthy males and females in order to fully begin to understand the degree to which bolus characteristics influence hyolaryngeal muscle activity in the elderly. The following results were found: 1) Gender had no significant effect on Duration and Amplitude, 2) Bolus type had no significant effect of Duration, but had a significant effect on Amplitude, and 3) There was no Gender X Condition interaction effect on Duration or Amplitude.

A study similar to ours by Im, Kim, Oommen, Hawn Ko et al. (2011) examined Pharyngeal Transit Duration (PTD) in young and older adults with normal functioning swallows. They investigated different bolus consistencies using water, thick liquid, and puree among different age and gender groups through analysis of the Videofluorscopic Swallowing Examination (VSFE). Each subject (40 subjects) was given 2 swallows of the water, thick liquid, and puree, a total of 6 swallows at 5 ml each. Their results showed that the PTD was shorter in males than in females. This could have been because males tend to utilize more muscles when pushing the bolus toward the esophagus than the females do (Im, Kim, Oommen, Hawn Ko et al., 2011). Contrary to their study our results suggest that gender does not influence how fast an individual swallows a bolus or how strongly the hyolaryngeal muscles contract when swallowing. A number of plausible reasons may explain this finding. One possibility is that wide variation exists across both males and females with regards to swallowing physiology, which would average out individual differences in swallowing Duration or Amplitude. This is supported by the large amount of variability in the data both within and between groups, but especially for females. Another possibility is that the sample size utilized in this study was not large enough to find a difference that actually exists between the genders. Figures 2 and 3 do show the same pattern, where females swallowed for longer Durations and with greater

Amplitudes than males. Future studies with large sample sizes will be needed to determine if this effect actually does exist. In the present study, that data revealed that gender did not have a significant effect on Duration and Amplitude.

The results also suggest that bolus consistency does not have an effect on the Duration of an individual's swallow. It became apparent throughout the study when looking at each participant's separate measurements that individuals exhibited a consistent Duration for each bolus trial in the different bolus conditions. That is, across swallows #1 through #5 in with any bolus consistency, individual participants were quite reliable in their Duration measures. As stated before, each individual is physiologically different, meaning each person's muscles work a little bit differently to complete the same task. One possibility for the current findings is that each participant manifested a similar muscular timing pattern once the swallow reflex was initiated. This could have resulted in the timing of the swallow not being dependent on the consistency or size of the bolus.

Our study confirms previous research by Viamen et al. (2004) and van den Engel-Hoek et al. (2012), which found no statistically significant difference between genders for Duration of muscle activity during a single swallow. On the contrary to our study, van den Engel-Hoek et al. (2012) and Im et al. (2011) inferred that the mean Duration was significantly different for varied bolus consistencies. However, van den Engel-Hoek et al.'s (2012) their study included swallowing saliva as opposed to the current study. Im et al.'s (2011) study concluded that thin and thick liquids had a shorter Duration than the puree consistency. These differences in bolus consistencies might explain the divergent findings across studies.

Our study does confirm findings of van den Engel-Hoek et al. (2012) study and Dodds et al. (1988) with regards to swallow Amplitude, which was significantly different for varied bolus consistencies in both studies. Consistent with our findings, van den Engel-Hoek et al. (2012) inferred that the solid food (in our case, the pudding and cookies) required greater muscular contraction (as measured via signal Amplitude) than the water (van den Engel-Hoek et al., 2012). On the contrary, their study found that swallow Amplitude of thick liquid was significantly greater than water, where as we found there to be no significant difference in Amplitude between the water (15 ml) and nectar thick liquid (15 ml). The Dodds et al. (1988) study found a direct positive correlation between the volume of the bolus and an increase in Amplitude, which would be consistent with findings from our study. However, other studies have also produced contrary results. For example, Zu et al. (2011) and Ueda et al. (2013) found that bolus consistency had little to no effect on the swallow Amplitude.

CONCLUSION

By using Surface Electromyography (sEMG) we were allowed to noninvasively study the Duration and Amplitude of 20 participant's swallows (10 female & 10 male). This study concluded Gender had no effect on Duration and Amplitude in young healthy adults (ages 18-25), and Gender X Bolus Condition had no effect on Duration and Amplitude as well. Meanwhile, different Bolus Types had no effect on Duration, but had a significant effect on swallow Amplitude. The significant effect on Amplitude from different bolus types most likely resulted from individuals utilizing more muscles for the more solid foods, resulting in production of a stronger swallow.

This study helps us to better understand how Gender and Bolus Types effect the Duration and Amplitude of hyolaryngeal muscle activity in young healthy males and females. The next step is to find out the normal ranges of swallow Duration and Amplitude in the elderly in order to fully begin to understand what is considered a disordered swallow.

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ABSTRACT

Objective: To measure the effect of Gender and Bolus Condition on Hyolaryngeal Muscular Activity in young healthy adults (ages 18-25) using Surface Electromyography (sEMG).

Method: 20 young healthy adult participants (10 male & 10 female) between the ages of 18-25 were recruited for this study. Dependent variables consisted of Amplitude and Duration measurements obtained from sEMG signals. sEMG signals were acquired using the Swallowing Signals Lab workstation model (Kaypentax, Montvale, NJ), set up in a similar method as Crary, Carnaby, and Groher (2006). Disposable self-adhesive electrode patches that consisted of three electrodes were placed 1 cm below the inferior rim of the mental protuberance of the mandible. This placement ensured that electrodes were over the laryngeal elevator muscles. Participants swallowed each bolus consistency (based on the National Dysphagia Diet levels 1 & 3) five times.

Results: This study found Gender had no effect on Duration and Amplitude in young healthy adults (ages 18-25), and Gender X Bolus Condition had no effect on Duration and Amplitude as well. Different bolus Consistencies did effect swallow Amplitude, but not Duration of the swallow.

Conclusions: The significant effect on Amplitude from different bolus types most likely resulted from individuals utilizing greater muscular contraction force when swallowing solid foods. This study adds to the current knowledge base and helps us to better understand how Gender and Bolus Types influence the Duration and Amplitude of hyolaryngeal muscle activity in young healthy males and females.