ABSTRACT

DURATION AND DISTANCE OF HYOID BONE MOVEMENT AS OBSERVED BY ULTRASOUND: THE INFLUENCES OF FLAVOR AND NECTAR-THICK CONSISTENCY

by Briana Christine Corcoran

The purpose of this study was to establish parameters regarding the total distance and duration of hyoid bone displacement during water and sour boluses of regular and nectar-thick consistencies among young and older adults. Distance and duration parameters for hyoid bone displacement in adults will assist in safe and accurate diagnoses of dysphagia. Thirty-two young adults and five older adults were assessed via an ultrasonic procedure. Following the capture of a swallow, hyoid bone measurements and durations were obtained through frame-by-frame analysis. Results indicated that aging did not significantly affect the distance of hyoid bone movement when participants were presented with water, nectar-thick water, cranberry juice, and nectar thick-cranberry juice. Further analysis indicated that mean hyoid bone movement for the water condition was longer than the mean movement of all other conditions. Any change observed in duration of hyoid bone displacement was determined to be insignificant across all conditions.
DURATION AND DISTANCE OF HYOID BONE MOVEMENT AS OBSERVED BY ULTRASOUND: THE INFLUENCES OF FLAVOR AND NECTAR-THICK CONSISTENCY

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DURATION AND DISTANCE OF HYOID BONE MOVEMENT AS OBSERVED BY
ULTRASOUND: THE INFLUENCES OF FLAVOR AND NECTAR-THICK CONSISTENCY

Chapter I: Introduction

Introduction

Ultrasound is real-time instrumental assessment of swallowing that produces images of structures in the body by propagation of sound energy through fluid or semi fluid matter such as blood and tissues (American Registry for Diagnostic Sonography, 2007; Chi-Fishman, 2005; Sonies & Dalakas, 1991). The majority of ultrasound machines are portable and only consist of a transducer, a computer, a display, and an image-capturing device. The transducer produces bursts of high-frequency sound waves by means of piezoelectric crystals. When an electric current is sent through the crystals, the crystals resonate at their fundamental frequency. The frequencies of transducer-produced sound waves are not audible by the human ear and typically range between 2 and 10 MHz (Arvedson & Brodsky, 2002). Transmission gel is placed on the head of the transducer, which is then placed on the skin within appropriate proximity of the structure to be viewed, creating a no-air contact with the skin. The high frequency sound wave transmits into the body and reverberates off of the internal structures, creating a video display (Bressmann, Heng, & Irish, 2005; Brown & Sonies, 1997; Piezoelectric transducers, n. d.). The transducer repeats the send/receive signal pattern several hundred times a second, generating a real-time 2-dimensional image (Bressmann et al.; Yang, Loveday, Metreweli, & Sullivan, 1997). Specific frequencies are preselected with the purpose of attaining the best compromise between spatial resolution and depth of penetration (Humphry & Duck, 1998). The reverberations of the original signal are recorded: the duration of the signal from send to receive is coded as distance, and the strength of the returning signal is seen as brightness (Shawker, Sonies, Hall, & Baum, 1984). Soft tissue, muscles, and glands will return as brighter shades compared to a more dense anatomic structure, such as the hyoid bone which will return as a dark shadow (Arvedson & Brodsky). Ultrasound has been used to observe the structures and functions of different anatomical features of the body, such as the heart, kidneys, liver, gallbladder, eyes, thyroid, salivary glands and lymph nodes (American Registry for Diagnostic Sonography; Radiology Info, 2009). The most commonly known use of ultrasound is for observing the fetus during routine prenatal care. Ultrasound has also been used for therapies, dental hygiene, cataract treatment, and to find flaws in construction materials (Radiology Info, 2009). Additional
investigation is required to establish normal parameters for hyoid bone movement in healthy young and healthy older adults to assist in the safe and accurate diagnoses of dysphagia.
Chapter II: Literature Review

*Physiology of the Swallowing Mechanism: The Four Phases of Swallowing*

Swallowing is a complex physiological process involving the coordination of many head and neck muscles. Once the bolus is prepared, the entire sequence of events lasts 1-1.5 seconds (Dodds, 1989; Dodds, Stewart, & Logemann, 1990). Historically, the swallow has been described as occurring in four phases, beginning with the preparation of a bolus and ending with the bolus being passed through the esophagus (Dodds; Dodds et al.; Martin-Harris, Michel, & Castell, 2005). Although, separating the act of swallowing into distinct phases allows for a detailed description of the complex interaction of the mechanisms, the phases overlap, with one event influencing another (Martin-Harris et al.).

The oral preparatory phase involves sophisticated interactions of the lips, tongue, mandible, buccal musculature, and salivary glands to prepare the bolus for transport and digestion. The phase is an individualized process that is dependent upon the volume, consistency, temperature and taste of the bolus introduced (Arvedson & Brodsky; Logemann, 1998; Robbins, Hamilton, Lof, & Kempster, 1992). The complex muscular interaction is almost entirely voluntary, therefore the duration of the oral preparatory phase is highly individualized (Jean, 2001).

Once a bolus enters the oral cavity, the mandible elevates and the lips seal, providing anterior closure (Cichero, 2006a). The soft palate rests against the back of the tongue to provide posterior oral cavity closure and consequently an unrestricted airway for nasal breathing (Logemann, 1998; Cichero, 2006a). The buccal musculature maintains tone around the cavity, which not only prevents liquid from entering the lateral sulci, but also assists the tongue in the manipulation of a liquid bolus (Casas, Kenny, & McMillan, 2003; Cichero, 2006a). Complex sensory information is providing constant feedback, by means of mechanoreceptors, thermoreceptors, proprioceptors and chemoreceptors located within the oral cavity. Information regarding taste, bolus placement, muscle movement, and self-awareness from the oral cavity to the brain is mediated through sensory receptors (Corbin-Lewis, Liss, & Sciortino, 2005). Information received from the taste receptors indirectly stimulates the salivary glands to secrete digestive enzymes (Khosh & Krespi, 1997).

For a liquid bolus, extensive preparation is not required. Rather the bolus is typically cupped on the dorsum of the tongue, with the tongue tip positioned on the maxillary alveolar
ridge (Dodds, 1989). Once the tongue tip is poised on the maxillary alveolar ridge, the oral transit phase is initiated (Dodds et al., 1990). The tongue then elevates and rolls posteriorly against the maxillary alveolar ridge and hard palate in a wavelike motion, to propel the bolus into the oropharynx (Cichero, 2006a; Dodds; Steele & Van Lieshout, 2009). The lips maintain an anterior seal of the oral cavity, allowing pressure to build within the cavity (Perlman, 1991). Anterior to posterior movement occurs within 0.5 seconds (Dodds et al.). When the bolus reaches and stimulates nerves at the level of the anterior faucial pillars, the pharyngeal phase is initiated (Logemann, 1998).

The purpose of the pharyngeal phase is to direct the bolus into the esophagus while protecting the airway from aspiration. A number of complex physiological processes occur within 1 second, once the bolus reaches the anterior faucial pillars (Curtis, Bruess, Dachman, & Maso, 1984; Dodds et al., 1990; Logemann, 1998):

a. Soft palate rises to make contact with the posterior pharyngeal wall.

b. Hyolaryngeal complex elevates in a superior-anterior manner.

c. Airway protection occurs at the level of the true vocal folds, the false vocal folds, and the aryepiglottis.

d. Cricopharyngeus sphincter relaxes.

e. Progressive contractions of the pharynx, directing the bolus downward.

The soft palate raises and seals the nasopharynx by making contact with the posterior pharyngeal wall. The hyoid bone and larynx elevate in a superior-anterior manner (hyolaryngeal elevation), reducing the size of the pharyngeal cavity. The hyolaryngeal elevation creates a decreased distance for the bolus to travel. In addition, the superior and anterior movement contributes to airway protection and to cricopharyngeal modulation (Ishida, Palmer, & Hiitemae, 2002). The superior elevation of the larynx contributes to airway protection that occurs at three levels (Logemann, 1998). First a contraction of intrinsic laryngeal muscles approximates the arytenoids cartilages that prompt adduction of the vocal folds (Cichero, 2006a). The approximation of the arytenoids cartilages is followed by an adduction of the ventricular folds (false folds). Lastly, pressure at the base of the epiglottis from laryngeal elevation causes the structure to tilt over the opening to the vestibule (Cichero, 2006a; Dodds, 1989). The anterior movement of the hyoid and larynx contributes to the opening of the cricopharyngeal sphincter.
(Ishida et al.). The muscular portion of the sphincter relaxes 0.1 second prior to hyolaryngeal movement that forces open the area to receive the bolus (Logemann).

The bolus reaches the base of the tongue and is directed posteriorly at the same time as hyolaryngeal elevation and nasopharyngeal port closure (Khosh & Krespi, 1997). The posterior pharyngeal wall contracts and the two structures move toward one another and make contact (Logemann, 1998; Dodds, 1989). The superior constrictor begins the progressive contraction of the lateral walls of the pharynx, and in conjunction with the velum and tongue, forces the bolus towards the opening of the esophagus. The medial and inferior constrictors contract sequentially in a descending sequence following the superior constrictor (Khosh & Krespi). The bolus is driven over the valleculae and is split in half when routed through the pyriform sinuses due to the epiglottis covering the vestibule (Cichero, 2006a). The bolus then comes together and travels into the esophagus (Logemann).

The purpose of the esophageal phase is to transport the bolus from the larynx to the stomach for digestion. The phase begins at the point the bolus enters at cricopharyngeal juncture of the upper esophageal sphincter (Dodds, 1989). The cricopharyngeus and the upper esophageal sphincter are normally in a tonic state; relaxation of the cricopharyngeus and the upper esophageal sphincter allow for the bolus to enter. The modulation of the upper esophageal sphincter is regulated to accommodate for various bolus sizes (Jacob, Kahrilas, Logemann, Shah, & Ha, 1989; Robbins et al., 1992). Esophageal peristalsis is not initiated until the pharyngeal phase is completed. Only when the contractions of the pharynx cease and the entire bolus passes through the upper esophageal sphincter, will esophageal peristalsis begin (Jacob et al., 1989). Meanwhile, the absence of stimuli within or around the vestibule opens the glottis and lowers the larynx (Cichero, 2006a).

Once the bolus has passed the upper esophageal sphincter, the muscle returns to tonic state of closure (Dodds, 1989; Cichero, 2006a). The bolus is propagated approximately 20 cm downward by peristaltic contraction and the assistance of gravity; duration of contraction varies among research, from 2-20 seconds (Logemann, 1998; Jean, 2001). At the inferior end of the esophagus, the lower esophageal sphincter relaxes which allows the bolus to pass through the gastroesophageal juncture and into the stomach. The complex physiological process of swallowing ends with a termination in the contraction of the lower esophageal sphincter (Logemann, 1998).
Overview of the Central Organization of Swallowing

Understanding the normal swallow provides a benchmark to compare normal and abnormal swallows (Mendell & Logemann, 2007). A number of neurophysiological studies and reviews have contributed to the understanding of normal swallow (Boden, Hardemark Cedborg, Eriksson, Headstrom, Kuylenstierna, Sundann, et. al, 2009; Doty, Richmond, & Storey, 1967; Hamdy, Jilani, Price, Parker, Hall, & Power, 2003; Hockman, Bieger, & Weerasuriya, 1979; Jean, 2001; Kaatzke-McDonald, Post, & Davis, 1996; Murray & Sessle, 1992; Storey, 1968; Weinstein, 1983). A number of studies conclude that the complex neuromuscular process happens within seconds. Many coordinated and overlapping interactions occur between afferent inputs and efferent outputs of the cerebral cortex, brain stem swallowing center, cranial nerves V, VII, IX, X and XII, the ansa cervicalis, and muscular (Dodds, 1989; Dodds et al., 1990; Pelletier & Lawless, 2003). Normal swallowing incorporates controlled patterns of oropharyngeal contractions under delicate sensory control, harmonized with respiration, as the successive passing of a bolus mainly occurs during a suspension of breathing in expiration (Miller, Bieger, Conklin, 1997; Selley, Flack, Ellis, & Brooks, 1989).

Central organization of the normal swallow involves interactions between the brainstem and central nervous system, however all specific locations of the constituent parts of the central organization of the swallow are not fully known. Much of what we know about the volitional and reflexive components has developed from animal research (Miller & Sherrington 1916; Logemann, 1983; Shingai & Shimada, 1976; Storey, 1968; Travers & Smith, 1979). The most recent literature proposes the existence of a central pattern generator (CPG), a network of neurons located in the brainstem that organizes and coordinates the reflexive muscular patterns of the swallow (Miller, 1982; Weinstein, 1983). In a normal, healthy swallow, multiple inhibition and excitations of participating muscles occurs in a specific and constant order. The results support the theory of a central pattern generator that integrates cortical and peripheral information to modify motor events according to a presented bolus (Sciortino, Liss, Case, Gerristen, & Katz, 2003).

Brainstem.

The CPG includes two primary pools of neurons on each side of the brainstem surrounding the reticular formation: the dorsal region, within and inferior to, the nucleus tractus solitarius (NTS); and the ventral region, within and adjacent to, the nucleus ambiguus (NA)
(Jean, 2001; Miller et al., 1997). The two areas are connected by interneurons and either side of the brainstem alone, right or left, can coordinate and carry out the motor sequencing of pharyngeal and esophageal phases of swallowing, (Doty, 1968; Doty, Richmond, & Storey, 1967). The afferent components of cranial nerves IX and X terminate with the NTS. Even after all of the cortical and subcortical regions above the brainstem have been damaged or removed, as in extensive traumatic brain injury, electrical stimulation to the CPG by means of the superior laryngeal branch of cranial nerve X, results in patterns of muscle contraction similar to those evoked by swallowing (Doty, 1968; Miller et al.). Although the primary neurons needed for swallowing reside in the brainstem, cortical areas and corticobulbar tracts have exhibited influence over the CPG component within the brainstem.

**Cortex.**

The central nervous system houses several corticobulbar pathways and cortical areas for the motor sequences needed for swallowing, such as the primary motor cortex. However, electric stimulation of only the primary motor cortex does not elicit swallows (Murray & Sessle, 1992). Interestingly, stimulation of the supplementary motor cortex evokes swallowing associated with mastication (Miller et al., 1997). Within the frontal cortex reside at least 3 specific regions in each hemisphere that modify the motor output, the duration, and/or the intensity of a swallow. These regions may also alter the threshold for the reflexively evoked swallowing activity of the brainstem’s CPG (Martin & Sessle, 1993; Miller & Sherrington, 1916). The four discrete areas include: the primary motor cortex, the principal cortical masticatory area (CMA) located on the precentral gyrus, and the deep CMA on the anterior face of the frontal operculum (Huang, Hiraba, & Sesle, 1989). Electrical stimulation of the descending corticobulbar pathways evokes swallowing associated with mastication (Miller et al., 1997).

**Integration of information for the brainstem and cortex.**

To evoke a swallow, a stimulus excites multiple peripheral sensory receptor fields of cranial nerves V, VII, IX and X. Sensory input regarding pressure, touch, taste and texture in the oral, pharyngeal, and/or esophageal areas travels from the oral and pharyngeal cavities to the brainstem, where the input is organized and processed (Kaatzke-McDonald et al., 1996). The type of stimulus will determine the extent to which the NTS activates a stereotypic response (Miller, 1982). Pressure has been shown to stimulate the greatest number of neurons in the NTS,
with taste stimuli being second best (Pelletier & Lawless, 2003). The dynamic fashion in which a stimulus is processed, instigates the NTS to sequentially activate the two specific pools (dorsal region encompassing the NTS and the ventral region encompassing the nucleus ambiguous) of motoneurons (Larsen, 1972). The NTS receives relayed sensory input and triggers a swallow via the NA (Miller et al., 1997). The ventral region relays the information to the cortical areas associated with the swallow. Neural pathways of the anteriolateral region in the frontal cortex descend the internal capsule and subthalamus to the level of the upper brain stem and synapse with the ventral substantia nigra and mesencephalic reticular formation region of the upper brainstem. Here, the neural impulses stimulate the CPG and in turn, cranial nerve nuclei V, VII, IX, X and XII and the cervical plexus rhythmically activate specific muscles and glands needed to pass a bolus from the oral cavity to the stomach (Miller et al., 1997).

Swallowing as Observed by Ultrasound

As a non-invasive procedure used to study the swallow, ultrasound is relatively inexpensive and portable, especially when compared to similar scanning modalities such as MRI (magnetic resonance imaging) and CT (computed technology) scans (Chi-Fishman, 2005; Radiology Info, 2008). While aspiration cannot be directly observed, soft tissues and dense tissues, such as the tongue, hyoid bone and thyroid cartilage, can be differentiated and measured during the swallow (Bressman, Heng, & Irish, 2005; Brown & Sonies, 1997; Chi-Fishman), (see Figure 1). Similarly to videofluorographic studies (VFFS) and fiberendoscopic evaluations of the swallow, the assessment of structural movement and coordination captured on the ultrasound largely depends on the expertise and instrumental experience of the ultrasonographer (Brown & Sonies, 1997). However, as more medical institutions and researchers are able to purchase ultrasound machines due to an increase in competition, experience and expertise will follow with use (Bressman et al.).

Ultrasound scanning, or sonography, is free of ionizing radiation and can be used repeatedly and for prolonged periods of time. To date, there are no known health risks for using ultrasound as outlined by FDA guidelines and performance standards (Association for Medical Ultrasound, 2002; Brown & Sonies, 1997; FDA, 2010). Ultrasound has been used to observe the structures and functions of different anatomical features of the body, such as the heart, kidneys, liver, gallbladder, eyes, thyroid, salivary glands and lymph nodes (Radiology Info, 2008) for many types of conditions that affect oral physiology from infancy to old age (Sonies, Chi-
Fishman, & Miller, 2003). The most commonly known use of ultrasound is for observing the fetus during routine prenatal care. Ultrasound can also be used as a valuable biofeedback tool for articulation therapy (Bernhardt, Gick, Bacsfalvi, & Ashdown, 2003; Modhah, Bernhardt, Church, & Bacsfalvi, 2008; Shawker & Sonies, 1984). Since the early 1980s, ultrasound has also been used to examine infant sucking and swallowing behaviors (Bosman, Hepburn, Josell, & Baker, 1990; Bu’Lock, Woolridge, & Baum, 1990; Jacobs, Dickinson, Hart, Doherty, & Faulkner, 2007; Miller & Kang, 2007; Smith, Erenberg, Nowak & Franken, 1985; Weber, Woolridge, & Baum, 1986), adult lingual activity (Casas et al., 2003; Chi-Fishman, Stone, & McCall, 1998; Miller & Watkin, 1996; Peng, Jost-Brinkmann, Miethke, & Lin, 2000; Shawker, Sonies, Stone, & Baum, 1983; Shawker, Sonies, & Hall, 1982; Soder & Miller, 2002) and to a lesser extent, pharyngeal swallowing (Chi-Fishman & Sonies, 2002; Fanucci, Cerro, Letto, Berardi, & Fraracci, 1997; Frattali, Sonies, Chi-Fishman, & Litvan, 1999; Kuhl, Eicke, Dieterich, & Urban, 2003; Shawker, Sonies, Hall & Baum, 1984). Real food and real liquids without contrast material form another advantage in using ultrasound to assess oropharyngeal swallowing, as contrast material is not needed (Casas et al., 2003; Lefton-Greif & Loughlin, 1996; Wijk, Wulfert, & Prinz, 2006; Yang, Loveday, Metreweli, & Sullivan, 1997). One of the primary disadvantages to using ultrasound as opposed to more commonly used methods such as VFFS or FEES is that ultrasound fails to directly detect aspiration. However, ultrasound can provide detailed information about the oral and pharyngeal phases of swallowing that other methods may not provide (Lefton-Greif & Loughlin).

During a basic ultrasonic investigation of the swallow, the subject is seated in a natural feeding position and a transducer is placed submentally, or under the chin (Casas et al., 2003; Yang et al., 1997; Lefton-Greif & Loughlin, 1996). Muscles of the tongue and palate, as well as the mandibular and hyoid shadows can be observed (Brown & Sonies, 1997). The images displays that are most commonly employed include “B-mode” or “M-mode” imaging (Wijk et al., 2006). B-mode images show two-dimensional sagittal slices of the oropharyngeal cavity, providing a lateral view of the swallow. In contrast, the M-mode creates a single column of pixel images that are abstracted from each frame of B-mode to represent movements as a function of time. The pixels pulled from B-mode are plotted sequentially, allowing movements of the oropharyngeal structures to be visualized in a graphic representation (Kawashima, Takahashi, Niikuni, Kanazawa, Nakajima, Akasaka, et al., 1999). B and M-modes can be used
simultaneously to allow quantification of swallow-related movements (Chi-Fishman, 2005; Stevens, 1978), such as hyoid bone movement (Huang, Hsieh, Chang, Chen, & Wang, 2009; Yabunaka, Obue, Hasimoto, Katsuda, Yamamoto, & Sanada, 2009).

Oropharyngeal structures are differentiated by density. The ultrasound transducer is sensitive to changes in acoustic impedance of tissues and displays low-density tissues as light shades of gray. In comparison, higher density tissues are displayed as darker shades of gray. Tissues of highest density, such as bone, are displayed shadows (Sonies et al., 2003; Wijk et al., 2006). All bone refracts the ultrasonic waves back to the transducer, producing an area of dark gray to black, which provides a strong contrast with surrounding structures.

*Hyoid bone movement as observed by ultrasound.*

The hyoid bone is the fulcrum from which anterior and superior movement of the larynx occurs during a normal swallow. The tongue and larynx attach both directly and indirectly to the hyoid bone via musculature, membranes, and ligaments. Without the movement of the hyoid bone, the larynx could not independently protect the airway or assist in opening of the upper esophageal sphincter (Brown & Sonies, 1997). To observe complete excursion of the hyoid bone via ultrasound, the mid-sagittal plane of reference is used by submental placement of the ultrasound transducer. The transducer is aligned and oriented with the midline of the mandible (symphysis menti) and posteriorly aimed to allow for full view of the hyoid bone’s echo-free shadow, (see Figures 1-4) (Chi-Fishman 2005; Chi-Fishman & Sonies, 2002; Sonies, Chi-Fishman, & Miller, 2003).

In many standard swallow studies involving ultrasound, the transducer is placed on the subject and he or she is given a bolus, typically 7-10cc for liquids (Brown & Sonies, 1997). The subject is then instructed to swallow and anatomic changes on the screen are observed. In B-mode, the movement of the hyoid can be measured in centimeters, (see Figure 3). In M-mode, the duration of movement of the hyoid can be measured in milliseconds, (see Figure 4). The examiner is able to use a frame-by-frame analysis to obtain detailed movement and duration measurements (Bressman et al., 2005; Chi-Fishman & Sonies, 2002).

Many investigators have used the displacement movements of the hyoid bone as temporal markers when studying specific swallowing behaviors (Chi-Fishman, 2005). For example, when the hyoid bone moves in an anterior-superior manner, at the height of the swallow, the hyoid is considered to be at maximal displacement. In the B-mode, full excursion of the hyoid bone is
viewed as the shadow moves anteriorly from a resting point, across the screen to maximal displacement, and back to the resting point (Chi-Fishman & Sonies, 2002). In M-mode, full excursion of the hyoid bone is viewed as a large graphical shift in the image, (see Figure 4), (Wijk et al., 2006). Full excursion of the hyoid bone demarcates the entire oropharyngeal swallow, from the trigger of the swallow, to the bolus passing into the esophagus (Ekberg, 1986), causing the ultrasonic procedure most beneficial when assessing the oral transit and pharyngeal stages (Chi-Fishman).

The Aging Swallow

As we age, our neural system and muscular tissue undergo biochemical alterations, causing minor anatomic and physiologic changes to our everyday behaviors and activities (Sonies, Parent, Morrish, & Baum, 1988). The same can be said for some changes observed in oropharyngeal swallowing anatomy and physiology (Cichero, 2006b; Ding, Logemann, Larsen, & Rademaker, 2003). However, the outcomes of normal changes tend to be minor effects on the swallowing process whereas major effects seen in clinical populations tend to be the result of pathologic change (Sonies et al., 1988). An understanding of the changes that occur in oropharyngeal swallowing anatomy and physiology with age is necessary to differentiate normal swallowing from disordered swallowing. The process of aging and physiologic decline is highly individualized and occurs regardless of chronological age; however some characteristics tend to predominate by a certain age (Feinberg, 1996). A summary of age related changes in deglutition can be found in figure 5.

Anatomic changes.

Age 65 is not only an age at which people become eligible for retirement and social security benefits but older adulthood is also a time in which most people notice anatomic and physiologic changes (Cichero, 2006b; Retirement information, 2010). Anatomical oropharyngeal swallowing changes evident in older adults include: ossification of laryngeal cartilages (with the exception of the cuneiform and corniculate cartilages), loss of elasticity of laryngeal ligaments, atrophy of laryngeal muscles, dehydration of laryngeal mucosa, and bowing and flaccidity of the vocal folds (Aronson, 1985; Moore & Dalley, 1999). The tongue and hyoid tend to be anatomically positioned lower due aging of the suprahyoid muscles and tissue laxity (Cichero, 2006b; Donner & Jones, 1991). The number of myelinating cells on specific nerves, such as the superior laryngeal nerve, may also be reduced (Jaredah, 1994). Anatomic changes involving
structures of the swallow generally have minor effects on the swallowing process; however, will in turn, cause both motor and sensory physiologic changes (Sonies et al., 1988).

Physiologic changes.

The most distinct physiologic changes of the swallow observed in older adults is delayed initiation of the swallow and increased duration needed to swallow, especially in older women (Cichero, 2006b; Sonies et al., 1988). During young adulthood, the swallow is triggered at the anterior faucial pillars and the phases of the swallow overlap (Tracy, Logemann, Kahrilas, Jacob, Kobara & Krugler, 1989); with old age, the initiation is moved posteriorly in the oropharyngeal cavity towards the valleculae and each phase of the swallow increases in duration (Ding et al., 2003; Logemann, 1990; Sonies et al., 1988). Electromyographic recordings support differences in lip, suprahyoid, and infrahyoid muscle activity in older adults from young adults. Longer EMG durations for all three sites were recorded for older adults when compared to the younger adults (Ding et al., 2003).

When comparing a group of older adults to a group of adults aged 45 and younger, a longer duration for swallowing is evident (Logemann, Pauloski, Rademaker, Colangelo, Kahrilas, & Smith, 2000; Sonies et al., 1988; Tracy et al., 1989), indicating that the change typically occurs between ages 45-65 (Robbins et al., 1992). Increased time needed to swallow is due to a number of different changes: slow bolus manipulation, weak lingual pump, poor bolus formation due to decreased production of saliva, extra hyoid gestures, more time needed to move hyoid bone to most superior/anterior position, longer upper esophageal sphincter opening, and longer velopharyngeal closure (Logemann et al., 2000; Nilsson, Ekberg, Olsson, & Hindfelt, 1996; Rademaker, Pauloski, Colangelo, et al., 1998; Sonies et al., 1988; Tracy et al., 1989). In addition, many manometric and videofluorographic reports indicated that pharyngeal contraction is believed to be slowed or reduced with age, (Dejaeger, Pelemans, Ponette, & Joost, 1997; Tracy et al.); however, other reports have indicated that pharyngeal contraction is to be unaffected with age (Shaker & Lang, 1994).

Many of the physiologic changes of the swallow seen in motor activity of older adults may be due to decreased neural processing duration (Rademaker et al., 1998). As previously stated, the majority of healthy adults are observed to have a mild delay in triggering the swallow, often seen to occur when the bolus reaches the valleculae (Tracy et al., 1989). The delay in triggering the swallow can be abnormal if resulting in frequent penetration or aspiration. The
trigger of the pharyngeal response is the catalyst of many different events involved in airway protection and if delayed, can place individuals at high risk for aspiration (Sciortino et al., 2003).

Chemosensory changes that occur in the laryngeal region of healthy adults may also contribute to trigger delays, multiple swallows to clear residue, and a higher threshold for coughing on laryngeal irritants (Cichero, 2006b; Donner & Jones, 1991; Feinberg, 1996; Schiffman, 1993). The reduction in sensory awareness of the laryngopharynx has been found to be progressive with increasing age (Aviv, Martin, Jones, Wee, Diamond, Keen, et al., 1994). A study found that the reduction in sensory awareness is evident by the age of 60, and becomes more significant over the age of 70 (Schiffman). A reduction in myelinating cells on the superior laryngeal nerve is thought to be responsible for reduction in sensation that the superior laryngeal nerve supplies as people age (Cichero, 2006b). In older individuals, reductions in sensory awareness may contribute to aspiration. A study compared the response to an aspirated chemical irritant of a group of 20-year-olds to an 80-90 year-old group. The threshold for coughing was found to be six times higher in older individuals than the younger individuals, indicating that an older individual is less likely to respond to foreign particles within the larynx (Donner & Jones, 1991).

Treatment Techniques

Water is typically considered to be the most difficult type of bolus for individuals with neurogenic oropharyngeal dysphagia to manage (Hargrove, 1980). Room-temperature water is the most likely consistency to penetrate the laryngeal vestibule or be aspirated into the lungs when swallowing is impaired (Larsen, 1972). In a presentation of room-temperature water, receptors sensitive to the osmolarity of water and mechanoreceptors are stimulated, however receptors specialized in taste and temperature are not stimulated (Martin, 1991), (see Figure 6). Current practice protocols for neurogenic oropharyngeal dysphagia include clinically based techniques that lead to greater cortical input, such as: downward pressure on the tongue, larger than 3ml boluses, self-feeding, thermal/tactile stimulation, sour boluses, cold boluses, thickened boluses, and boluses that require chewing (Dantas, Kern, Massey, Dodds, Kahrilas, Brasseur, et al., 1990; Matthes, 1998; Sciortino et al., 2003). Although many clinical techniques increase oral sensory awareness and improve oropharyngeal mechanics, this paper will focus only on influences of a sour bolus, influences of a cold bolus, and changes in bolus viscosity (Bisch, Logemann, Rademaker, Kahrilas, & Lazarus 1994; Cichero & Murdoch, 2006; Hargrove;

_Sour bolus._

A sour stimulus has been described as having an acidic base; acid is the source of sour sensory input to oral chemoreceptors. A mild acidic base of a sour bolus has been shown to be effective in evoking the swallow in rats (Kajii, Shingai, Kitagawa, Takahasi, Taguchi, Noda, et al., 2002). Clinical research has shown that a sour bolus causes a quicker onset of the oral swallow in subjects with neurogenic oropharyngeal dysphagia (Logemann, Pauloski, Colangelo, Lazarus, & Fujii, 1995). A sour stimulus can be presented as a focused application to the oropharyngeal area, stimulating a small amount of oral chemoreceptors, or can be integrated into a bolus, which will in turn stimulate a larger group of oral and pharyngeal chemoreceptors (Palmer, McCulloch, Jaffee, & Neel, 2005). Presentation of a sour-integrated bolus increases the amount of stimulation to the oral and pharyngeal receptor fields of the nervous system prior to the initiation of the swallow via mechano- and chemo-receptors, (Palmer et al.; Logemann, 1997a), (see Figure 7). The increased stimulation alters the response threshold of the receptor fields, facilitating oral onset (the point at which the bolus is propelled posteriorly) and transmission of the bolus, exciting afferent fibers synapsing with the nucleus tractus solitarius (NTS). Animal studies have shown that half of the neurons within the NTS are activated by taste (Travers & Smith, 1979). The alteration in response threshold is thought to increase strength and speed of the oropharyngeal swallow as evidenced by an increase in muscle contraction, an increase in coordination and timing of the swallow, and an increase in airway protection (Palmer et al.). An increase in the number of stimulated afferent neurons leads to a more robust signal to the NTS. The strong signal to the NTS results in a larger activation of the nucleus ambiguous (NA) and other swallow motorneurons (Ding et al., 2003).

In electromyographic (EMG) studies of normal subjects, the presentation of a sour bolus has been shown to produce: a quicker oral onset time, variable time latencies between the administration of a bolus and the onset of the swallow across subjects, and an increase in the strength of muscle contraction in all subjects when compared to a water bolus (Ding et al., 2003; Palmer et al., 2005). A few subjects were noted to increase the time between sour bolus administration and initiation of the swallow when compared to a water bolus; whereas a few subjects were noted to decrease time between administration and initiation. The changes in the
oropharyngeal swallow observed with a sour bolus presentation are believed to be a result of increased stimulation of the oropharyngeal receptors. Further, the duration of muscle contraction for taste versus nontaste conditions was shortened for some subjects and had the opposite finding in others. However, the effect of a sour bolus on the duration for bolus transport has been shown to be consistent within subjects (Palmer et al.). Submental EMG onset times were significantly shorter for three different taste conditions: sweet, salty, and sour (Ding et al.), signifying that the use of a variety of strong flavors in will improve swallow function.

Clinical research for patients who had suffered a stroke, resulting in neurogenic oropharyngeal dysphagia, has found a number of relevant changes to the oropharyngeal swallow with a sour bolus, including decreased: risk of aspiration and penetration, pharyngeal delay, time for oral onset, oral transit, and pharyngeal transit (Logemann et al., 1995; Pelletier & Lawless, 2003). The reduction in time for oral onset and pharyngeal delay resulted in an overall significant improvement of the efficiency of the swallow. In turn, a decrease in frequency of aspiration was noted when compared to non-sour boluses. However, many subjects indicated that the sour stimulus was unpalatable. A palatable sour bolus, citric acid mixed with sweetener, did not significantly improve swallowing behaviors (Pelletier & Lawless). Clinical research supports the theory that a sour bolus provides increased gustatory and trigeminal stimulation to the brainstem in people with neurologic impairments, as has been shown in the normal population (Ding et al., 2003; Palmer et al., 2005). Despite the large amount of evidence for use of a sour bolus, one study concluded an oral delay occurs with an unpleasant bolus in healthy young and older adults, as well as with individuals that had suffered a stroke (Hamdy et al., 2003).

**Consistency changes.**

Many studies support a therapeutic strategy of providing thickened liquids, for the management of individuals who have difficulties of airway protection (Bisch et al., 1994; Lazarus & Leder, 2009; Logemann, Gensler, Robbins, Lindblad, Brandt, Hind, et al., 2008; Raut, McKee, & Johnston, 2001). The rationale for this strategy is that foods that form a cohesive bolus in the mouth are easiest to swallow, as a liquid becomes thicker, the speed of bolus movement is reduced (Logemann et al., 2008). Normal individuals will not have difficulty with water and other thin liquids, however individuals with neurogenic oropharyngeal dysphagia present with a high risk of aspiration (Pelletier & Lawless, 2003). Thickening the consistency of
water and other thin liquids for individuals with neurogenic oropharyngeal dysphagia decreases risk of aspiration (Kendall, Leonard, & McKenzie, 2001).

Normal individuals have consistent oropharyngeal responses to thickened liquids that are related to the viscosity of the bolus. The distance of hyoid bone elevation and overall timing of pharyngeal transit as been found to be comparable between a thin liquid to a paste bolus (Kendall et al. 2001). However during thin liquid trials, oropharyngeal transit was faster. The hyoid bone maintained elevation slightly longer with paste boluses. Researchers theorized that prolonged elevation in response to more viscous material ensures that the duration of bolus transport is maintained as a constant (Kendall et al.). Maximum amplitude and duration of activation of muscles in the orbicularis oris region, the submental region, and the infrathyroid region were observed with thickened consistencies via EMG. Thickened liquids assist in prolonging the elevation of the hyolaryngeal complex as evidenced by an increase in the activation of suprathyroid and infrathyroid musculature (Ding et al., 2003).

**Cold bolus.**

Current research has shown that the human anterior faucial pillars contain thermosensitive receptors that respond to changes in temperature (Kaatzke-McDonald et al., 1996). Foods and liquids have typically been recommended to be served at a temperature warmer or cooler than body temperature. Patients with neurogenic oropharyngeal dysphagia will often comment that cold fluids are easier to swallow and are less inclined to aspirate cold fluids. The cold bolus follows the same increased stimulation theory as a sour bolus. While a body-temperature bolus (such as room-temperature water) will solely stimulate mechanoreceptors, a cooler/warmer than body-temperature bolus will stimulate mechanoreceptors, as well as thermosensitive receptors, (see Figure 8). The increase in receptor activation has been suspected to recruit more neuronal pathways, which send a stronger signal to the NTS (Hargrove, 1980; Logemann, 1998; Martin, 1991).

The use of cold fluids and the avoidance of room-temperature fluids have been suggested in many texts on “best practices” for swallowing management (Cichero & Murdoch, 2006; Perlman & Shulze-Delrieu, 1997). A cold stimulus can be presented as a focused application to the anterior faucial arches within the oropharyngeal area, or can be integrated into a bolus. Focused application has traditionally involved a cooled laryngeal mirror that is applied to the base of the anterior faucial pillars for a determined length of time, to decrease the threshold of
the swallowing response (Cichero & Murdoch, 2006; Kaatzke et al., 1996; Logemann, 1983; Swigert, 2007). Results from laryngographic measures indicated that cold stimulation evoked a decrease in swallowing latency in healthy individuals and significantly shorter pharyngeal response time, earlier laryngeal closure, and longer laryngeal elevation in dysphagic individuals (Bisch et al., 1994). Despite these positive suggestions that thermal stimulation may be a viable means to facilitate a swallow, particularly in the dysphagic population, the literature is less persuasive in healthy populations.

Change in manometric (Knauer, Castell, Dalton, Nowak & Castell, 1990), laryngographic (Kaatzke-McDonald et al., 1996) or videofluorographic (Ali, Laundl, Wallace, deCarle, & Cook, 1996) measurements of the pharynx or the upper esophageal sphincter were not found in response to cold stimuli in healthy subjects. Animal data indicates that thermal stimuli are the weakest for activating oropharyngeal receptors (Hamdy et al., 2003), thus suggesting the clinical view that combined use of a cold stimulus and other treatment techniques is more effective.

*Combination of sour, cold and consistency.*

When a patient presents with neurogenic oropharyngeal dysphagia, a therapist is unlikely to use only one of the above techniques. Many patients will refuse to consume thickened liquids due to altered taste and texture (Huckabee & Pelletier, 1999). However, the likes and dislikes of a bolus may or may not have an influence on swallowing physiology (Pelletier & Lawless, 2003). The characteristics of a bolus, such as taste and texture may affect the individual’s experience with eating, but it may or may not affect the individual’s swallowing physiology.

Combinations of the discussed techniques have been clinically found to be the least aversive and most successful in reducing a patient’s risk of aspiration (Kagel & Leopold, 1992). A shortened pharyngeal delay is associated with a cold, thickened sour bolus (Sciortino et al., 2003). Sips of cold, sour lemonade between food trials with patients with neurogenic oropharyngeal dysphagia have been recommended to increase sensory awareness (Palmer et al., 2005). Clinical evidence and results from previous studies support the theory of a cumulative effect when activating different oropharyngeal receptors through taste, temperature, and consistency in healthy and dysphagic individuals (Ding et al., 2003; Hamdy et al., 2003; Huckabee & Pelletier; Kagel & Leopold, 1992; Palmer et al., 2005; Sciortino et al.; Wijk et al., 2006). Cold citrus water was found to provoke a reduced volume per second and a smaller volume capacity per swallow, regardless of age or the presence or absence of neurogenic oropharyngeal dysphagia (Hamdy et
A cold and sour stimulus can facilitate a faster, more organized oropharyngeal swallow (Kagel & Leopold). Larger levels of input to the NTS and higher cortical centers alter the swallow response, (see Figure 9). Awareness of the bolus is increased in individuals with neurogenic oropharyngeal dysphagia via thermal, chemical and mechanosensation.

**Statement and Significance of the Problem**

The hyoid bone plays a significant role in the swallow as well as in airway protection from aspiration. A multitude of studies have been dedicated to normal swallowing, abnormal swallowing and various treatments. Very few use ultrasound to observe hyoid bone movement despite the fact that real time ultrasound imaging produces a detailed picture of hyoid bone movement. These images can be reviewed frame by frame to analyze the swallow reflex and swallowing patterns (Bressman et al., 2005). Ultrasound is a diagnostic and progress-monitoring tool that can be easily utilized by speech language therapists across many settings.

Significant benefits of this study include establishment of ultrasound as an effective assessment of hyoid bone movement and normative data on hyoid bone movement in the adult population. However, the main benefit is the accumulation of normative data. The normative data collected regarding temporal and durational aspects of abnormal to normal hyoid bone movement is crucial for speech-language pathologists to effectively provide research-based services to their clients.

**Purpose of the Study**

The purpose of this study is to provide normative data regarding hyoid bone movement and duration of movement with different flavor and consistency boluses. Effects of cold, sour and thickened boluses on hyoid bone movement and duration in normal young and older adults were observed via ultrasonography. Future speech-language pathologists will be able to use the data collected to positively improve therapy sessions by using ultrasound to assess the swallow. The current study and data collected will provide a solid foundation for establishing methods, procedures and data collection in future studies.

**Research Question**

Research Question: What are the normal parameters of duration and distance of hyoid bone movement in adults?

a. What are the normal parameters when assessing 10 cc cold water swallows?
b. What are the normal parameters when assessing 10 cc cold nectar-thick water swallows?
c. What are the normal parameters when assessing 10 cc cold sour swallows?
d. What are the normal parameters when assessing 10 cc cold nectar-thick sour swallows?

Statistical Hypotheses

1. A sour bolus will decrease the duration of hyoid bone movement.
2. A sour bolus will not influence the distance of hyoid bone movement.
3. Nectar-thick consistency will increase the duration and distance of hyoid bone movement.
4. Body Mass Index (BMI) and gender will not influence the duration or distance of hyoid bone movement across all conditions.
5. As age increases, the duration of hyoid bone movement will increase across all conditions.
6. As age increases, the distance of hyoid bone movement will decrease across all conditions.
Chapter III: Methods and Procedures

Recruitment and Selection of Subjects

The methods and procedures utilized in this study were reviewed and approved by the Committee for the Use of Human Subjects in Research (CUHSR) for Miami University. Subjects were recruited from greater Cincinnati area and were included in the study if the candidates were healthy and between the ages of 18-35 or 65 and older. Subjects were excluded from the study if he or she was younger than 18 years of age or between the ages of 36-64. The subject was also excluded from the study if he/she did not possess appropriate cognitive functioning as determined by a cognitive screening and clinical judgment, or did not pass the oral motor screening. Any subjects with a significant medical history, per subject report, that may have influenced oral or pharyngeal swallowing ability were excluded from the study. Significant medical history was defined as having wet vocal quality during meals, head and neck cancer, history of cerebral vascular accidents, moderate or severe traumatic brain injury, radiation of the head and/or neck, a history of Parkinson’s disease, multiple sclerosis, Huntington’s chorea, early onset dementia, goiters, or odyophagia (pain during swallowing).

Selected members of the team visited social and philanthropic organizations of Miami University to recruit subjects. Written permission for recruitment from the leader of each of the social and philanthropic organizations was obtained prior to giving the organizations a verbal description of the research study (see Appendices A-B). In addition, recruitment flyers were posted at various businesses in Oxford, Ohio, upon permission from the owner or director (see Appendix C). Each subject that participated in the research study received $10 or a service credit for his or her organization as compensation for time and travel. Once a subject signed up for an appointment and arrived on site, he or she signed informed consent (see Appendix D). In addition, a questionnaire (see Appendix E), oral motor screening and cognitive screening (see Appendix F) served as tools to determine participant eligibility. Participation of the study was not required and the subject was able to refuse participation at any time.

Research Procedures/Methods

While the study discussed in this paper was part of a larger study, only the eligibility screening phase and the flavor-consistency phase will be discussed. After signing informed consent, the subject was given a written questionnaire (see Appendix E). The purpose of the questionnaire was to screen for normal subjects and minimize risks. The form completed by the
subject prior to the initiation of his/her session. Examiners were present in the room to answer any questions. The St. Louis University Mental Status Examination (SLUMS) was administered to determine appropriate cognitive functioning. Subjects were asked to respond to the brief screening that is typically utilized as part of standard clinical evaluation. The screening assessed abnormal cognitive change (abnormal: scoring less than 21 out of a total of 30 points). The examination involved the subject responding to verbal and visual stimuli that assessed his/her attention, memory, orientation and executive functioning. In addition, subjects submitted to a brief oral motor screening that is also utilized as part of standard clinical evaluation. The screening focused on anatomical relationships of the oral cavity structures. Symmetry, range of motion and coordination were observed to ensure that the subject was within adult norms. Height and weight was collected using a Detecto scale. BMI was then individually calculated for each subject. Age was also calculated using the subject’s given date of birth.

Ultrasound data was collected using a portable Aloka 900 SSD, transducer (type UST 987-7.5 MHz, 65 degree, 20 mm radius) and Medicapture USB200. The probe depth was placed at 5 cm in order to obtain a more detailed view of the hyoid bone shadow and posterior tongue (Frattali et al., 1999). For the level and type of diagnostic ultrasound used in the study, there are no known harmful effects (Ziskin & Petitti, 1988). All diagnostic equipment operated within FDA guidelines. Subjects were seated upright in a chair and the probe was placed in the mid-sagittal plane of reference. Both B and M-modes were utilized. B-mode incorporates an anatomic view of the tongue and hyoid bone shadow, which allows for visualization of hyoid bone movement and measurement of displacement (see Figure 1). Frame by frame analysis began at the resting point and the point of furthest displacement (Shawker et al., 1984; Chi-Fishman & Sonies, 2002), (see Figure 3). M-mode presents temporal changes of the anatomic structures and allows for measurement of the duration of hyoid bone displacement (Wijk, Wulfert, & Prinz, 2006). The hyoid bone casts a thin band of shadow during the swallow, which was analyzed to determine total time needed for hyoid bone movement (see Figure 4).

Extensive ultrasound training for measurement of hyoid bone movement occurred for all primary and secondary researchers. The primary researchers were thoroughly trained and had at least 4 years of experience with data collection and analysis of ultrasound imaging. An extensive training program was initiated for the secondary researchers, extending a full year prior to this study. During this time, training regarding proper procedures, probe placement, data analysis, and
“practice” sessions were completed. Different members of the team administered different phases of the larger study.

Pilot data was collected from the first 11 subjects enrolled to determine that a sample size of at least 25 was needed for statistical significance. The pilot data phase required each subject to swallow three 10 ml water boluses presented via plastic soufflé cup, with a 5-minute break after completion. The next phase that was initiated was the flavor-consistency phase. For each subject, discrete boluses of thin and pre-thickened liquid were presented via plastic soufflé cup. Thin liquids included cold water and cold cranberry juice. Pre-thickened liquids included cold nectar-thick water without lemon and cold nectar-thick cranberry juice. All boluses were measured using 3cc syringes prior to the session and stored in a refrigerator. The task order for the discrete swallows was randomized. Distance and duration of the subject’s hyoid bone movement was measured in B and M-modes respectively for each of the discrete boluses. Each subject was instructed on what flavors and consistencies he or she may be presented and that he or she should maintain a comfortable yet upright seated position during the entire procedure.

The transducer was placed in the mid-sagittal plan of reference to view full excursion of the hyoid bone via the hyoid bone’s echo-free shadow. A specific line of reference along the y-axis of the ultrasound monitor was used as a basis for horizontal measurement to ensure consistency across measurements. Once the small soufflé cup was handed to the subject, the subject was instructed to “go ahead.” Immediately following the capture of the swallow, the examiner conducted a frame-by-frame analysis to identify and measure the distance between resting position and maximum displacement of the hyoid bone shadow. Analysis included using an internal function of the ultrasound device that measures distance of structures over time. Total hyoid bone movement was measured by drawing a continuous horizontal line from the hyoid bone’s resting position, to the point of maximum displacement along the 4th line of the ultrasound monitor. The still image of the measured swallow was captured via Medicapture, a device allowing for capture of full motion video or still images from medical imaging equipment. Each still image of each measured swallow was saved onto a flash-drive, and was later reviewed for quality and consistency.

Data Analysis

Statistical analyses were conducted using Statistical Analysis System (SAS 9.2 for Windows) to integrate descriptive statistics and a Type III Test of Fixed Effects Analysis of
Variance (ANOVA) for both B- and M-modes across four conditions (water, nectar-thick water, cranberry juice, and nectar-thick cranberry juice). An alpha level of .05 was used for all statistical tests. Additionally, the Turkey-Kramer method was used in conjunction with the ANOVA to find which means are significantly different (or greater than the standard error) from one another to provide a narrower confidence limit, with an adjusted $p$ value. For the purpose of pilot data analysis, three swallows were collected and measured in B and M-modes, for a total of 33 swallows. For the purpose of flavor and consistency data analysis, 12 swallows were collected and measured for B-mode and M-mode, for a total of measured 420 swallows. Two subjects were excluded from flavor and consistency data analysis due to the absence of all twelve data points across all conditions. The three B-mode and the three M-mode replicated values at each subject and condition combination were averaged. Subsequently, each subject had one B-mode and one M-mode value for each condition. The data reported was analyzed using a mixed model to determine if the condition, age, gender, and/or BMI influenced the two response variables.
Chapter IV: Results

All participants recruited qualified for participation, however two subjects were excluded from data analysis due to the absence of all data points. The cognitive screening utilized in this study was determined to be too sensitive. The screening disqualified subjects that were cognitively able to participate in the study. Based on the screening’s scoring boundaries, 15 of 37 total subjects, were considered to have a mild neurocognitive impairment. Therefore clinical judgment in combination with the cognitive screening was used to determine cognitive eligibility. Thirty-seven subjects were eligible for participation in the study, however only 35 were included in data analysis. Of the participants eligible for the study, seventeen participants were female and twenty participants were male. The average age of the participants included in data analysis was 28 years (SD=18, range 20-86 years), and only four subjects were over the age of 65. Descriptive analysis was implemented in the study to summarize and draw inferences from the collection of data. Descriptive data included, mean hyoid bone displacement (cm), mean duration of hyoid bone displacement, range, standard deviation, and standard error.

Research Question

For the purpose of normative data, the present study calculated descriptive statistics for means of comparison among the four presented conditions (see Tables 1a, 1b, 2a, and 2b). Measurements recorded for 105 swallows at a bolus size of 10 cc of cold water, revealed a mean displacement of 1.84cm with a range of 0.99-3.22cm (SD=0.58, SE=0.05) and mean duration of 571ms with a range of 427-760ms (SD=136, SE=13). Measurements recorded for 105 swallows at a bolus size of 10 cc of cold nectar-thick water revealed a mean displacement of 1.66cm with a range of 0.73-2.86cm (SD=0.52, SE=0.05) and mean duration of 579ms with a range of 414-847ms (SD=140, SE=14). Measurements recorded for 105 swallows at a bolus size of 10 cc of cold cranberry juice revealed a mean displacement of 1.68cm with a range of 0.92-2.76cm (SD=0.49, SE=0.04) and mean duration of 568ms with a range of 414-737ms (SD=122, SE=12). Measurements recorded for 105 swallows at a bolus size of 10 cc of cold nectar-thick cranberry juice revealed a mean displacement of 1.66cm with a range of 1.03-3.15cm (SD=0.51, SE=0.04) and mean duration of 566ms with a range of 396-828 (SD=147, SE=14).
### Table 1a - Mean Distance of Hyoid Bone Movement

![Bar chart showing mean distance of hyoid bone movement for different conditions](chart)

### Table 1b – Mean Distance of Hyoid Bone Movement

<table>
<thead>
<tr>
<th>Condition</th>
<th>Mean</th>
<th>Std Dev</th>
<th>Std Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>1.84</td>
<td>0.58</td>
<td>0.06</td>
</tr>
<tr>
<td>Nectar-Thick Water</td>
<td>1.67</td>
<td>0.52</td>
<td>0.05</td>
</tr>
<tr>
<td>Cranberry Juice</td>
<td>1.68</td>
<td>0.49</td>
<td>0.04</td>
</tr>
<tr>
<td>Nectar-Thick Cranberry Juice</td>
<td>1.66</td>
<td>0.51</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Hypotheses

Hypothesis 1: Flavor will decrease the duration of hyoid bone movement.

The addition of cranberry flavor did not significantly alter the duration of hyoid bone movement ($p = 0.8924$). The mean duration for the water condition was approximately 570.97ms (SE = 13.24) and the mean duration for the cranberry juice condition was approximately 568.22ms (SE = 11.86).
**Hypothesis 2:** Flavor will not influence the distance of hyoid bone movement.

When compared to water, the presentation of cranberry juice was found to statistically decrease the distance of hyoid bone movement (adjusted $p=0.0051$). The mean distance of hyoid bone displacement for the water condition was 1.84cm (SE = 0.06) and the mean distance of displacement for the cranberry juice condition was 1.68cm (SE = 0.04).

**Hypothesis 3:** Nectar-thick consistency will increase the duration and distance of hyoid bone movement.

The addition of nectar consistency did not significantly alter the duration of hyoid bone movement when compared to any other condition ($p = 0.8924$). The mean duration for the water condition was approximately 570.97ms (SE = 13.24) and the mean duration for the nectar-thick water condition was approximately 579.97 (SE = 13.23). When compared to water, the presentation of nectar-thick consistency was found to statistically decrease the distance of hyoid bone movement (adjusted $p=0.0051$). The mean distance of hyoid bone displacement for the water condition was 1.84cm (SE = 0.06) and the mean distance of displacement for the cranberry juice condition was 1.67cm (SE = 0.05).

**Hypothesis 4:** BMI and gender will not influence the duration or displacement of hyoid bone movement across all conditions.

Participant’s BMI did not significantly influence the duration of hyoid bone movement ($p$ value = 0.3030) in any of the four conditions. Participant’s gender did not significantly influence the duration of hyoid bone movement ($p$ value = 0.6882) in any of the four conditions.

**Hypothesis 5:** As age increases, the duration of hyoid bone movement will increase across all conditions. **Hypothesis 6:** As age increases, the distance of hyoid bone movement will decrease across all conditions.

Despite unequal age-group sizes, participant’s age did not significantly influence the duration ($p$ value = 0.1174) or distance ($p$ value = 0.3995) of hyoid bone displacement in any of the four conditions.
Chapter V: Discussion

Discussion

Ultrasound measurements in duration (ms) and distance (cm) of hyoid bone movement were collected in healthy young and older adults across four 10cc conditions: water, nectar-thick water, cranberry juice and nectar-thick cranberry juice. The primary objectives of this study were to (a) determine the normal parameters that should be observed when using ultrasound to assess duration and distance of hyoid bone movement in adults and (b) determine the influence of different characteristics of a bolus on the duration and distance of hyoid bone movement. The collected data on young and older adults provides preliminary clinical data in ultrasonic measurements of the duration and distance of hyoid bone movement. Preliminary confidence intervals have been established and measurements outside these ranges should be regarded as abnormal, and further testing should be considered.

The results revealed two major patterns with the addition of sour flavor and/or nectar consistency: 1) the mean displacement of hyoid bone decreased, and 2) the mean duration of hyoid bone maintained a constant. Both patterns occurred regardless of the variation age, gender, and BMI. Only the distance of hyoid bone movement was affected when the sour flavor and/or nectar consistency was added. These phenomena refute the first, second, third, fifth and sixth hypotheses, and accept the fourth hypothesis. While the mean averages for distance of the different conditions follow a trend from least to most stimulable (water, juice, nectar-thick water, nectar-thick juice), the means are not statistically different. The standard errors between juice, nectar-thick water, and nectar-thick cranberry juice are large enough to allow for the mean distance of the three differing conditions to overlap.

First and second hypothesis.

The distance of hyoid bone movement was the only dependent variable affected with the addition of cranberry flavor to the 10cc bolus, refuting both the first and second hypotheses. Flavor did not decrease the duration of hyoid bone movement and influenced the distance of hyoid bone movement. Mean duration of hyoid bone movement for the presentation of a cold-water bolus was 570.97ms (SE=13.23). The addition of cranberry flavor only decreases the duration of mean hyoid bone movement to 568.22ms (SE=11.86). The difference in duration between the water condition and the cranberry juice condition were not significantly different (p=0.8924). Duration results are consistent with previous literature; overall timing of hyoid bone
movement does not vary among bolus types. Researchers have theorized that prolonged elevation in response to more viscous material ensures that the duration of bolus transport is maintained as a constant (Kendall et al., 2001).

The presentation of a cold-water bolus produced a mean distance of 1.83cm. The addition of cranberry flavor decreased the mean distance to 1.68cm. The difference in distance between the water condition and the cranberry juice condition was found to be statistically significant (p=0.0051). Previous neurological research has indicated that with a more robust signal sent to the NTS, suprahypoid muscle activation and contraction increases (Ding et al., 2003; Palmer et al., 2005). While the effect of increased contraction and activation of suprahypoid muscles on hyoid bone movement has not been directly studied, a theoretical assumption could be that with each additional variable placed on a bolus, i.e. acidic properties, that the mean distance of the hyoid bone movement would increase and duration would decrease. However, the current study’s results indicate the opposite effect is taking place. With the addition of acidic/flavor properties, mean hyoid bone movement decreased, while the duration maintained a constant. More research needs to take place in order to understand the overall effect of increased contraction and activation of laryngeal muscles on hyoid bone movement.

Third hypothesis.

The distance of hyoid bone movement decreased with the addition of a thickening agent to the 10cc bolus, refuting the third hypotheses. This contradicts previous adult studies that reported greater hyoid bone displacement with thicker consistencies (Chi-Fishman & Sonies, 2002; Dantas et al., 1990). However, a few studies have found no significant effects between consistency and hyoid bone displacement (Ishida et al., 2002; Kendall et al., 2001). These studies are not directly equivalent to this study due to methodological differences, however because of discrete displacement and duration measures of various bolus types, typical observations and conclusions can be drawn. An ultrasonographic study established vertical displacement of 10cc room-temperature boluses of varying consistencies at 1.84cm ±0.72, and an overall start to end duration of 1130ms ± 36 for females and 1240ms ± 40 for males (Chi-Fishman & Sonies). The vertical displacement of the current study is comparable for thin consistency, with a displacement measure at 1.83cm ± 0.57. Although results showed that duration of hyoid bone movement was the greatest with each successive thickened bolus, that trend was not observed in the current study. A videofluorographic study established vertical displacement of 10cc of
barium-water at 0.71cm ± 0.33 for males and 0.58cm ± 0.38 for females. The study concluded that hyoid displacement, although variable, was significantly smaller for thin liquids than for thicker consistencies (Ishida et al., 2002). In both ultrasound studies, mean hyoid bone movement was longer in displacement for thin liquids than in any other condition. This contradiction in may be due to the nature of measurements between the two instrumental assessments. A possible explanation for the contradiction may be that in the videofluoroscopy, the hyoid bone was already in a high position (given that the back of the tongue is elevated with thin liquids to prevent premature spillage into the pharynx) immediately prior to the onset, and that during the ultrasound, the movement of the hyoid bone prior to onset was measured.

*Fourth, fifth, and sixth hypotheses.*

Results indicated no change in hyoid bone movement across BMI, gender, and age, accepting the fourth hypothesis and refuting the fifth and sixth hypothesis. While gender was proportionally balanced in the current study (15 females and 20 males), only 4 adults over the age of 65 participated. Small older subject sample size should be considered when considering the data. A previous ultrasonographic study revealed that older subjects’ hyoid bones moved farther and for a longer duration, males’ hyoid bones moved farther and for a longer duration, and females’ hyoid bones moved for a shorter duration and shorter distance (Chi-Fishman & Sonies, 2002). Previous research has also shown that as a person ages, the individual requires a longer duration to swallow (Logemann et al., 2000; Sonies et al., 1988; Tracy et al., 1989). There is no current research to indicate whether or not the longer duration needed for swallowing in older adults correlates to hyoid bone movement.

The slight variances in hyoid bone movement between genders and age groups in previous studies may be the result of anatomical differences (i.e. size of oral cavity, distance between mandible and hyoid bone, etc), likes/dislikes of bolus types, and individual variations in eating habits. Males tend to display a greater hyoid bone excursion due to the lowered position of the hyoid bone (Ishida et al., 2002) and the dislikes associated with a thickened bolus may correlate with decreased hyoid bone movement (Hamdy et al., 2003). Contradictions in anthropometric influences on hyoid bone movement between the current study and previous studies may be due to the small number of participants over the age of 65 and/or the methods of measurement. As previously discussed, increased time needed to swallow can be due to a number of reasons: slow bolus manipulation, weak lingual pump, poor bolus formation due to
decreased production of saliva, extra hyoid gestures, delayed trigger of the pharyngeal swallow, more time needed to move hyoid bone to most superior/anterior position, decreased laryngeal elevation, longer upper esophageal sphincter opening, and longer velopharyngeal closure (Logemann et al., 2000; Nilsson, Ekberg, Olsson, & Hindfelt, 1996; Rademaker, Pauloski, Colangelo et al., 1998; Sonies et al., 1988; Tracy et al., 1989). While an increase in duration was not observed for the older adults in this study, extra hyoid gestures were observed more often in older adults than in younger adults. Refer to figure 10 for a side-by-side comparison of a 20-year old male and an 84-year-old female.

Limitations and Future Research

Normal parameters regarding the total distance and duration of hyoid bone displacement in young healthy adults were established for 10cc bolus sizes of water, nectar-thick water, cranberry juice and nectar-thick cranberry juice. This study proposes that the addition of nectar-thick consistency and/or sour flavor decreases the distance of hyoid bone excursion and does not have an influence on the duration of hyoid bone movement. Possible underlying mechanisms include: stronger signals to the NTS, and likes/dislikes associated with the different types of boluses presented.

Given the results of the current study, future research should continue to collect data regarding the normal parameters for distance and duration of hyoid bone movement in all age groups. The accessible population was limited to Southwest Ohio and consisted mainly of the middle socioeconomic class. Future research will need to consider geographic diversity, sample size, age groups, and clinical populations to develop more statistical power among the general population. The effects of and differing acidity levels should also be explored.

The current study employed strict training, measuring, and randomization protocols. Examiners in future studies should maintain strict methods and also statistically analyze inter rater reliability. Although examiners in the current study maintained strict methods, no statistical comparison exists to support inter rater reliability. Larger and more comprehensive studies will be necessary to investigate other anthropometric factors (race, geographic location, oral cavity size) and other bolus characteristics (room temperature, thicker consistencies). Additional investigations are required to continue establishing normal parameters for hyoid bone movement in healthy adults, to assist in the safe and accurate diagnoses of dysphagia.
FIGURE 1 – B-MODE VIEW OF THE HYOID SHADOW

FIGURE 2 – SCHEMATIC OF HYOID BONE AS SEEN VIA B-MODE
FIGURE 3 – SAMPLE MEASUREMENT IN B-MODE

FIGURE 4 – SAMPLE MEASUREMENT IN M-MODE
FIGURE 5 – AGE RELATED CHANGES TO THE SWALLOW

<table>
<thead>
<tr>
<th>Phase of Swallow</th>
<th>Decreased:</th>
<th>Increased</th>
</tr>
</thead>
</table>
| Anticipatory      | -sense of smell  
                  | -taste sensitivity  
                  | -perception of thirst (men)  
                  | -regulation of fluid intake (men)  |           |
| Oral              | -tongue driving force  
                  | -speed in tongue movement  
                  | -peak suction pressure  | -duration  
                  |                  | -number of jaw strokes for mastication  
                  |                  | -retention post swallow  |
| Pharyngeal        | -laryngeal sensation  
                  | -pharyngeal sensation  
                  | -laryngeal excursion  
                  | -oropharyngeal pump efficiency  | -duration  
                  |                  | -number of swallows to clear the bolus  
                  |                  | -muscular contraction amplitudes  
                  |                  | -number of penetration episodes  |
| Esophageal        | -speed of transit  
                  | -clearance efficiency  
                  | -pressure amplitude  |           |

(Adapted from: Aviv et al., 1994; Cichero, 2006b; Ding et al., 2003; Donner & Jones, 1991; Feinberg, 1996; Logemann, 1990; Selley et al., 1989; Shaker & Lang, 1984)
FIGURE 6 – RECEPTOR RESPONSE TO WARM WATER BOLUS

FIGURE 7 – RECEPTOR RESPONSE TO A SOUR BOLUS
FIGURE 8 – RECEPTOR RESPONSE TO A COLD WATER BOLUS

FIGURE 9 – RECEPTOR RESPONSE TO A COLD SOUR BOLUS
FIGURE 10 – M-MODE OF 84-YEAR-OLD vs. 20-YEAR-OLD
References


Normal nipple position in term infants measured on breastfeeding ultrasound. *Journal of Human Lactation, 23*(1), 52-59.


mechanisms. *Physiological Review, 81*(2), 929-969.


Nutrition for the Elderly, 8(1), 59-64.


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Appendix A: Recruitment Permission Form

Recruitment Permission Form.

__________________________ has agreed to allow the ultrasound team from the Speech Pathology and Audiology Department of Miami University to contact ____________________ via ____________________ (e-mail/ flyers/ phone/ etc.) for possible participation in the Ultrasound Swallowing Study. I understand that the team will recruit for this study only and all information will be kept confidential.

__________________________
Signature

__________________________
Date

__________________________
Title
Appendix B: Description of the Study

Hello!

My name is Briana Corcoran and I am a graduate student in the Speech Pathology Department of Miami University. I am conducting a research study that uses ultrasound to look at swallowing in normal subjects ages 18-35 and 65+. Ultrasound is safe, not painful, and does not use radiation. You will be asked to complete: a short questionnaire about your health, a cognitive screening, and an oral motor screening.

If you meet the inclusion criteria of the study, then you will be asked to participate in the study. You will be given small amounts of liquid while the ultrasound transducer is placed under your chin. Gel will be put on the transducer before each picture is taken. This gel makes it the ultrasound picture clearer. It easily wipes off and will not stain clothes.

Things to know:

– Information obtained from the study will be kept confidential
– You may decide to remove yourself from the study at any time or refuse to answer or participate in anything that makes you feel uncomfortable.
– This study will help us understand more about swallowing and how ultrasound may benefit subjects with swallowing difficulties.
– You will receive your 1 hour of service or $10 visa gift card once you have formally enrolled in the study (signed consent), a time as been scheduled, and data collection has been initiated.

Thank you from the Miami University Ultrasound Research Team!

If you have any additional questions about the study, please contact:

Briana Corcoran, Research Team Leader
513-260-1088 email: kellembe@muohio.edu

Dr. Donna Scarborough, Ph. D., CCC-SLP
513-529-2506 email: scarbod@muohio.edu
Ultrasound Study

Department of Speech Pathology and Audiology

NEEDED: HEALTHY SUBJECTS BETWEEN AGES 18-35

Subjects needed for a graduate research study looking at the swallow of healthy individuals using non-invasive ultrasound while swallowing liquids.

Please contact Briana Corcoran, Graduate Student, for more information at: (513) 260-1088 or Kellembc@muohio.edu

This research has been approved by the Miami University Institutional Review Board, 09-557.
Ultrasound Study
Department of Speech Pathology and Audiology

NEEDED: HEALTHY SUBJECTS
AGES 65+

Subjects needed for a graduate research study looking at the swallow of healthy individuals using non-invasive ultrasound while swallowing liquids.

Please contact Briana Corcoran, Graduate Student, for more information at: (513) 260-1088 or Kellembc@muohio.edu

This research has been approved by the Miami University Institutional Review Board, 09-557.
Appendix D – Informed Consent

Informed Consent

**Title of Research:** Use of Ultrasound in Measuring Hyoid Bone Movement

**Research Team:** Dr. Donna Scarborough, CCC-SLP, Briana Corcoran, B.S., and Kimberly Hubacher

Before agreeing to participate in this research study, it is important that you read the following explanation of the study. This statement describes the purpose, procedures, benefits, risks, discomforts, and precautions of the program.

**Explanation of Procedures.** This study uses ultrasound to look at swallowing in normal subjects ages 18-35 and 65+. Ultrasound is safe, not painful, and does not use radiation. You will be asked to complete: a short questionnaire about your health, a cognitive screening, and an oral motor screening. If you meet the inclusion criteria of the study, then you will be asked to participate in the study. Once your height, weight, and jaw size are measured, you will be given small amounts of water or fruit juice while the ultrasound transducer is placed under your chin. Gel will be put on the transducer before each picture is taken. This gel makes it the ultrasound picture clearer. It easily wipes off and will not stain clothes. There will be a maximum of 4 phases in the study and you will be provided with a short break between each phase.

**Risks and Discomforts** It is important to understand that the questionnaire, cognitive screening, and oral motor examination will minimize risks and discomforts associated with swallowing water or fruit juice.

**Benefits** Although there are no direct benefits to the people in this study, the data collected in this study can aid speech-language pathologists in appropriately assessing and serving clients with difficulty swallowing.

**Confidentiality** All information obtained from the study will be kept confidential. In this study, only Dr. Donna Scarborough, Briana Corcoran, & Kimberly Hubacher will have access to the confidential data. Data will be collected under a code that will allow the researchers to distinguish your data from the others while keeping your identity anonymous to outside sources. After the data has been thoroughly analyzed, discussed and written up in a formal project, your identifying code
will be dropped and only the statistical information will be kept for research purposes. Once this code is established and testing results are recorded, the final compiled data will be stored in Bachelor Hall in the testing room in a locked file cabinet.

**Withdrawal without Prejudice** You may decide to remove yourself from the study at any time or refuse to answer or participate in anything that makes you feel uncomfortable.

**Payments to Subject for Participation in Research** You will receive your 1 hour of service credit for your social/philanthropic organization or $10 visa gift card once you have formally enrolled in the study (signed consent), a time as been scheduled, and data collection has been initiated.

**Questions**

Any questions concerning the research project can be directed towards:

Briana Corcoran, Graduate Student, Research Team Leader  
513-260-1088  email: kellembc@muohio.edu

Dr. Donna Scarborough, Ph. D., CCC-SLP  
513-529-2506  email: scarbod@muohio.edu

Questions regarding rights as a person in this research project should be directed to the Office of Advancement of Research and Scholarship of Miami University at 513-529-3600 or email: humansubjects@muohio.edu

**Agreement**

This agreement states that you have received a copy of informed consent. I confirm that I am at least 18 years of age.

Subject’s signature ________________________________  
Subject name (print) ________________________________  
Date ________________________________  
Witness ________________________________
Appendix E – Questionnaire

Subject Questionnaire

Subject Number: ___________________________ Date:

Date of Birth: ___________________________ Primary Language: ___________________________

**Medical Information:**

<table>
<thead>
<tr>
<th>Do you have a history of</th>
<th>If yes, please explain:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1</strong> Red dye allergy</td>
<td>Yes No</td>
</tr>
<tr>
<td>Fructose allergy</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>2</strong> Head and neck cancer</td>
<td>Yes No</td>
</tr>
<tr>
<td>Cerebral vascular accidents (stroke)</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>4</strong> Traumatic brain injury</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>5</strong> Concussion</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>6</strong> Parkinson’s disease</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>7</strong> Multiple sclerosis</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>8</strong> Huntington’s chorea</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>9</strong> Early onset dementia</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>10</strong> Goiters</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>11</strong> Pain during swallowing</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>12</strong> Gastroesophageal reflux disease or other intestinal and/or stomach problems</td>
<td>Yes No</td>
</tr>
<tr>
<td><strong>13</strong> Seizures</td>
<td>Yes No</td>
</tr>
</tbody>
</table>

**Do you...**

<table>
<thead>
<tr>
<th>Have a head or stomach cold/virus</th>
<th>Yes No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Take medications</td>
<td>Yes No</td>
</tr>
<tr>
<td>Notice that you cough after</td>
<td>Yes No</td>
</tr>
</tbody>
</table>

Any juice alternative?
<table>
<thead>
<tr>
<th>Mealtime</th>
<th>17</th>
<th>18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notice a “gurgly” or “wet” voice quality after eating or drinking</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Notice food or liquid coming out of your nose when you eat/drink</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>
Appendix F – Cognitive Screening

VAMC SLUMS Examination
Questions about this assessment tool? E-mail aging@slu.edu.

Subject Number ____________________________  Age ____________________________
Is patient alert? ____________________________  Level of education ____________________________

1. What day of the week is it?
2. What is the year?
3. What state are we in?
4. Please remember these five objects. I will ask you what they are later.
   Apple  Pen  Tie  House  Car
5. You have $100 and you go to the store and buy a dozen apples for $3 and a tricycle for $20.
   How much did you spend?
   How much do you have left?
6. Please name as many animals as you can in one minute.
   0-4 animals  5-9 animals  10-14 animals  15+ animals
7. What were the five objects I asked you to remember? 1 point for each one correct.
8. I am going to give you a series of numbers and I would like you to give them to me backwards.
   For example, if I say 42, you would say 24.
   87  649  8537
9. This is a clock face. Please put in the hour markers and the time at
   ten minutes to eleven o’clock.
   Hour markers okay
   Time correct
10. Please place an X in the triangle.
    □  □  □
    Which of the above figures is largest?
11. I am going to tell you a story. Please listen carefully because afterwards, I’m going to ask you
    some questions about it.
    Jill was a very successful stockbroker. She made a lot of money on the stock market. She then met
    Jack, a devastatingly handsome man. She married him and had three children. They lived in Chicago.
    She then stopped work and stayed at home to bring up her children. When they were teenagers, she
    went back to work. She and Jack lived happily ever after.
    What was the female’s name?
    When did she go back to work?
    What work did she do?
    What state did she live in?

TOTAL SCORE ____________________________

Department of Veterans Affairs  SAINT LOUIS UNIVERSITY

<table>
<thead>
<tr>
<th>High School Education</th>
<th>Normal</th>
<th>Less than High School Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-30</td>
<td>Normal</td>
<td>25-30</td>
</tr>
<tr>
<td>21-26</td>
<td>MNC*</td>
<td>20-24</td>
</tr>
<tr>
<td>1-20</td>
<td>Dementia</td>
<td>1-19</td>
</tr>
</tbody>
</table>
* Mild Neurocognitive Disorder