August 2013

# The Effects of Expiratory Muscle Strength Training on Swallowing and Voice Measures in Healthy Older Adults

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THE EFFECTS OF EXPIRATORY MUSCLE STRENGTH TRAINING ON

SWALLOWING AND VOICE MEASURES IN HEALTHY OLDER ADULTS

by

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A Thesis Submitted in

Partial Fulfillment of the

Requirements for the Degree of

Master of Science

in Communication Sciences and Disorders

at

The University of Wisconsin – Milwaukee

August 2013

ABSTRACT
THE EFFECTS OF EXPIRATORY MUSCLE STRENGTH TRAINING ON SWALLOWING AND VOICE MEASURES IN HEALTHY OLDER ADULTS

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The University of Wisconsin – Milwaukee, 2013
Under the Supervision of Professor Marylou Pausewang Gelfer

This study investigated the effects of a four week expiratory muscle strength training (EMST) exercise program on healthy older adults (65-79 years). The investigators were interested in possible changes to the swallowing and voice production systems, both of which are in the scope of practice for a speech language pathologist. Specific voice variables included maximum phonation time, conversational intensity level, and upper and lower limits of available intensity range. Swallowing variables were related to tongue function and included maximum isometric pressure and mean swallowing pressure. Finally, maximum expiratory pressure was measured as a comparative value to other EMST studies. A Control group and a Treatment group were involved in this study, with both groups screened for any past history of speech, language, swallowing, or respiratory disorders.

Pre-test to post-test significant differences were found between the Treatment and Control group for the upper limit of available intensity range and maximum expiratory pressure. The results indicate that older adults can increase their vocal volume following an EMST exercise program. Further research is necessary to evaluate other lingual strength and function variables, and effects of detraining following EMST device use.

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# ACKNOWLEDGMENTS

I would like to thank the following people who played a significant role in the completion of this thesis:

Dr. Marylou Gelfer. I truly appreciate all the countless hours, meetings, and flexibility in completing this work. You were always available to provide advice and insight, all while balancing your other responsibilities. For all that you have done, thank you.

Dr. Caryn Easterling. You were my inspiration to initiate this project. I always looked forward to your feedback, as I knew my work would be better because of it. This thesis would not be what it is if it were not for you.

Dr. Sabine Heuer. Thank you for your feedback and support throughout this process. Your words of encouragement were always appreciated.

Gretchen Metcalf. Thank you for helping make the ends meet.

The participants. Your kindness in helping me with this project was overwhelming. Thank you for sacrificing your time to help this work.

My family. For whom the phrase “thank you” is just not enough.

# The Effects of Expiratory Muscle Strength Training on Swallowing and Voice Measures in Healthy Older Adults

## *Introduction*

Speech language pathologists are professionals who are trained to evaluate, treat and counsel individuals with communication and swallowing disorders. In the hospital setting, speech language pathologists are likely to see clients with neurologically-based disorders that affect voice and swallowing. The majority of anatomical components required for phonation and swallowing are housed within the upper aerodigestive tract, defined as the oral and nasal cavities, pharynx, larynx, trachea, and portions of the esophagus. The structures of the upper aerodigestive tract are shared by the phonatory, swallowing, and respiratory systems. Because of their role in rehabilitation, it is important for speech language pathologists to understand the association and interaction between the phonatory and swallowing systems, as well as the role and interplay of respiration, as it may be possible to achieve positive treatment outcomes without targeting each system individually. The relationship between the previously mentioned systems will be highlighted throughout the introduction.

### *Swallowing*

Swallowing, also known as deglutition, is described as the passage of food and liquid through the mouth, pharynx, and esophagus into the stomach. However, the anatomy and physiology of swallowing is complex and therefore not easily defined. The intricacy of the deglutitive process makes it highly susceptible to disruption, although a healthy adult typically does not develop swallowing problems. Swallowing problems, or dysphagia, usually result from neurological disorders, including those prevalent with aging and the associated anatomical and physiological changes (Logemann, 1998). When dysphagia occurs, it may eventually result in additional health challenges such as inadequate nutrition, dehydration, and aspiration pneumonia. In addition, the social or quality of life aspects of meal times can be altered secondary to dysphagia (Logemann, 1998).

The speech language pathologist is a member of the team of professionals responsible for working with those who have dysphagia. The physician, nurse, dietician, occupational therapist, physical therapist, pharmacist, and radiologist may also be involved in treating swallowing problems (Logemann, 1998). However, it is the speech language pathologist's role (and included in the professional scope of practice) to evaluate swallow physiology and provide recommendations including compensatory strategies, rehabilitative treatment, and appropriate diet consistencies to improve the dysphagic patient's quality of life (Logemann, 1998). The speech language pathologist is qualified and trained to identify the swallowing problems and then develop a plan to improve function through rehabilitative therapy and/or compensatory treatment.

Professionals who diagnose and treat dysphagia require specific knowledge regarding the anatomy and physiology of the swallowing mechanism in order to competently provide evaluation, treatment, and management recommendations. Knowledge of the anatomy and physiology of the swallowing mechanism makes the speech language pathologist qualified to analyze its physiologic function and dysfunction, and to determine the steps required to return the disordered physiology to its normal function (Logemann, 1998). One important aspect of the swallowing mechanism to consider is the tongue, and its role during deglutition.

The tongue is integral in successful bolus manipulation and generation of pressure for bolus propulsion. The tongue is divided into two portions, and is controlled by intrinsic and extrinsic muscles. The oral tongue includes the tip and the blade anteriorly, and ends posteriorly at the circumvallate papillae (Logemann, 1998). The pharyngeal tongue, also referred to as the tongue base, begins at the circumvallate papillae and extends inferiorly to the hyoid bone. The oral tongue is under cortical and voluntary control (Logemann, 1998). The pharyngeal tongue is controlled subcortically and involuntarily, by the medullary swallow center in the brainstem (Logemann, 1998). The extrinsic muscles of the tongue are innervated by the hypoglossal nerve (cranial nerve XII), except for the palatoglossus muscle, which is innervated by the vagus and accessory nerves (cranial nerves X-XI; Seikel, King, and Drumright, 2010). The intrinsic muscles of the tongue are also innervated by the hypoglossal nerve (cranial nerve XII; Dodds, Stewart, and Logemann, 1990).

The tongue is active and essential in the oral preparatory, oral, and pharyngeal phases of the swallow. In the oral preparatory phase of the swallow, the tongue maintains a “dipper” posture; that is, the bolus is underneath the anterior tongue; or a “tipper” posture with the bolus in a supralingual position (Dodds et al., 1990). In the oral phase, the tongue tip lifts the bolus against the hard palate, so that the bolus and tongue move posteriorly. Simultaneously, the tongue sides and tip remain sealed against the alveolar ridge, preventing the bolus from spilling out of the oral cavity (Dodds et al., 1990). During the pharyngeal phase, the tongue base ramps against the pharyngeal walls to move the bolus down into the pharynx (Dodds et al., 1990).

In addition to the tongue, the *hyolaryngeal complex* also plays a crucial role in normal swallow biomechanics. During swallowing, the hyolaryngeal complex is elevated and moved anteriorly, providing airway protection and forward traction on the upper esophageal sphincter (Dodds et al., 1990). The hyolaryngeal complex is composed of three attachment sites: the hyoid bone, thyrohyoid membrane, and laryngeal cartilages (Pearson, Langmore, Yu, and Zumwalt, 2012), and a variety of muscles including the sternothyroid, thyrohyoid, digastric, stylohyoid, mylohyoid, geniohyoid, hyoglossus, and genioglossus (Zemlin, 1998). The hyoid bone is located at the base of the tongue, and is one attachment of the many muscles listed above (Logemann, 1998). For example, it is connected anteriorly to the mandible through the mylohyoid, the anterior belly of the digastric, and the geniohyoid.

The mylohyoid originates on the inside surface of the jaw. It has a fan-like span, coursing from both sides of the mandible toward the midline. From an inferior view, the angle is oblique while heading in a slightly posterior direction. The mylohyoid has two insertion points based on the location of the fibers. The posterior fibers of the mylohyoid insert on the body of the hyoid bone. The anterior fibers conjoin with the fibers of the opposite side at the median raphe (McFarland, 2009). The overall action of this muscle moves the hyoid bone forward and up, assisting with the superior and anterior movement required for swallowing (McFarland, 2009).

The digastric is located superficially in relation to the mylohyoid. The digastric is divided into two portions: the anterior belly and the posterior belly. The anterior belly originates near the midline of the mandible, on the internal surface. The insertion point for the anterior belly is the intermediate tendon, a loop of connective tissue attached to the hyoid bone. The anterior belly courses in a straight path from the mandible to the intermediate tendon (McFarland, 2009). The anterior belly of the digastric lifts the hyoid bone and pulls it anteriorly. The posterior belly of the digastric originates on the mastoid process of the temporal bone, and inserts on the intermediate tendon that connects to the hyoid bone (Colton et al., 2011). The function of the posterior belly is to draw the hyoid bone posteriorly and superiorly. Contraction of both the posterior belly and anterior belly of the digastric elevates the hyoid; their anterior and posterior vectors cancel each other out (Seikel et al., 2010).

The geniohyoid is located deep to the mylohyoid. It would almost appear that the fan-like shape of the mylohyoid provides a surface for the geniohyoid to lie on. With that in mind, and a superior view, the geniohyoid courses posteriorly from its origin at the mental symphysis of the mandible to the insertion point on the anterior surface of the hyoid bone (Colton, Casper, and Leonard, 2011). The general function of the geniohyoid is to pull the hyoid bone upward and forward (Colton et al., 2011).

Indirect posterior attachments of the hyoid bone include the styloid and mastoid processes of the temporal bone of the skull. The hyoid bone is connected to the styloid process via the stylohyoid muscle and to the mastoid process via the posterior belly of the digastric (Pearson et al., 2012). The stylohyoid is superficially located when compared to the posterior belly of the digastric. The muscle originates on the styloid process of the temporal bone and inserts on the hyoid bone (Colton et al., 2011). The stylohyoid pulls the hyoid bone posteriorly and superiorly.

Two extrinsic muscles of the tongue also aid in elevating the hyoid: the hyoglosssus and genioglossus. The hyoglossus muscle fibers extend from the greater cornu of the hyoid bone to the side of the tongue in a vertical manner (Hixon, Weismer, and Hoit, 2008). The muscle will depress and pull back the tongue when it contracts. If the tongue is more fixed than the hyoid bone, the hyoglossus will elevate the hyoid bone (Hixon et al., 2008). The genioglossus muscle fibers move from the inside of the mandible underneath the tongue to the body of the hyoid bone (Hixon et al., 2008). Contraction of this muscle can move the hyoid bone anterosuperiorly (Hixon et al., 2008).

The mylohyoid, digastric, geniohyoid, stylohyoid, hyoglossus, and genioglossus are all considered suprahyoid muscles (Hixon et al., 2008). These aptly named muscles located above the hyoid bone all function to elevate the hyoid bone. Finally, the hyoid bone itself serves as the superior boundary of the larynx, connecting to the thyroid cartilage via the thyrohyoid ligament and thyrohyoid muscles (Logemann, 1998). Hyolaryngeal muscles involved in the superior and anterior movement of hyoid bone are innervated by the mandibular branch of the trigeminal nerve (cranial nerve V) and the facial nerve (cranial nerve VII; Dodds et al., 1990).

Through an examination of tongue movement and swallowing as mediated by the suprahyoids, it is evident that the hyoid bone plays a central role in swallowing by anchoring the movement of the larynx and serving as the attachment point for inferior tongue musculature (Zemlin, 1998). The laryngeal movement required for swallowing follows the anterior and superior movement initiated by the muscles that attach to the hyoid bone. However, involvement of the entire hyolaryngeal complex is not observed until the initiation of the pharyngeal phase of the swallow. The pharyngeal phase is initiated once the head of the bolus is sensed at some point between the “anterior faucial arches and the point where the tongue bases crosses the lower rim of the mandible”

(Logemann, 1998, p. 29). According to the reflex-chain hypothesis, the sensation of the head of the bolus at the ramus of the mandible triggers the pharyngeal phase of the swallow (Dodds et al., 1990). The sensation is monitored by the swallowing sensory centers that are located in the brainstem. The trigger of the pharyngeal phase leads to elevation of the hyoid bone, which in turns elevates the larynx.

Layers of closure occur within the larynx when the superior movement of the larynx is at “50% of its maximum elevation” (Logemann, 1998, p.33). The vocal folds close first, which halts respiration. This movement demonstrates the reciprocal nature of swallowing and respiration (i.e., when deglutition occurs, respiration should not occur and vice versa; Martin-Harris, 2006). Continuing superiorly through the larynx, the ventricular folds also close. Finally, the epiglottis covers the laryngeal vestibule (Logemann, 1998). The inferosuperior closure is a method of expelling any penetrated portion of the bolus that may have entered the airway (Logemann, 1998).

The reciprocity between deglutition and respiration is linked with the phases of respiration. The swallow typically occurs during the expiratory phase of respiration (Logemann, 1998; Martin-Harris, 2006). Physiologically, this is consistent with the vocal folds, as they should be in a slightly adducted state (Martin-Harris, 2006). After the swallow, expiration should occur again (Martin-Harris, 2006). Expiration after the swallow acts a safety mechanism to help clear any bolus particles remaining in the airway. The apneatic period that occurs with swallowing only occurs during the pharyngeal phase of the swallow (Martin-Harris, 2006). The swallow apnea period may vary with bolus size, age, and/or various neurological disorders (Martin-Harris, 2006).

The hyolaryngeal complex is pulled superiorly, resulting in the aforementioned airway closure, and anteriorly, resulting in a traction force (Dodds et al., 1990). The traction force is responsible for opening the upper esophageal sphincter (UES). The traction force is produced by contraction of the suprahyoid muscles, resulting in the principle muscular influence on the UES opening for deglutition. The distance the hyolaryngeal complex moves relates to the distance of the anterior-posterior deglutitive opening of the UES. The time it takes for the hyolaryngeal complex to move, as well as how long it is extended away from its typical position, relates to the duration of deglutitive UES opening (Dodds, et al., 1990).

In addition to the anterior and superior movement of the hyoid bone, a few other events occur. Prior to the hyoid bone movement, the velopharyngeal port is closed to prevent any nasal regurgitation. At nearly the same time, the superior, medial, and inferior pharyngeal constrictors respectively contract. Intrabolus pressure, or the pressure generated by the bolus as it is propelled into the pharynx, also acts to widen the UES, depending on the size of the bolus (Logemann, 1998). Successful completion of the aforementioned physiologic events prevents food or liquid from entering the airway, and directs the bolus into the esophagus where peristalsis moves it toward the stomach (Logemann, 1998).

The scope of the speech language pathologist’s clinical training and competency includes expertise in the areas of both swallowing and voice disorders. Deglutition and voice production share the same structures and muscles, and therefore the physiologic function and dysfunction of one can affect the other.

*Voice production*

Similar to swallowing, voice production can be easily defined but requires a more in-depth discussion to understand the intricacies of the process. The vocal folds, which are located within the larynx, vibrate as a result of contact with one another and airflow. The vibration then produces a tone, which is modified by structures within the head including the lips, tongue, and pharynx (Colton et al., 2011). The result of the tone production and modification is a person’s voice. Voice is the “carrier signal” of speech, and allows a speaker to project his or her message. It can be used to convey emotion, instruct a classroom, and sing a song. Additionally, people relate to the way their voice is produced. People are aware of what their voice “should” sound like and can easily identify when something is wrong. The cause of such changes can be a variety of pathologies, alterations in the voice production mechanism, or a change in the way a person views him- or herself, and/or a reduction in the possible ways a person chooses to interact with others.

The speech-language pathologist has training, skills, and competencies in regard to voice. He or she can work to discover the underlying cause of the voice disorder, rather than the immediate problem. Knowledge of etiological factors can aid the speech language pathologist in developing a treatment plan for the person who has a voice disorder. Strategies to reduce further damage to the voice production mechanism, modification of disordered physiology, or therapy to strengthen voice can all be utilized to help patients (Colton et al., 2011). The speech language pathologist works in conjunction with a team comprised of an otolaryngologist, psychologist, nurses and other professions depending on the particular patient (Colton et al., 2011). The team works together to diagnose and treat the voice disorder. Like swallowing, it is important that the speech language pathologist have an understanding of the anatomy and physiology associated with voice production. The knowledge of anatomy and physiology can help the professionals involved in voice evaluate the disorder, and determine possible treatment to resolve the problem.

The voice production mechanism can be divided into two parts for the purpose of discussion. The first part is the phonatory subsystem, which includes the intrinsic and extrinsic muscles of the larynx. The second part is the respiratory subsystem that includes the inspiratory and expiratory muscles. The two subsystems work together to produce voice.

The phonatory subsystem required for voice is centralized around the larynx and the movement of the vocal folds. The larynx is composed of the hyoid bone, various cartilages including the thyroid cartilage, cricoid cartilage, two arytenoid cartilages, two corniculate cartilages, two cuneiform cartilages, and the epiglottis (Colton et al., 2011). All of the cartilages are composed of hyaline, a cell type. Hyaline cartilage is softer than bone, however, it is susceptible to ossification as a person ages (Colton et al., 2011). The cartilages are held together by connective tissue and the intrinsic muscles of the larynx, which have origin and insertion points within the larynx and function to modify the vocal folds.

The intrinsic muscles of the larynx have important functions in opening, closing and compressing the vocal folds. That muscles that are in direct control of the previously mentioned tasks are the lateral cricoarytenoids, interarytenoids, and posterior cricoarytenoid. All of the muscles are innervated by the vagus nerve (cranial nerve X) combined with the bulbar fibers of the spinal accessory nerve (cranial nerve XI; Hixon et al., 2008).

The lateral cricoarytenoid muscle and interarytenoid muscle are responsible for bringing the vocal folds together. The lateral cricoarytenoid begins at the lateral aspect of the cricoid cartilage and courses superiorly and posteriorly to attach to the muscular process of the arytenoids (Hixon et al., 2008). Contraction of this muscle rocks the vocal processes of the arytenoids towards the center, subsequently moving the vocal folds towards midline. The interarytenoid muscle also functions to approximate the vocal folds. The interarytenoid muscle is composed of two portions: the transverse arytenoid, which originates on the posterior side of one arytenoid and inserts on the posterior side of the other arytenoid; and the oblique arytenoid, which begins at the posterior side of one arytenoid and courses upward to attach at the apex of the other arytenoid (Hixon et al., 2008). Contraction of the transverse arytenoid muscle pulls upward and inward on the arytenoid cartilages, whereas the oblique arytenoid muscle pulls one arytenoid toward the other via a “tipping motion” (Hixon et al., 2008). These actions result in closing off the posterior airway by closing the cartilaginous glottis (Colton et al., 2011).

The posterior cricoarytenoid muscle pulls the vocal folds away from midline. This muscle originates on the cricoid lamina, and courses up and backward to insert on the back of surface of the arytenoid cartilages at the posterior surface of the muscular processes (Hixon et al., 2008). When this muscle contracts, the vocal processes of the arytenoid cartilages rock away from the center position (Hixon et al., 2008). Phonation and speech production require the movement of the vocal folds both towards and away from midline, which only occurs through the contraction of the previously mentioned muscles.

Phonation is best described by the aerodynamic-myoelastic theory, first developed by Johannes Muller, and later expanded upon and popularized by Janwillem van den Berg in 1958 (Beherman, 2007). The theory incorporates both the aerodynamic factors of airflow (which generates the Bernoulli force) and subglottic pressure; and the myoelastic elements that occur due to vocal fold elasticity and muscle contraction. All of these factors combine to initiate and sustain phonation.

As mentioned earlier, the vocal processes of the arytenoid cartilages rotate in to approximate the vocal folds via the lateral cricoarytenoid and interarytenoid (McFarland, 2009). The pressure below the glottis begins to build as air flowing up from the lungs is blocked due to the partial closure of the vocal folds. The subglottal pressure eventually overcomes the vocal fold resistance and begins to push the inferior borders of the vocal folds laterally (Behrman, 2007). The upper borders of the vocal folds are eventually pushed laterally as well, due to their attachment to the lower borders and the continued subglottal pressure. The vocal folds continue to open until subglottic pressure is less than the supraglottic pressure, and tissue elasticity starts moving the vocal folds back to midline. When the vocal folds reach a critical distance apart, airflow between them creates the Bernoulli force; which brings them completely together. The Bernoulli Force occurs because the pressure exerted on the inner surfaces of the vocal folds by subglottal air decreases as the velocity of the moving air between the vocal folds increases (Behrman, 2007). Once the vocal folds are closed, subglottic pressure begins to increase once more as the cycle starts over. It should be noted that in this model, subglottic pressure is not a constant, and may vary with how loudly a person is speaking.

Intensity of voice, an acoustic measure, is perceived as vocal loudness. Intensity increases as the square of the amplitude of the sound wave (Behrman, 2007). Amplitude of the sound wave created by vocal fold vibration is controlled by subglottal pressure and resistance of the vocal folds (Behrman, 2007). Increasing the subglottal pressure increases the amount of air molecules escaping when the glottis is open, and causes greater amplitude of glottal opening (Behrman, 2007). Greater tension must also be present in the vocal folds, to furnish the resistance against increasing subglottic pressure, in order to have all necessary components for a louder voice.

The extrinsic muscles of the larynx have one connection to the larynx and the other attachment outside of the larynx. More specifically, almost all of the laryngeal attachments of the extrinsic muscles are made at the hyoid bone. The extrinsic muscles of the larynx are divided into two groups: the suprahyoid muscles and the infrahyoid muscles, depending on if they attach above or below the hyoid bone. According to Colton et al. (2011), the suprahyoid muscles include the anterior and posterior bellies of the digastric, mylohyoid, geniohyoid, and stylohyoid. However, as cited earlier, the hyoglossus and genioglossus are often included in the suprahyoid muscle grouping (Hixon et al., 2008). The overlap of muscles and muscle functions in the upper aerodigestive system highlights how closely linked the deglutition, phonatory, and respiratory systems are with one another. The specific anatomy of the suprahyoid muscles has been discussed in the swallowing section. The general function of pulling the hyoid bone anteriorly, superiorly, or posteriorly not only aids in swallow mechanics but can also modify voice production. The suprahyoid muscles also move the larynx upward, which can tense the vocal folds. In general, the suprahyoids contribute to voice production by raising the larynx, resulting in the tensing of the vocal folds and therefore increasing pitch at the upper extremes (Hixon et al., 2008; Behrman, 2007).

Since airflow and subglottic pressure are such important components of phonation, it is evident that respiration must play a crucial role in the production of voice, in order to provide exhaled air to create subglottal pressure and the Bernoulli Force. In addition, during running speech, a talker must have a sufficient volume of air and control of his or her respiratory system to produce utterances of the desired length. This need for respiratory support is critical to both the production of voice itself and to its functional use. Given this importance, the anatomy and physiology of the respiratory system should be familiar to the speech language pathologist, so that it can be drawn on for therapeutic applications.

As mentioned earlier, the respiratory subsystem is divided into inspiratory and expiratory muscles. The inspiratory muscles include the muscles of the neck, thorax (primary and accessory), back, and upper limbs (Seikel et al., 2010). The primary muscle of inspiration is the diaphragm, which separates the abdominal and thoracic cavities (Seikel et al., 2010). The diaphragm is the main muscle that allows for the expansion of the lungs required to take in a breath. Depending on the speaker’s planned message, the inspiration may or may not be deeper than normal rest breathing. The diaphragm has its origins at the rib cage, xiphoid process, and the vertebral column. It inserts superiorly and medially into the central tendon, which creates an inverted bowl-like appearance (Seikel et al., 2010). When the diaphragm contracts, it functionally increases the thorax volume by pulling down on the central tendon, expanding the superior-inferior dimension of the lungs (Hixon et al., 2008).

The other muscles of inspiration act in conjunction with the diaphragm to increase the size of the thorax in order for the lungs to expand. Two important muscles of this process include the external intercostals and pectoralis minor. The external intercostal muscles course toward midline and downward and attach between each rib. These muscles are separated by each rib, and contraction of a single muscle elevates the rib below it (Hixon et al., 2008). Various levels of contraction can be used to raise the rib cage and allow for expansion of the lungs. Pectoralis minor also appears to function toward this goal. Originating from the second through fifth ribs, the muscle inserts on the anterior surface of the scapula (Hixon et al., 2008). The anatomical positioning of this muscle suggests that it can be used to raise the ribs if the scapula is stabilized, and to expand the thoracic cavity.

The muscles of expiration are divided into two parts: the anterior/lateral thoracic muscles and the abdominal muscles. One of the anterior/lateral thoracic muscles is the interosseous portion of the internal intercostals. The internal intercostals function to pull the ribs downward. They originate at the inner superior surface of the rib immediately below and then run upward and inward to insert on the inner inferior surface of the rib above. The muscles are in a vertical direction that angles slightly distally. The internal intercostals almost form a right angle with the external intercostals, which run downward and inward.

The external oblique muscle is one of the abdominal muscles that is involved in expiration. McFarland (2009) describes the muscle as “sheetlike.” It originates at the external surfaces of ribs five through twelve. The muscle moves roughly at a 45 degree angle downward and inward to insert at the iliac crest, the inguinal ligament, and the linea semilunaris (McFarland, 2009), which is lateral to rectus abdominis muscle (Seikel et al., 2010). It functions in speech expiration to pull down on the ribs, and to reduce the size of the thoracic cavity by compressing the abdominal viscera and forcing them upward against the diaphragm.

The internal oblique muscle, another of the abdominal muscles, can also be described as “sheetlike.” The internal oblique originates at the iliac crest and the inguinal ligaments, also two of three insertion points of the external oblique. The internal oblique has an additional origination point at the thoracolumbar fascia (McFarland, 2009). The muscle runs upward and medially to insert at the costal cartilages of the lowest three ribs. The costal cartilage insertion allows the muscle to bring the costal cartilages closer to the pubis as well as to compress the abdomen as described for the external oblique muscle (McFarland, 2009).

A third abdominal muscle is the transverse abdominis. The transverse abdominis has similar origins to the internal oblique muscle plus other attachments. The iliac crest, inguinal ligaments, thoracolumbar fascia, and the cartilages of the lower six ribs are all points of origin for the transverse abdominis (McFarland, 2009). The muscle inserts at the midline of the abdomen. Transverse abdominis moves in a lateral direction and functions to compress the abdomen as well as forcing compression of the thoracic cavity via the upward movement of the abdominal viscera against the diaphragm (McFarland, 2009). Functionally, the external oblique, internal oblique, and transverse abdominis all work together to provide even and consistent airflow for voice production by forcing the abdominal viscera upward, pushing up on the diaphragm, and reducing the volume of the thoracic cavity.

The final abdominal muscle to be discussed is the rectus abdominis. There are four to five segments that originate at the pubis inferiorly and insert superiorly at the xiphoid process as well as the cartilage of the fifth, sixth, and seventh ribs (Seikel et al., 2010). Like the other abdominal muscles, the rectus abdominis functions to compress the abdomen, although it follows a vertical course (McFarland, 2009). During speech breathing, the rectus abdominis and the other expiratory muscles help regulate the flow of air out of the lungs.

Two simultaneous types of pressure are required for speech breathing. The first is a constant subglottal pressure. This pressure is required to maintain vibration of the vocal folds. For a sustained voicing effort there must be constant pressure (Seikel et al., 2010). The other pressures required for speech breathing are much shorter. These small and quick bursts are used to impose amplitude or loudness inflection and variety into our speech. The quick bursts are what make our speech dynamic and help us avoid monotone speech. They are accomplished through varying the subglottal pressures and abrupt vocal fold approximation. The larynx is neurologically prepared to change for different sound productions by adjusting vocal fold stiffness, airway resistance, and glottal size and configuration (Hixon et al., 2008).

Expiration of the air has to occur slowly and must be controlled if speech durations are to support a speaker’s planned utterance length. The muscles of inspiration and expiration are responsible for that controlled airflow. The muscles of inspiration stay slightly contracted during exhalation to slow down the airflow, relaxing very gradually.

This is referred to as “checking action” (Seikel et al., 2010). Checking can also be referred to as impedance of exhaled airflow. Without the checking action created by the inspiratory muscles, speech durations would be significantly shorter.

The muscles of inspiration only gradually relax to a certain point. Once resting lung volume is reached at approximately 55% vital capacity in the upright body position or 38% of vital capacity in the supine position, speakers require the use of expiratory muscle effort to continue phonating (Hixon et al., 2008). The contraction of the expiratory muscles allows the thoracic cavity to decrease in volume at the continued constant rate required for speech (Seikel et al., 2010). Tension in the abdominal expiratory muscles pushes inward on the abdominal viscera, which in turn forces them up and pushes on the diaphragm, as described above. The resulting action reduces the volume of the lungs.

Speech breathing does come at the cost of overcoming recoil forces and therefore takes effort. A deeper inhalation results in a greater resting lung volume. (Seikel et al., 2010) The maintenance of subglottal pressure also requires effort from the respiratory system. Finally, vocal inflections can be controlled by pulsed contractions of expiratory muscles. The change in contraction also can cause an increase in effort for the respiratory system.

The phonatory and respiratory subsystems that contribute to voice production require coordination and muscular strength to produce appropriate voice quality. Unfortunately, the voice production mechanism can change due to the effects of aging. Weakening of the muscles of respiration can affect a person’s ability to phrase sentences and convey emotion through varied intensity and pitch modification.

Swallowing is also affected by normal, healthy aging, due to the sensory and motor changes that occur during the aging process. An elderly person may have slower movement of the hyolaryngeal complex (Kendall and Leonard, 2001). The tongue, an established component of deglutition, also changes with age. Tongue pressure reserve declines, and the time it takes to reach the peak pressure for swallowing increases (Robbins, Levine, Wood, Roecker, and Luschei, 1995; Nicosia et al., 2000). A further examination of how aging affects the upper aerodigestive tract is necessary to aid in determination of potential preventive options.

*Aging*

The number of people over the age of 65 is increasing in the United States, compared to previous decades (Ferrand, 2012), resulting in more opportunities to observe the normal, healthy signs of the aging process. The importance of muscle function in deglutition and voice production have been highlighted in the previous sections. In aging, an adult’s muscles undergo degenerative changes called *sarcopenia*. Sarcopenia refers to age-related changes that affect the quantity and quality of muscle fibers (Waters, Baumgartner, Garry, and Vellas, 2010). The fiber changes include smaller muscle fibers with slowed muscle contractile response. Because of sarcopenia, elderly adults may experience functional disruption in activities of daily living (Waters et al., 2010).

An overall decrease in muscular performance is common and expected as healthy individuals age. The muscular changes that are more easily observed first occur in the proximal limb muscles (Campbell, McComas, and Petito, 1973). Information regarding the functional changes in swallowing can be extrapolated from this information. The alterations in the proximal limb muscles can be measured and compared to that of younger individuals to clearly identify the degeneration that is suspected to take place. The parameters for estimating muscle strength include an increase or decrease in cross-sectional area of activated muscle fibers, maximal twitch tension, and number of motor units. The general properties and condition of existing motor units are also of concern (Campbell et al., 1973). Of the four listed parameters, the most significant factor is the reduction in the number of functional motor units.

The motor units, typically fast (type II) muscle fibers, become less functional as they are denervated. This denervation occurs because the motor axons begin to die (Carlson, 2004), however it typically does not occur before age sixty (Campbell et al., 1973). Of the existing motor units, compensatory changes may occur by recruiting nerve fibers that have lost their initial function (Campbell et al., 1973). The result would be a loss in strength for the older group when compared to a younger group because the adopted fibers sprout from slow twitch muscle fiber motor units rather than the original fast twitch muscle fibers (Carlson, 2004). The change and/or lack of innervation to the muscle fiber can lead to the fibers' disappearance (Carlson, 2004). These changes may not be as observable in the swallowing and voice mechanisms compared to proximal limb muscles, however, they are nevertheless present and could be detrimental to the quality of life of the older adult. For example, muscular changes to the tongue can result in altered lingual pressure generation effort for swallowing purposes. Adequate pressure generation and other oral tongue functions are necessary in the initiation of the pharyngeal swallow (Robbins et al., 1995).

In addition to muscle weakness as a correlate of aging, ossification of cartilage and degenerative changes to joints and attachments occur all over the body, the parts of the voice production mechanism included (Colton et al., 2011; Ferrand, 2012). The ossification of cartilage results in less flexibility, which can alter normal vocal fold vibration (Ferrand, 2012). Degeneration of the cricoarytenoid joint can limit the range of motion of the arytenoids, effecting the adduction and abduction of the vocal folds (Ferrand, 2012). A change in mass of the vocal folds also may occur, resulting in bowing of the folds during phonation (Hagen and Lyons, 1996). Unfortunately, cartilage ossification, joint degeneration, and decreased vocal fold mass are difficult to reverse, however muscles can be strengthened regardless of age (Carlson, 2004).

*Effects of Aging on Swallowing.* The essential roles that the tongue and hyolaryngeal complex play in the successful swallow have been discussed earlier. The two structures both have significant muscular components and are therefore vulnerable to muscular weakening associated with sarcopenia. Several studies have been conducted to determine the changes that occur to the tongue and hyolaryngeal complex due to aging.

Measurable changes that occur to the tongue are mostly related to how strong the tongue is, in the presence and absence of swallowing. *Maximum isometric pressure* (MIP) is a tongue strength measurement that involves pushing the tongue against the hard palate, and is measured by determining the pressure in between the two structures. Maximum isometric pressure has been found to be significantly greater in a younger group when compared to an older group (Youmans, Youmans, and Stierwalt, 2009). A more indirect method of tongue strength, but perhaps a more functional measurement, is *mean swallowing pressure* (MSP). Mean swallowing pressure uses the same measurement unit and device used to measure in MIP, however, participants are told to swallow normally rather than to push the tongue forcefully against the hard palate (Youmans et al., 2009). In the research related to tongue strength, MSP did not significantly change with age.

The absence of change in MSP during aging requires further explanation, given that MIP did change with age in the Youmans et al. study (2009). It has been suggested that there is a functional reserve in swallowing, an idea that the tongue does not require its total strength capacity use during saliva or food swallowing (Youmans et al., 2009). A study investigating the ability to strengthen the tongue in older individuals found that individuals were able to increase lingual pressure as well as increase MSP following an exercise program (Robbins, Gangnon, Theis, Kays, Hewitt, and Hind, 2005). Therefore, a functional reserve may exist, although there does seem to be a relationship between MIP and MSP when lingual strengthening exercises are performed.

Despite the lack of changes to MSP in older individuals, another physiologic component was found. The time it takes for an older individual to reach their peak MSP was significantly longer when compared to younger individuals (Nicosia et al., 2000). This finding only occurred with liquids and not semisolids, however thin liquid is the most common consistency that is aspirated (Nicosia et al., 2000).

Current studies indicate that muscle composition changes related to aging effect the tongue, although these changes do not necessarily result in a functional disadvantage. The absence of functional findings may be related to the method of lingual strength measurement. The studies involved in lingual strengthening concentrated on the anterior portion of the tongue. As mentioned earlier, the anterior portion is a valuable component of swallowing, but it is the base of the tongue that is responsible for propelling the bolus into the pharynx. The base of the tongue is anatomically closer to the hyolaryngeal complex and both are involved in the transition from the oral phase to the pharyngeal phase during swallowing.

The hyolaryngeal complex also changes due to age, but it may be difficult to determine what physiological changes reflect anatomical change. For example, a slower rate of elevation of the hyoid bone and a reduced duration of elevation have been found in older individuals when compared to a younger control group (Kendall and Leonard, 2001). The excursion of the hyoid and larynx was also reduced compared to those of the young (Easterling, 2012). This physiological change may be due to alterations in suprahyoid muscles that attach to the hyoid bone, resulting in a decreased traction force on the UES. Further, the swallow transit is slower in older adults, especially noted after three consecutive swallows (Dejaeger and Pelemans, 1996). These changes that take place do not necessarily constitute a disorder, but older adults are considered to be “in a less favorable position” in terms of deglutition (Dejaeger and Pelemans, 1996, p. 134).

The functional implications of age-related deglutition changes are observable in the tongue and hyolaryngeal complex. The tongue may require more time to generate the pressure required for swallowing (Nicosia et al., 2000). A neurological injury such as stroke, which has already been determined to be more prevalent in older adults, could alter the coordination required for swallowing (Logemann, 1990). The combination of increased time to generate sufficient pressure and neurologically-based incoordination and or weakness could result in dysphagia. Therefore, an older individual could be at greater risk for bolus penetration or aspiration. A “slow” swallow could be especially problematic, as it would take longer to eliminate the bolus from the oral and pharyngeal cavities. The risk of aspiration would further increase if solid or liquid residue was still present in the pharynx after the swallow, caused by reduced deglutitive anteroposterior UES opening due to the reduced traction force caused by weakened suprahyoid muscle contraction.

*Effects of Aging on Voice.* Numerous changes can also occur to voice due to aging, for various reasons. The aged voiced has been noted to include “an altered pitch, hoarseness, lack of intensity, and warble” (von Leden and Alessi, 1994, p. 275). The various changes that occur could relate to the effects of aging on the structures and tissue types that compose the larynx. Cartilages that are composed of hyaline become ossified (von Leden and Alessi, 1994) and surfaces associated with joints may become thinned or damaged (Kahane, 1987). The muscles involved in the larynx and respiration are also not immune to the age-related changes seen in the rest of the body.

Regarding respiration, significant differences have been found in vital capacity (VC) when comparing older individuals to younger individuals (Awan, 2006; Hagen and Lyons, 1996). Vital capacity combines inspiratory reserve volume, expiratory reserve volume, and tidal volume; and can be more functionally defined as the amount of air that can be inspired after a maximal expiration (Seikel et al., 2010). Vital capacity therefore represents the functional respiration quantities associated with speech. As a result, a reduction in VC has the potential to effect other aspects of speech.

The functional ramifications of a lower VC are evident in measurements of speech and voice. Maximum phonation time (MPT) has been found be significantly lower in older groups when compared to younger groups (Awan, 2006). Older individuals have also been found to speak slower during longer utterances, as well as take in and use more air (Huber, 2008). Contradictory findings with vocal loudness have been reported, with some stating that there is an increase in vocal loudness with age, and others finding a gradual decrease of vocal intensity (von Leden and Alessi, 1994). A reduction in vital capacity could provide one possible rationale for changes in length and intensity of phonation.

A research study by Turley and Cohen (2009) investigated how people respond to changes in voice and swallowing with aging. Respondents in a survey given to a group with a mean age of 82.4 years indicated that 19.8% perceived that they had a voice problem and 13.7% perceived that they had a swallowing problem. Individuals who responded positively tended to report problems in both areas (voice and swallowing; Turley and Cohen, 2009). However, only a quarter of those who said they had voice and/or swallowing problems sought treatment. The respondents indicated that they viewed their problems as normal parts of aging, or did not know treatment existed (Turley and Cohen, 2009). The results of the Turley and Cohen (2009) study suggest that there is a need for treatment that can be used with the elderly to improve voice and swallowing function.

*Review of Relevant Research*

A definite relationship exists between deglutition and phonation. These two processes share musculature located within the upper aerodigestive tract, including the suprahyoid muscle group (Seikel et al., 2010). Additionally, they are both coordinated with respiration. Deglutition and respiration are reciprocal, with the swallow occurring during the expiratory phase of respiration (Martin-Harris, 2006). Sustained phonation requires the effort of the expiratory muscles to maintain a constant airflow (Seikel et al., 2010). Therefore, the possibility exists to efficiently improve both the phonatory and swallowing systems by targeting mutual structures.

The discussion of what naturally occurs to the muscles responsible for tongue function and voice production in normal older adults, and the highlighted relationship between the two subsystems begs the question: Can anything be done to reverse the changes? Strengthening the expiratory muscles of respiration could be a therapy target for improving voice function in the elderly, so they are able to better control the flow of air required to initiate and maintain vocal fold vibration. One possible technique to improve voice and speech function is expiratory muscle strength training (EMST). The recently-developed EMST device is the EMST 150, developed by Aspire Products LLC (Pitts et al., 2009). This hand-held instrument has a one-way valve that requires a set amount of expired air to release the valve, so that air can flow from the mouth through the device. The threshold of the EMST device is set at a certain percentage of a person's *maximum expiratory mouth pressure* (Pitts et al., 2009). Maximum expiratory mouth pressure (MEP) is measured after a subject has filled his or her lungs to total lung capacity and places their mouth around a mouth piece. The nose of the subject is occluded as he or she expels air as forcefully as possible out of the mouth (Chiara, Martin, Davenport, and Bolser, 2006). The pressure of this expired air is the subject's MEP. This aerodynamic measurement is an indirect method of examining expiratory muscle strength by determining how much force can be generated while expelling air only through the mouth (Kim and Sapienza, 2005). Therefore, adjusting the threshold to greater resistance can "result in peripheral adaptations to the muscle[s]" (Pitts et al., 2009, p. 1302).

In addition to expiratory muscles, suprahyoid muscles are also significantly involved in EMST use. These muscles engage in greater periods of contraction, higher peak amplitudes, and greater average amplitude of contraction during EMST exercises than they would demonstrate during a typical swallow (Wheeler, Chiara, and Sapienza, 2007). As mentioned earlier, suprahyoid muscles are involved in moving the hyolaryngeal complex in the anterior and superior direction required for successful swallowing. One principle of exercise strength training is *overload*, or a muscle working at a level beyond what it is used to, is required for a strength training effect to occur (Powers and Howley, 2004). Over the course of a strength training program, the muscles involved adapt to the overload. These muscle gains have been associated with neural (or peripheral) adaptations and muscle hypertrophy, or the physical bulk of the muscle post-exercise regime. The neural adaptations which occur first are an improved management of motor unit firings and an improved ability to recruit motor units as a result of exercise (Powers and Howley, 2004). Thus, using EMST procedures may potentially improve swallowing functions with suprahyoid muscle strengthening, as well as respiratory functions.

Early EMST studies focused on exercise effects that benefit respiration. One such study examined how respiratory effort changed after performing EMST tasks (Suzuki, Sato, Okubuo, 1995). The researchers recruited ten male volunteers with a mean age of 30 years, all non-smokers and considered healthy. The subjects were divided into two groups, a control group and study group. Instead of the modern EMST device, an *inspiratory* muscle training device was developed that was modified for expiratory muscle training function. Each participant in the study group had their threshold set at

30% of their MEP, or 30% of the subject's maximum pressure while expiring air from a point of inhalation to total lung capacity. Exhalation through a closed valve unit was performed, with each subject's lips completely sealed around the device, which was connected to a differential pressure transducer (Suzuki et al., 1995). Study group participants used the device twice a day for 15 minutes for four weeks. Sensation of respiratory effort was evaluated by a modified Borg scale (a scale where the user self-identified the effort required to produce each breath), while minute ventilation (the volume of air exhaled from the lungs) was evaluated using the 2900 Energy Measurement System during a progressive exercise test (Suzuki et al., 1995). Both measures decreased for the study group when performance on the first day of the program was compared to performances on the end of the fourth week. The control group's Borg scale and minute ventilation measures did not significantly change when the same comparison was made (Suzuki et al., 1995). This result suggests that the use of an EMST device can reduce perceived respiratory effort as well as decrease the amount of air used during exercise.

It is also meaningful to determine the significance of the strength and functional gains that accrue by using the EMST device. Thirty-two healthy participants with an average age of 25.22 years participated in a study to evaluate the gains associated with EMST use (Baker, Davenport, and Sapienza, 2005). The participants were equally divided into two groups, one group that trained for four weeks and a group that trained for eight weeks. Each participant used a pressure-threshold trainer 5 days a week for one training session that consisted of five sets of five breaths that were set at 75% of the participant's MEP. A significant increase in MEP was noted for both groups, with no significant differences between the four week group and the eight week group. Thus it appeared that past the fourth week, there was no additional gain from training with the EMST (Baker et al., 2005).

Expiratory muscle strength training has also been used in multiple studies to evaluate cough and swallowing function in different patient populations such as individuals with Parkinson disease. Participants involved in one study included ten males with Parkinson disease with an average age of 72.9 years (Pitts et al., 2009). They were instructed to use an EMST device for four weeks, using it five times a week for five sets of five breaths. The EMST devices were set at 75% of each participant's MEP. The study compared penetration and aspiration of a 30-mL thin liquid bolus using the penetration/aspiration (P/A) scale both before and after exercises (an objective seven point scale that describes depth of penetration/aspiration, patient behaviors, and effectiveness of patient response during a videofluoroscopic swallow evaluation). In addition, MEP and voluntary cough were measured with an oral pneumotachograph. The P/A scores significantly decreased for the subject group as a whole, indicating improved efficiency of swallowing on average. The values of MEP increased significantly from the pre-test to the post-test for the group. Results of the study also indicated significant increase in cough volume acceleration, which relates to the ability to remove penetrated and/or aspirated material from the airway (Pitts et al., 2009). Thus, use of the EMST device decreased the risk of penetration and aspiration as seen by the improvements of P/A scores, as well as provided an improvement in the ability to clear debris in the airway by improving cough volume acceleration.

The effects of EMST on subjects with Parkinson disease were also studied within the context of swallow timing and biomechanics, specifically anterior hyoid movement and anteroposterior (A-P) deglutitive upper esophageal sphincter (UES) opening (Troche et al., 2010). Sixty participants with Parkinson disease (average age of 67.6 years) were recruited and randomly divided into two groups. One of the groups received EMST treatment, and the other group used a non-functional EMST device (sham group). The EMST was used identically in both groups in the same format as Pitts et al. (2009). The EMST group functionally performed better in terms of duration of hyoid elevation and UES A-P deglutitive opening diameter. Due to the progressive nature of Parkinson disease, both groups decreased in the deglutitive duration of hyoid elevation. However, the sham group presented a significant loss, whereas the EMST group was not significant. Upper esophageal sphincter A-P opening diameter and anterior excursion of the hyoid bone significantly increased in the EMST group and decreased in the sham group (Troche et al., 2010).

Investigation of the effects of EMST are not limited to swallowing and respiration measures; voice improvement may also be possible through exercise with this device. A study was conducted involving 18 professional voice users divided into a dysphonia group and a lesion group (Wingate, Brown, Shrivastav, Davenport, and Sapienza, 2006). The lesion group all had benign vocal fold lesions whereas the dysphonia group presented with laryngeal irritation or edema. Both groups received three weeks of biweekly voice therapy and five weeks of EMST exercises. Half of each group received voice therapy followed by EMST and the other half had EMST followed by voice therapy. EMST was conducted at 75% of the individual’s MEP, five times a week for five sets of five breaths. The dysphonia group and the lesion group self-reported a significant reduction in vocal symptoms after both treatments via a voice rating scale. A Voice Range Profile evaluating vocal intensity at a variety of fundamental frequencies was completed both pre- and post-test for each subject. The resulting phonetograms showed subjects had a greater dynamic range (i.e., could produce both louder and softer phonations at the target frequencies) when the post-test was compared to the pre-test (Wingate et al., 2006).

Voice function following the use of EMST was also investigated in people with multiple sclerosis (MS). The study investigated MEP, sustained vowel prolongation, words per minute during connected speech, and quality of life questionnaires that relate to dysphonia (Chiara, Martin, and Sapienza, 2007). Seventeen participants with MS (14 females, 3 males; average age of 48.9 years) were compared to a healthy control group (12 females, 2 males; average age of 44.1 years). The MS group and the control group used a device similar to the EMST 150 (a Positive Expiratory Pressure threshold trainer) for eight weeks at 5 days per week for 4 sets of 6 exercise breaths. The threshold EMST setting was varied through the training program based on the participant's MEP: 40% the first week, 60% the second week, and 80% from the third week on (Chiara et al., 2007). Maximum expiratory pressure increased for both of the groups, however there was no significant improvement in voice production as measured by sustained vowel prolongation or words per minute during connected speech. Interestingly, vowel prolongation and words per minute increased in participants with MS after detraining from EMST, or four weeks *after* discontinuing the EMST treatment. The *Voice-Related Quality of Life* questionnaire was lower in participants with MS compared to the healthy control for pre-training and did not improve while using the EMST device (Chiara et al., 2007). These results suggest that although immediate change was not noted, change occurred after a period of discontinued use. An increase in vowel prolongation suggested that the participants were eventually better able to manage the airflow required for phonation.

From the other studies that have been conducted using EMST, it may be possible that this device could be used as an exercise program for treating voice and swallowing problems associated with aging, and/or preventing such problems from developing. Only a small number of studies have been conducted to determine how older adults with no voice or swallowing disorders respond to exercise using the EMST device. One such study gathered 18 healthy sedentary individuals with a mean age of 78.25 years for male subjects (N=4) and 76.64 years for female subjects (N=14; Kim, Davenport, and Sapienza, 2009). The experimental procedure consisted of two weeks of pre-training baseline sessions, followed by four weeks of EMST treatment where the participants used an EMST device in the same way as the Parkinson disease group (Pitts et al., 2009; Troche et al., 2010). The results showed that MEP significantly improved over the study, with a rapid increase during the first week. The study also found an average increase of 61% for the peak expiratory flow rate (PEFR) for the individuals involved. Peak expiratory flow rate was measured during a capsaicin-induced cough (Kim et al., 2008). It will be important to investigate EMST use without the added effect of capsaicin and PEFR to determine clinical implications of EMST. If respiratory variables do improve, EMST may facilitate positive functional anatomical and physiological changes.

*Summary and critique.* Through the review of the relevant literature, it is evident that EMST can improve respiratory function in healthy normal participants (Baker et al., 2005), individuals with Parkinson disease (Pitts et al., 2009; Troche et al., 2010), and older adults (Kim et al., 2008). The primary respiratory measurement improvement that is common to nearly all of the studies is maximum expiratory pressure, which is intuitive given that MEP is an indirect method of measuring expiratory muscle strength, as discussed earlier. In terms of swallowing functions, studies have found improved P/A scores and greater hyoid bone excursion in patients with Parkinson disease following EMST use (Pitts et al., 2009; Troche et al., 2010). The greater anterior excursion of the hyoid bone would indicate an increased contractile force of the suprahyoid muscles. In terms of laryngeal functions, professional voice users who had a voice disorder benefited from the use of an EMST device in that they were able to improve their dynamic range when comparing their pre-treatment and post-treatment vocal abilities (Wingate et al., 2006). Additionally, expiratory muscle strength training has also been identified as having unexpected positive effects regarding treatment for dysphagia (Sapienza, Wheeler-Hegland, Stewart, and Nocera, 2008). Therefore, EMST exercises may affect more systems than respiration and could potentially be an indirect therapy treatment or a preventative method for both voice and swallowing disorders. This “cross system effect” was investigated by another group, who found techniques aimed at strengthening extrinsic laryngeal muscles can aid or diminish the effects of dysphagia and dysphonia (LaGorio, Carnaby-Mann, and Crary, 2008).

Although the results seem to indicate that EMST use may have a cross system effect, the studies that were performed did not answer some questions related to changes in voice production and swallowing function. As mentioned earlier, the tongue plays a crucial role in manipulating and propelling the bolus into the pharynx. Additionally, the hyoglossus and genioglossus are both considered suprahyoid muscles and extrinsic tongue muscles. The ability to strengthen these muscles through exercise could aid in increasing the deglutitive anterior and superior movement of the hyolaryngeal complex. No EMST studies have investigated specifically altered tongue strength and pressure generation during swallowing.

The few studies that investigated EMST and voice production present a limited scope of information. The Wingate et al. (2006) study combined EMST use with voice therapy; therefore it is impossible to isolate the effects of the two therapy approaches, although the total outcome was positive. The Chiara et al. (2007) study on the effects of EMST use on the voices of individuals with multiple sclerosis showed less positive outcomes, with no gains in number of words per minute in speech. The research group anticipated that increased breath support would result from EMST use, which would allow for a greater amount of words per minute. However, this assumption may have been faulty on conceptual grounds; and further, the progressive nature of multiple sclerosis and its articulation component makes generalizing EMST effects to a healthy individual difficult. Thus, the effects of EMST use on vocal function are currently inadequately investigated.

## *Purpose*

The literature suggests that swallowing function as well as the voice production mechanism change with age. Various studies have suggested that there may be potential to improve swallowing and vocal functioning by exercising with an expiratory muscle strength training (EMST) device, although findings related to swallowing appeared more significant than those related to voice production. The appearance of significance is likely due to the sheer volume of studies investigating deglutitive measures rather than voice measures. Therefore, it may be beneficial to explore EMST to improve functional voice measures as well as deglutitive measures.

One purpose of this study was to investigate changes in a healthy older adult's voice production as a result of an EMST exercise program. Measures of vocal function included maximum phonation time (MPT), conversational intensity level (CIL), upper limit of available intensity range ($AIR_{UL}$), and lower limit of available intensity range ($AIR_{LL}$). These voice tasks were selected because of their relative dependence on respiration.

A second purpose of this study was to investigate how EMST would affect deglutitive tongue strength measures, specifically maximum isometric pressure (MIP) and mean swallowing pressure (MSP), in healthy older adults. Maximum isometric pressure is the amount of pressure expressed in kilopascals that the tongue can exert when applying maximum force against a pressure bulb within the mouth. The isometric component of the exercise indicates that the tongue is in a static position throughout the exercise. Mean swallowing pressure is the amount of pressure generated during a swallow with instruction to swallow saliva as you normally would. Maximum isometric pressure and mean swallowing pressure were selected as the swallowing-related dependent variables because they provide information on tongue strength for a non-swallowing task and for a swallowing task.

This study will address the question of whether EMST improves the following functions in healthy older adults when compared to other healthy older adults who do not participate in EMST treatment: (i) MPT, (ii) CIL, (iii) $AIR_{UL}$, (iv) $AIR_{LL}$, (v) MIP, (vi) MSP, and (vii) maximum expiratory pressure (MEP). The latter task (MEP) was selected as a control variable. It was the most strongly-related task to the actual EMST exercises, and if no changes were seen in MEP in the Treatment group, then any other observed changes would be suspect. The researcher hypothesized that statistically significant results would be observed at the $p = 0.05$ level when comparing the Control group to the Treatment group for all functional measurements. The overall goal of this research is to provide additional information regarding the role of expiratory muscle strength training as a potential prevention or treatment exercise aimed at delaying or reversing the symptoms associated with age-related swallowing and voice problems.

## *Method*

### *Participants*

The participants for the study included eighteen healthy older adults. The participants were divided into two groups: a Treatment group who used an expiratory muscle strength training (EMST) device with pre- and post-testing measures, and a Control group that only participated in pre- and post-testing. The eighteen individuals had a mean age of 71 years, 5 months (range = 66 years, 5 months to 79 years, 2 months). Participants were randomly assigned to the Treatment or Control groups, except for the last three participants who were assigned to balance age and gender composition between the groups. This resulted in a mean age of 71 years, 11 months (range = 66 years, 5 months to 79 years, 2 months) for the Treatment group, and 70 years, 11 months (range =

65 years, 6 months to 76 years, 3 months) for the Control group. Gender balance was as follows: three males and six females in the Treatment group, and two males and seven females in the Control group. The inclusionary criteria for the participants were: current age between 65 and 79 years, non-smoker for the past ten years, no history of respiratory diseases or conditions, no history of speech and/or language disorders, no history of voice disorders, no history of dysphagia, and a score of less than or equal to 3 on a self-reported current health status scale (1 = excellent health, 5 = poor health).

Participants were recruited for this study through fliers, presentations to senior resource centers, and personal communication (see Appendix A for flier). Individuals that responded to the flier or presentation and individuals contacted via personal communication were asked questions regarding their current age, current health status, information regarding past health (including voice disorders and dysphagia), history of smoking, and history regarding speech and/or language problems (see Appendix B for complete list of questions). Individuals who met all criteria were invited to participate in the study, and were scheduled for a pre-test meeting.

*Experimental procedures*

Data were collected at five sites in the Southeastern Wisconsin area: a residence in Beaver Dam, WI; a church in West Allis, WI; the Center for Communication, Hearing and Deafness (CCHD) in West Allis, WI; the Shorewood Senior Resource Center in Shorewood, WI; and the Speech and Language Clinic on the University of Wisconsin – Milwaukee campus in Milwaukee, WI. Participants were assigned to a particular data collection site according to their preference.

Prior to beginning the pre-test, individuals reviewed the consent form (see Appendix C) and were encouraged to ask any questions pertaining to the study. Only individuals who were willing to complete the exercise program if assigned to the Treatment group were enrolled. Participants also completed a Mini-Mental Status Examination (MMSE; Folstein, Folstein, and McHugh, 1975), which indicated an absence of cognitive decline, and increased the likelihood of adequate cognition to understand directions and comply with the exercise program. All participants then completed the same order of voice, tongue, and respiratory pre-test measures. The same order was used for both the pre- and post-tests. The order of the individual procedures, the abbreviations of the variables, and variable definitions can be found in Table 2-1.

Table 2-1. The order of procedures, dependent variables name, abbreviations, and definitions

| Variable Name | Variable Abbreviation | Variable Definition |
|---|---|---|
| 1. Maximum phonation time | MPT | The maximum length of time an individual can sustain a vowel phonation. |
| 2. Conversational intensity level | CIL | The vocal intensity an individual demonstrates during conversational speech. |
| 3. Upper limit of available intensity range | $AIR_{UL}$ | The maximum average vocal intensity an individual can produce in connected speech |
| 4. Lower limit of available intensity range | $AIR_{LL}$ | The minimum average vocal intensity an individual can produce while maintaining phonation in connected speech. |
| 5. Maximum isometric pressure | MIP | The maximum amount of pressure exerted by the tongue against the top of the mouth. |
| 6. Mean swallow pressure | MSP | The amount of pressure exerted by the tongue during a swallow. |
| 7. Maximum expiratory pressure | MEP | The maximum amount of air pressure exerted out of the mouth upon exhalation. |

Following the pre-test, accepted participants were randomly assigned to the Treatment group or Control group according to the following method: The eighteen participants were separated into four groups, based on their testing site and/or their date of testing. For each group, an even amount of index cards was created that either said “treatment” or “control.” Participants blindly selected a card following their pre-test session and were then informed of their group membership. As stated above, the final three subjects were assigned to optimize age and gender balance between groups.

*Equipment*

The KAYPentax Multi-Speech software (Model 3700; version 3.4.1) running the subprogram Real-Time Pitch (Model 5121; version 3.4.1) was used to evaluate the maximum phonation time (MPT) of each participant for pre- and post-test data. The Multi-Speech software was used on a Dell Latitude E6420 (Intel Core i5-2540M; 2.60 GHz) laptop running Microsoft Windows XP Professional. Phonations were recorded using a Shure SM48 microphone combined with an M-Audio AudioBuddy Dual Mic Preamp/Direct Box. A sound level meter (SLM; Brüel and Kjær Hand-Held Analyzer Type 2250) was used to determine conversational intensity level (CIL) and upper and lower limits of available intensity range (AIR). The Iowa Oral Performance Instrument (IOPI) was used to determine tongue strength for both maximum isometric pressure (MIP) and mean swallowing pressure (MSP). The Micro Respiratory Pressure Meter (RPM-01) was used to measure maximum expiratory pressure (MEP). The expiratory mouthpiece was attached to the Micro RPM, which was then attached to an individual mouth piece. Finally, each of the nine participants in the Treatment group received an EMST 150

(Aspire Products LLC) device. All of the previously mentioned equipment was transported to and from each individual testing location.

*Calibration and Set-Up Procedures*

*Iowa Oral Performance Instrument*. A connecting tube was used to connect the IOPI handheld device to an individual tongue bulb. Prior to each use of the IOPI, the connecting tube was attached to a bulb designated to each individual participant. In order to complete the set-up routine, the IOPI was set to read “0” on the LCD screen of the instrument prior to each trial of MIP or MSP through use of the device’s “Reset” button. This procedure set an accurate baseline for the tongue-to-palate pressure measurement against one air-filled bulb with the approximate dimensions of 3.5 cm long and 4.5 cm in diameter (Youmans et al., 2009). The measurements produced by the IOPI were recorded by the experimenters in kilopascals. Set-up and resetting the device occurred whenever the equipment was moved to a new location for the purposes of collecting measurements. In the event that the instrument read “1” or greater in between trials, the IOPI was reset until it read “0."

*Brüel and Kjær Hand-Held Analyzer Type 2250 Sound Level Meter.* (The sound level meter will be referred to as SLM). The SLM was calibrated by turning the device on and selecting the “Main Menu” icon followed by the “Calibration” option. A Sound Calibrator Type 4231 device (Brüel and Kjær) was attached to the microphone preamplifier of the SLM. The sound calibrator produced calibration tones at two levels (90 dB SPL and 114 db SPL). The calibrator was turned on to the 90 dB SPL level, and the researcher waited until the dB SPL fluctuation stabilized. The “Start” option was then selected on the SLM. The researcher selected “Yes” after the calibration was complete, indicating an acceptance and use of a new sensitivity level which was saved in the calibration history. The researcher confirmed adjustments by verifying accuracy at the 114 dB SPL by using the sound calibrator. Acceptable calibration levels were ± 0.20 dB SPL according to the manual for the device, and they were met. Calibration was performed prior to testing.

*Voice Sampling and Analysis Procedure.*

The voice sampling procedures took place in isolated rooms in the various data collection sites. The rooms were selected based on relatively low levels of background noise (50 dB [re: Weighting Network C] or better; Hansen, 2001) and limited distractions. The participants received a verbal explanation (see Appendix D) regarding the measurements that were to be taken during the pre- and post-test sessions prior to each task.

*Maximum phonation time procedures.* All voice measures were performed with the participants in the standing position. Maximum phonation times were recorded using a hand-held microphone. Participants were instructed to hold the microphone at a constant distance and maintain a direct orientation toward the microphone. Processing time on the Real-Time Pitch program was set to 60 seconds to ensure that each subject’s complete production would be recorded. Maximum phonation time measurement was made after clients took a deep inhalation and produced the vowel /a/ for as long as they could sustain voice production. Prior to the task, researchers provided a full model for each participant, which included a maximum production of sustained phonation at a relatively soft intensity level. Participants were given three trials. The experimenter hit the record option prior to the onset of phonation of the participant. The experimenter stopped recording once the participant was finished phonating and saved the data to a removable disk for later analysis. The sound files were reviewed after the pre- and post-testing of all subjects was completed.

Maximum phonation time data were analyzed by recalling the saved data from the Multi-Speech program. The onset of phonation was selected as the starting point; and the middle of the lowest dot of the frequency tracing, which indicated cessation of phonation, was selected as the ending position. The researcher selected “Statistics,” and recorded the time between cursors.

*Conversational intensity level procedures.* Conversational intensity level and available intensity range measures were made with a set mouth-to-microphone distance of twelve inches between the speaker and the SLM (Gelfer and Pazera, 2005). The SLM was placed in a stationary position on a tripod and subjects stood in front of it, with the investigator less than three feet away.

Conversational intensity level was collected first. For this task, each participant read the Rainbow Passage (see Appendix E) while maintaining a level of volume consistent with speaking to someone who would be approximately three feet away. The twelve-inch mouth-to-microphone distance was maintained by a string attached to the sound level meter held by the participant. A small knot was placed in the string so the participants could hold the string with their thumb and index finger. The participant’s intermediate phalange of the index finger was placed on the point of their chin. No model was given for this particular task. The SLM was turned on and a project number was assigned to each participant. The measurement duration was increased to 45 seconds. The “Measurement Mode” was set to “Manual,” and the “Start” button was pressed once. The

“Start” button was pressed again immediately after the participant spoke the first word of the passage. The “Start” button was pressed a final time at the conclusion of the reading, and the project was saved. Conversational intensity level data were retrieved by accessing the participant’s specific file within the “Explorer” menu, and noting the “C-weighted equivalent continuous noise level” or $L_{CEQ}$, a measure of overall loudness of the signal in dB (re: Weighting Network C).

*Available intensity range procedures.* Available intensity range was also collected via oral reading of the first two sentences of the Rainbow Passage (see Appendix F). The participants were asked to read the first two sentences of the passage as loudly as they could to determine the upper range of intensity. The participants were allowed to practice the task prior to the measurement. The researcher provided a full model, and gave feedback on the participant’s attempt if the participant did not produce what the investigator deemed adequate intensity and effort. The participants then read the same portion of the passage as quietly as possible, to determine the lower limit of available intensity range. A full model was again provided by the researcher prior to testing. The participants were allowed to practice the task, and they received feedback regarding the ability to maintain voicing and the appropriateness of their intensity. The measurement process for the upper and lower ranges of intensity was identical to that of CIL.

*Tongue strength and function sampling procedure.*

For the maximum isometric pressure value, the IOPI was turned on and set to “Peak Mode,” which indicated settings to obtain the highest pressure. The “Peak Reset” button was pressed, which set the value to 0 kPa. Researchers and participants looked at a picture of tongue bulb placement (see Appendix G). The picture was a secondary method of ensuring accurate placement. The primary method of tongue bulb placement involved the researchers placing the bulb on the tongue blade. The tongue blade position is defined as midway between 10mm posterior to the tongue tip and 10 mm anterior to the most posterior circumvallate papilla (Robbins et al., 1995). The measurements were made within the participant's oral cavity prior to recording data. This involved using the bulb as an approximate measurement device (i.e., the bulb was approximately 35 mm in length, therefore a third of the bulb length was approximately 10 mm) to obtain the 10mm measurements. The researchers instructed the participants to press the tongue bulb with their tongue as hard as possible for approximately three seconds (Hewitt et al., 2008). The number was recorded and the "Peak Reset" button was pressed. Participants were allowed to rest at their discretion prior to additional pressure samples (Hewitt et al., 2008). Researchers repeated the instructions and MIP values were collected two more times. The highest value was recorded of the three possible values.

For the mean swallow pressure, the IOPI was again set to "Peak Mode" and the "Peak Reset" button was pressed. The tongue bulb placement procedure from Appendix G was repeated and followed by participants. Researchers instructed the participants to swallow normally, and not to add any additional force with their tongue. The investigator demonstrated the "dry swallow" procedure. Following the subject's attempt, the pressure was recorded and the subjects were encouraged to rest and take a drink of water in between dry swallows. Two more dry swallows with rest periods were performed, with the researcher recording the average of the three values. For both tongue strength measures, participants could view the IOPI to see their values. During the MIP measurement, participants were encouraged to use the biofeedback to produce higher pressure levels.

*Maximum Expiratory Pressure Sampling Procedure*

A disposable, individual use mouthpiece was attached to the Micro RPM. The participants were instructed to create a tight seal around the mouthpiece, and to direct airflow only through the mouthpiece. They were also encouraged to hold their cheeks just above the jaw line and gently push them forward to prevent buccal expansion. The participants were told to inhale maximally prior to creating a seal around the mouthpiece. Full participant instructions can be found in Appendix D. The subjects exhaled as forcefully as possible through the mouthpiece. Ten trials of MEP were obtained until three consecutive values were made within +/- 5% of one another (Kim et al., 2009). The three values were than averaged to determine each individual's MEP.

*Resistance Adjustment of the EMST Device for Treatment Group*

The participants in the Treatment group initially had their EMST device set to 75% of their MEP. The investigator adjusted the threshold of the EMST accordingly, and encouraged the participant to try out the device. Multiple trials were performed until Treatment group participants demonstrated adequate understanding. They were provided feedback and instructions to complete the exercise program.

*Training for Treatment Group*

Participants who were using the EMST 150 completed five sets of the exercise regimen with five repetitions per set. Based on previous research, the exercise program took place over four weeks. Participants were instructed to place the mouthpiece of the EMST 150 in their mouth, behind their teeth, with their lips closed around the device. A hard, forceful breath was performed, using the chest and stomach muscles to blow air through the mouthpiece of the device lasting a couple seconds or until the threshold was met (i.e., the resistance pressure was met, and air flowed freely through the device). The participants were told to rest for 15-30 seconds in between breaths, and one minute in between sets. A copy of the instructions was given to each member of the Treatment group (see Appendix H). Participants were encouraged to log daily use in an effort to maintain consistency and note any adverse effects (see Appendix I). The daily exercise logs were collected upon completion of the four week training. All participants who completed the EMST exercise program indicated via checkmark that they completed every exercise breath required.

Participants in the Treatment group were contacted via phone once per week to ask questions regarding performance of the exercises, and to address any concerns related to the EMST. Additionally, these participants were met with on a weekly basis to adjust the resistance of their EMST devices. Expiratory muscle strength trainers were adjusted by having the individuals perform additional MEP measurements, because it was assumed that MEP would increase over the duration of the exercise program, necessitating increased resistance of the EMST. Participants' EMST devices were always set to 75% of their updated MEP value.

*Statistical Analysis*

The dependent variables that were included in the statistical analysis included change scores for: MPT, CIL, $AIR_{UL}$, $AIR_{LL}$, MIP, MSP, and MEP. Change scores were calculated for each subject by subtracting the pre-test value from the post-test value. The independent variable was EMST use at two levels: Treatment and Control. Given the number of participants and the type of data (ratio level), parametric statistics were used. Individual t-tests were performed for each individual change score at the levels of the independent variable.

## *Results*

### *Descriptive Statistics*

The purpose of this study was to determine whether use of an expiratory muscle strength training (EMST) exercise program improves performance on a variety of voice, swallowing, and respiratory tasks. Specific tasks that were tested before and after EMST use included maximum phonation time (MPT), conversational intensity level (CIL), upper and lower limits of available intensity range ($AIR_{UL}$; $AIR_{LL}$), maximum isometric pressure (MIP), mean swallowing pressure (MSP), and maximum expiratory pressure (MEP). In order to explore for the presence of significant differences between the Treatment group that completed an exercise program using the EMST device and a Control group that did not, summary statistics were first calculated.

Analyses yielded mean values, standard deviations, and ranges for all dependent variables for the Treatment and Control groups. The descriptive statistics for age and Mini-Mental Status Examination (MMSE) score can be seen in Table 3-1. Results were similar between the Treatment and Control groups, with only small differences noted. In terms of age, the Treatment group averaged approximately one year older and scored an average of almost one point higher on the MMSE.

Descriptive statistics are presented in Tables 3-2 through 3-8 for all dependent variables in the pre- and post-test conditions for the Treatment and Control groups. Individual data for both Treatment and Control group participants, and weekly data for maximum expiratory pressure completed by the Treatment group, can be found in Tables 3-9 through 3-12. Visual inspection of Tables 3-2 to 3-8 showed that in the pre-test, between-group measurements yielded similar results for MPT, CIL, $AIR_{UL}$, and $AIR_{LL}$. For example, maximum phonation times differed by only 0.11 seconds in the pre-test between the Treatment and Control groups; vocal intensity (CIL) differed by less than 2dB (re: Weighting Network C); and both upper and lower limits of AIR differed by less than 1 dB (re: Weighting Network C). This indicates that the Treatment and Control groups were quite similar to one another for the voice-related variables.

However, differences between groups in the pre-test were observed when reviewing measures of tongue strength and respiratory values. Overall, the Control group demonstrated increased pre-test MIP and MSP values when compared to the Treatment group. The respiratory variable MEP was noted to be greater in the Treatment group compared to the Control group prior to EMST use.

Due to these observed differences prior to the Treatment group performing EMST exercises, the decision was made to calculate change scores as the dependent variables. Change scores were defined as the post-test result for each task minus the pre-test result, for each subject. This procedure permitted the investigators to determine which group demonstrated the most change from the pre-test to the post-test, despite the between-group differences noted in pre-test levels.

Similarities and difference were also noted when comparing the pre- and post-test data between groups. Maximum phonation time, conversational intensity level, and the lower limit of available intensity range did not change considerably for either the Treatment or Control group from the pre-test to the post-test. However, an increase in the post-test value for $AIR_{UL}$ was noted for the Treatment group, but not for the Control group.

Tongue strength and respiratory measures required investigation for each measure and group, as they varied noticeably. Maximum isometric pressure values increased slightly from pre- to post-testing for the Treatment group, but remained stable for the Control group. Mean swallowing pressure marginally increased for the Treatment group, however the Control group decreased by approximately four kilopascals. Finally, MEP increased for both groups, but the increase was much greater in the Treatment group. The overall variability within each group, as measured by the standard deviation, was different for each task, or dependent variable. However, neither group consistently demonstrated increased variability compared to the other group.

*Inferential Statistics*

As previously stated, change scores were established for each dependent variable as a method of measuring difference between pre- and post-testing. These new variables were evaluated further by performing independent-sample t-tests to compare the values between the Treatment and Control groups. Significance level was set at $p < 0.05$ (Schiavetti and Metz, 2006).

The change scores for $AIR_{UL}$ between the Treatment group (change score = 3.561; standard deviation = 2.263) and the Control group (change score = 1.472; standard deviation = 1.074) were found to be significantly different ($t = 2.502$; $df = 16$; $p = 0.024$). Change scores for MEP between the Treatment group (change score = 32.344; standard deviation = 13.230) and the Control group (change score = 6.422; standard deviation = 13.476) were also found to be significantly different ($t = 4.118$; $df = 16$; $p = 0.001$). No other change score comparisons for the dependent variables were found to be significantly different (PASW Statistics, 2010).

Effect sizes were calculated for the $AIR_{UL}$ and MEP variables to verify the validity of the t-tests performed (Schiavetti and Metz, 2006). Effect size provides an evaluation of "how much a dependent variable is explained by an independent variable" (Schiavetti and Metz, p. 210). It has also been described as a measure of overlap between two data sets (Coe, 2002). Both Cohen's *d* and Hedge's *g* were calculated, and yielded an effect size of 1.251 and 1.179 for $AIR_{UL}$ and 2.059 and 1.941 for MEP, respectively. Given the strength of the effect size, the results of the previous t-tests can be confidently accepted.

Table 3-1. Age (in years) and Mini-Mental Status Examination (MMSE) score (out of a possible 30) for both groups in the pre- and post-tests. Standard deviations are presented in parentheses.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Age (SD) | 71.95 (4.37) | 70.98 (3.84) |
| MMSE Score (SD) | 29.33 (1.32) | 28.44 (1.74) |

Table 3-2. Maximum phonation time (MPT) measured in seconds (s) for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 20.93 (8.35) | 21.04 (5.39) |
| Post-test | 21.41 (7.47) | 20.51 (5.93) |
| Change score | 0.476 | -0.530 |

Table 3-3. Conversational intensity level (CIL) measured in db (re: Weighting Network C) for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 67.56 (1.66) | 69.30 (2.85) |
| Post-test | 68.41 (1.53) | 69.69 (3.68) |
| Change score | 0.843 | 0.392 |

Table 3-4. Upper limit of available intensity range ($AIR_{UL}$) measured in dB (re: Weighting Network C) for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 86.93 (4.79) | 87.23 (5.38) |
| Post-test | 90.49 (4.10) | 88.70 (5.76) |
| Change score | 3.561 | 1.472 |

Table 3-5. Lower limit of available intensity range ($AIR_{LL}$) measured in dB (re: Weighting Network C) for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 60.96 (2.13) | 60.99 (3.34) |
| Post-test | 61.48 (2.10) | 60.79 (2.57) |
| Change score | 0.514 | -0.194 |

Table 3-6. Maximum isometric pressure (MIP) measured in kilopascals for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 52.67 (12.37) | 59.22 (10.20) |
| Post-test | 56.67 (10.20) | 59.56 (10.25) |
| Change score | 4.000 | 0.333 |

Table 3-7. Mean swallowing pressure (MSP) measured in kilopascals for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 26.89 (11.10) | 33.59 (14.64) |
| Post-test | 27.48 (12.51) | 29.74 (11.14) |
| Change score | 0.592 | -3.853 |

Table 3-8. Maximum expiratory pressure (MEP) measured in cm $H_2O$ for both groups in the pre- and post-tests. Standard deviations are in parentheses. Change scores (post-test – pre-test) are also displayed.

| | Treatment (N = 9) | Control (N = 9) |
|---|---|---|
| Pre-test | 85.28 (31.35) | 78.86 (35.39) |
| Post-test | 117.62 (21.42) | 85.28 (33.70) |
| Change score | 32.344 | 6.422 |

Table 3-9. Participant number, group, gender, and age

| Participants | Group | Gender | Age |
|---|---|---|---|
| 1 | Control | Female | 76 years, 3 months |
| 2 | Treatment | Female | 75 years, 8 months |
| 3 | Control | Female | 74 years, 7 months |
| 4 | Control | Male | 70 years, 2 months |
| 5 | Treatment | Male | 79 years, 2 months |
| 6 | Control | Female | 67 years, 5 months |
| 7 | Treatment | Female | 71 years, 4 months |
| 8 | Control | Male | 65 years, 6 months |
| 9 | Control | Female | 66 years, 10 months |
| 10 | Control | Female | 70 years, 7 months |
| 11 | Treatment | Male | 74 years, 11 months |
| 12 | Treatment | Female | 70 years, 1 month |
| 13 | Control | Female | 73 years, 1 month |
| 14 | Treatment | Female | 66 years, 5 months |
| 15 | Treatment | Female | 74 years, 7 months |
| 16 | Treatment | Male | 68 years, 1 month |
| 17 | Control | Female | 74 years, 5 months |
| 18 | Treatment | Female | 67 years, 4 months |

Table 3-10. Individual data from the pre-test for both the Control group and Treatment group.

Control Group

| Participants | MPT (s) | CIL (dB) | $AIR_{UL}$ (dB) | $AIR_{LL}$ (dB) | MIP (kPa) | MSP (kPa) | MEP ($cmH_2O$) |
|---|---|---|---|---|---|---|---|
| C1 | 20.43 | 70.31 | 83.96 | 65.74 | 52 | 28.7 | 55.7 |
| C2 | 27.49 | 65.30 | 79.73 | 57.48 | 55 | 27 | 80.3 |
| C3 | 16.06 | 70.70 | 89.48 | 61.06 | 73 | 57.3 | 161.7 |
| C4 | 22.14 | 69.16 | 83.25 | 65.55 | 55 | 32 | 67 |
| C5 | 15.47 | 69.12 | 94.53 | 58.91 | 80 | 43.3 | 84.3 |
| C6 | 14.55 | 67.41 | 85.66 | 61.49 | 50 | 28 | 59.7 |
| C7 | 18.12 | 73.98 | 91.43 | 63.31 | 58 | 52.7 | 97.3 |
| C8 | 27.83 | 65.67 | 82.71 | 58.47 | 55 | 13.7 | 40 |
| C9 | 27.21 | 72.04 | 94.28 | 56.86 | 55 | 19.7 | 63.7 |

Treatment Group

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T1 | 16.38 | 67.63 | 79.75 | 64.73 | 61 | 31.3 | 47.3 |
| T2 | 28.90 | 64.44 | 82.34 | 59.98 | 49 | 28.7 | 104 |
| T3 | 13.97 | 67.29 | 84.09 | 63.26 | 33 | 24.3 | 93.3 |
| T4 | 17.56 | 65.87 | 89.12 | 58.75 | 47 | 26 | 79.3 |
| T5 | 16.92 | 67.79 | 84.76 | 59.45 | 65 | 9.3 | 86.3 |
| T6 | 36.08 | 69.17 | 87.26 | 59.10 | 71 | 37.7 | 77.3 |
| T7 | 28.86 | 67.98 | 91.75 | 63.00 | 57 | 27 | 68.3 |
| T8 | 18.88 | 67.78 | 95.20 | 60.30 | 53 | 45 | 154.7 |
| T9 | 10.85 | 70.11 | 88.02 | 60.11 | 38 | 12.7 | 57 |

Table 3-11. Individual data from the post-test for both the Control group and Treatment group.

Control Group

| Participant Number | MPT (s) | CIL (dB) | $AIR_{UL}$ (dB) | $AIR_{LL}$ (dB) | MIP (kPa) | MSP (kPa) | MEP ($cmH_2O$) |
|---|---|---|---|---|---|---|---|
| C1 | 17.59 | 68.64 | 85.92 | 62.83 | 53 | 35.7 | 54.7 |
| C2 | 20.97 | 65.84 | 81.90 | 55.59 | 56 | 20 | 79.7 |
| C3 | 26.82 | 73.19 | 90.31 | 61.07 | 73 | 51.3 | 147.7 |
| C4 | 26.96 | 70.17 | 83.51 | 60.52 | 60 | 25.7 | 89 |
| C5 | 12.60 | 66.62 | 98.10 | 60.18 | 77 | 27.3 | 94.7 |
| C6 | 15.42 | 64.54 | 86.21 | 61.05 | 53 | 20.3 | 61.3 |
| C7 | 13.42 | 74.47 | 93.63 | 65.30 | 65 | 35.7 | 127.7 |
| C8 | 24.05 | 69.46 | 83.77 | 60.55 | 46 | 15.3 | 50.3 |
| C9 | 26.8 | 74.29 | 94.93 | 60.03 | 53 | 36.3 | 62.4 |
| Treatment Group | | | | | | | |
| T1 | 15.78 | 68.86 | 84.76 | 61.42 | 68 | 42.3 | 88.7 |
| T2 | 21.28 | 66.68 | 63.89 | 87.11 | 50 | 23.3 | 132.3 |
| T3 | 11.67 | 69.96 | 86.05 | 61.67 | 59 | 21.7 | 120.3 |
| T4 | 20.19 | 68.81 | 95.88 | 61.68 | 44 | 46.3 | 118 |
| T5 | 26.90 | 67.73 | 90.29 | 60.37 | 66 | 9 | 119.3 |
| T6 | 28.10 | 68.03 | 90.99 | 61.33 | 71 | 33 | 127.7 |
| T7 | 35.30 | 70.20 | 95.18 | 64.90 | 53 | 33.7 | 105.3 |
| T8 | 18.62 | 65.67 | 94.73 | 57.52 | 55 | 25 | 157.3 |
| T9 | 14.84 | 69.71 | 89.40 | 60.53 | 43 | 13 | 89.7 |

Table 3-12. Maximum expiratory pressure weekly changes for the Treatment group.

| Participant Number | Pre-Test ($cmH_2O$) | Week 1 ($cmH_2O$) | Week 2 ($cmH_2O$) | Week 3 ($cmH_2O$) | Post-Test ($cmH_2O$) |
|---|---|---|---|---|---|
| 2 | 47.3 | 66.7 | 71.3 | 74.3 | 88.7 |
| 6 | 104 | 109 | 137.3 | 142.3 | 132.3 |
| 8 | 93.3 | 110 | 125 | 121 | 120.3 |
| 12 | 79.3 | 86.7 | 98 | 102.7 | 118 |
| 13 | 86.3 | 122.7 | 127.7 | 122.7 | 119.3 |
| 15 | 77.3 | 87.3 | 108 | 115.3 | 127.7 |
| 17 | 68.3 | 73.7 | 97.7 | 106.7 | 105.3 |
| 18 | 154.7 | 147.3 | 130.3 | 155.3 | 157.3 |
| 20 | 57 | 73.7 | 75 | 68.7 | 89.7 |

*Discussion*

Previous literature demonstrated that expiratory muscle strength training (EMST) may be a potential rehabilitation method for those with voice and swallowing deficits for various disordered populations. The present study aimed to further explore possible benefits from the EMST in a healthy older adult population. Specifically, the question was asked: Does use of the EMST device in a standard exercise program improve the following voice, swallowing, and respiratory variables in healthy older adults?:

a. Maximum phonation time (MPT)
b. Conversational intensity level (CIL)
c. Upper limit of available intensity range ($AIR_{UL}$)
d. Lower limit of available intensity range ($AIR_{LL}$)
e. Maximum isometric pressure (MIP)
f. Mean swallowing pressure (MSP)
g. Maximum expiratory pressure (MEP)

This question was answered by comparing a Treatment group that completed exercise training using the EMST for four weeks to a Control group that did not. Both groups were tested initially, and then tested four weeks after the initial testing. The results of the study indicated that the amount of change seen in the majority of voice and tongue strength measures was not significantly different when comparing the Treatment and Control groups to each other. However, significant differences were found for $AIR_{UL}$ and MEP. Thus, the results of this study suggest that EMST primarily improves respiratory function (MEP), although a significant benefit to vocal functioning ($AIR_{UL}$) was also seen.

*Limitations of the Present Study*

Limitations of this study include the population, testing environments, and measurement. The population for this particular study involved healthy older adults in the age range of 65 to 79 years old. It was particularly challenging to find and enroll 18 individuals who matched this study's inclusionary and exclusionary criteria. Individuals interested in participating in the study were often excluded based on medical problems or other factors that would qualify them as "unhealthy," and thus not eligible to participate. Individuals who were ultimately selected demonstrated significant variability in overall health. Unfortunately, this study did not have criteria to ensure similar health status between groups. Additionally, assuring that the Treatment and Control groups were equally motivated during the post-test was beyond the investigators' control.

The difficulties described in the preceding paragraph resulted in two other limitations regarding the selected population. First, there were more women than men in both groups, with one more woman in the Control group compared to the Treatment group. Second, all participants were selected from Southeastern Wisconsin. Therefore, this study did not depict the complete diversity seen in 65- to 79-year old United States citizens.

The testing environment also varied for subgroups of participants. Participants were tested at four different locations. Background noise was measured and recorded prior to all pre- and post-testing at all locations, as three of the experimental variables were related to sound intensity. The recorded background noise levels were under 50 dB (re: Weighting Network C), however, two instances were observed with higher background noise levels of approximately 60 db (re: Weighting Network C). In order to further assess the significance of higher background noise, noise levels were also analyzed using the A Weighting Network, which more closely approximates human hearing (with a de-emphasis in the low frequencies; Hansen, 2001). In all pre- and post-test measurements, noise was between 34 dB and 45 db (re: Weighting Network A). Moreover, precautions were also taken to reduce any effects of occasional background noise, such as performing subtests an additional time if an increase of background noise was noted.

Limitations also existed with the measurement process. First, two different individuals (the investigator and advisor) were involved in data collection. Both investigators used the same set of instructions (see Appendix D) and, observed each other during the pre-test to assure that they followed similar methods. However differences in data collection might still have existed that could have affected the study's outcome. For instance, despite being blind to the exact data from the pre-test, both investigators were aware of which individuals belonged to which group during the post-test. This may also have affected the study's outcome, but since neither investigator knew the subject's specific pre-test performance levels, it is not likely that this compromised the study's validity. An additional problem with measurement involved reliability. Because of the measurement instrumentation used in this study, reliability could only be assessed for MPT. The other variables (CIL, AIR, MIP, and MEP) were measured in real time, and it was not possible to save a recording of the task. Despite the inability to complete test-re-test reliability measures, efforts to improve reliability were done in other ways. These included the use of standard printed instructions and figures to ensure that all subjects were instructed and responded in the same manner, and that the equipment was used in the same way for each participant.

Finally, precise timing of initial and final measurement points for intensity-related variables was not possible. As stated above, these measures were made in real time, and no analog or digital signal file was available. However, measurement inaccuracies in starting the measurement process too early or too late, or ending the measurement process too early or too late most likely occurred randomly, and thus were not expected to introduce systematic bias into the data.

*Comparison to Previous Literature*

The EMST device was "designed specifically for individuals who want to enhance their breathing and swallow function" (Aspire Products LLC, n.d.). Although the research base for expiratory muscle strength training is growing, the literature is relatively limited by the current investigated populations and variables. The present study sought to add to current research and compare the results of respiratory, swallowing, and voice production variables to the findings of the other studies in existence.

Measurement of MEP was found in nearly every study involving the EMST device. Maximum expiratory pressure is an indirect method of measuring expiratory muscle strength, by quantifying how much force is present when expelling air though the mouth (Kim and Sapienza, 2005). The present study was able to replicate an increase in MEP in a healthy older population similar to the study performed by Kim et al. (2009). The previously mentioned study had a population of sedentary older adults, 14 females and 4 males, who averaged 78.25 years (Kim et al., 2009). The group increased their MEP value from 77.14 cm$H_2O$ to 110.83 cm$H_2O$. This increase was similar to the present study's Treatment group who increased from 85.28 cm$H_2O$ to 117.62 cm$H_2O$. It was important that this variable significantly increase in this study to demonstrate that the

Treatment group adequately completed the exercise. Based on the significant findings of the MEP value, it is likely that the EMST device was used appropriately in the current study and as described in previous studies.

Suprahyoid muscle activation was also identified in previous research involving the EMST. Increased periods of contraction, higher peak amplitudes, and greater average amplitude of contractions were observed in previous literature involving EMST use than when compared to a typical swallow (Wheeler et al., 2007). Two extrinsic tongue muscles, the hyoglossus and genioglossus, also belong to the suprahyoid muscle group. Because of this overlap, the present investigator was interested in potential changes to tongue strength and function. A previous study investigated MIP and MSP in 32 older adults (16 males and 16 females) who averaged 68.81 years (Youmans et al., 2009). They found that MIP averaged 60.13 kPa and MSP averaged 33.40 kPa (Youmans et al., 2009). Our study showed an initial averaged MIP value of 52.67 kPa that increased to 56.67 kPa and initial averaged MSP that increased to 27.48 kPa. These results suggest that the tongue strength measures presented in this study are comparable to other studies, supporting the validity of these measures. Youmans et al. (2009) did not include an EMST program in their study, thus it is not possible to say whether or not the results of the current study support previous research.

The review of literature for expiratory muscle strength training and voice production has focused on individuals with dysphonia, vocal fold lesions, and multiple sclerosis (MS; Wingate et al., 2006, Chiara et al., 2007). Results from these studies showed improvement in vocal intensity for individuals with dysphonia and vocal fold lesions. Individuals with MS did not immediately demonstrate increased vowel prolongation, however improvement was noted four weeks after discontinued EMST use (Chiara et al., 2007). Although the present study did not investigate a disordered population, an increase in vocal intensity was also observed. However, no increase in vowel prolongation was noted for the current study.

Overall, the present study's results support previous literature regarding the effects of EMST on MEP. However, results differe somewhat from existing EMST research regarding vocal loudness. These differences may have occurred because previous research of EMST use and voice production has mainly targeted a disordered population, while the current study is based on a population of healthy older adults. Therefore results may be different based on that factor alone. Additionally, investigation of swallowing following EMST use has looked at laryngeal function and suprahyoid muscle use utilizing videofluoroscopy and surface electromyography (EMG); whereas the present study investigated tongue strength more directly.

*Theoretical Implications*

Other studies involving EMST exercise programs reported significant changes in swallowing function including decreased severity of penetration and/or aspiration (Pitts et al., 2009), increased cough volume acceleration (Pitts et al., 2009; Kim et al., 2007), and increased upper esophageal sphincter (UES) anteroposterior opening diameter and anterior excursion of the hyoid bone (Troche et al., 2010). No other studies to date have investigated EMST use and anterior tongue function, therefore it is difficult to make direct comparisons.  Although no significant changes were found in MIP, change in isometric anterior tongue strength did occur in the Treatment group. Maximum isometric pressure saw an increase of four kPa over the four week period. Only a relatively small increase was noted for MSP. This finding is consistent with other studies, which found that maximum anterior tongue strength increases, whereas MSP remains relatively stable across the lifespan. Mean swallowing pressure may not have increased in the current study because swallowing is considered a submaximal pressure task, and with a normal population, an increase was not required to maintain a functional swallow (Robbins et al., 1995).

Additionally, tongue strengthening programs that use the Iowa Oral Performance Instrument as a method of exercise typically last eight weeks (Lazarus et al., 2000; Robbins et al., 2005). The present investigator wanted to identify the possibility of EMST as an anterior tongue strengthening method, but did so according to previous respiration literature that stated improvements are typically made in four weeks. For example, Baker et al. (2005) identified that no significant changes in MEP occurred after the fourth week of exercise. It is possible, based on previous tongue strength research, that significant tongue strength gains require eight weeks of exercise. Additionally, although MIP is not a functional measurement, any increase in tongue strength may be beneficial at a later time in the event of a neurological insult.

Another possibility for the lack of significant findings in MIP and MSP is that the EMST does not target anterior lingual strength. Currently, the only research on muscle activation during EMST use is surface electromyography of the suprahyoid muscles (Wheeler et al., 2007). No studies have fully investigated lingual muscle activation with use of an EMST exercise program, and this study only evaluated oral lingual function and strength changes. Secondly, although this study featured older adults, all participants were considered healthy with no swallowing problems. Although age-related deficits might have existed in our participants, it is likely their swallow was still functional.

The relationship between increased expiratory muscle strength, MEP, and voice production was further investigated with the completion of this study. The results indicate that older adults can increase their vocal intensity through use of EMST, but not their length of phonation. Increased maximum expiratory pressure indicates a person's ability to forcefully exhale, so the increase in vocal intensity is logical. However, improvements related to expiratory muscles may not affect MPT because MPT requires intact laryngeal valving, and an EMST exercise program does not specifically address vocal fold functioning. For example, MPT is negatively correlated with vocal fold bowing, which can occur as a result of aging (Inagi, Khidr, Ford, Bless, Heisey, 1997; Hagen and Lyons, 1996). The age-related changes that take place in the larynx, especially atrophy of intrinsic muscles can possibly lead to a reduction in laryngeal resistance (Hoit and Hixon, 1987). The reduced resistance can "result in a higher rate of lung volume expenditure (Hoit and Hixon, 1987, p. 363).

*Clinical Implications*

The clinical implications of this particular study are limited to voice production at this time. Previous studies demonstrated positive effects of EMST use and dysphagia including: increased cough acceleration (Pitts et al., 2009; Kim et al., 2007), reduced severity of bolus penetration or aspiration (Pitts et al., 2009), and increased UES anteroposterior opening and anterior hyoid excursion (Troche et al., 2010). Anterior lingual strength and function changes following EMST use had not been clinically investigated prior to this study. The results of the present study indicate further research is needed to determine if EMST use be used as a method of improving dysphagia due to anterior tongue weakness.

Regarding vocal production, this study found that the EMST device could be beneficial in treating older adults with decreased vocal intensity. Healthy older adults who have recreational or vocational demands that require a loud, projected voice may benefit from using the EMST device, especially if they have previously noted decreased ability to produce a loud voice.

According to Turley and Cohen (2006), older adults who have dysphonia or dysphagia as a result of aging are unlikely to seek out speech language services for their problems. The speech language pathologist needs to serve more as a preventative specialist in both swallowing and voice disorders. Expiratory muscle strength training may be able to target and improve the age-related changes and can be recommended within the scope of practice of a speech language pathologist. The EMST device could serve as an instrument to restore voice changes that occurred as a result of aging or to prevent further age-related changes. However, the present study only indicated that EMST use can increase vocal intensity. Further research needs to be completed to address other voice and swallowing measures altered by aging such as voice quality measures, treatment duration for tongue strength, and determining the needs of the older adult population.

*Implications for Future Research*

As discussed in the previous section, future research is necessary to address questions that developed as a result of the present study. One area of future research pertains to tongue strength and function. While this study did not find any significant changes to oral tongue strength and function following an EMST exercise program, positive changes were observed. Tongue strength literature typically utilizes an eight week exercise program to yield significant increases in MIP. Although typical EMST exercise programs are four weeks, an eight week treatment may be necessary to observe significant tongue strength gains. Additionally, the posterior portion of the tongue was not investigated in the current study. It is possible that EMST use may increase posterior tongue strength and function and thus increase the propulsive forces required for safe deglutition. Unfortunately, posterior tongue strength and/or bolus propulsive force may be difficult to isolate and quantify.

There are two areas of voice that would benefit from further research. The first area involves the concept of detraining, or a period of rest following the EMST exercise program where individuals do not continue to use the EMST. This four week period following EMST use was performed by Chiara et al. (2007), and they noted increased phonation times for individuals with multiple sclerosis. This was an interesting finding, given that the increased phonation time was not observed immediately following completion of the EMST exercise program. Future research may explore the benefit of a detraining period for healthy older adults. Given the role of expiratory muscles during speech breathing, perhaps individuals need to adapt to muscular changes. The increased muscle strength and four week time period may allow increased control of breath stream management used during phonation.

The second voice-related area that would benefit from further research pertains to voice quality. The measurements performed in this study were quantitative in nature. However, age-related voice changes can also affect perceived vocal quality. Future research can investigate measures of vocal roughness as well as self-perception of vocal quality. Additionally, listeners can evaluate and rate the pre- and post-test Treatment group recordings to determine if any overall quality changes occurred following the EMST exercise program.

Finally, future research needs to consider additional variables affecting the older adult population. As previously stated, the present study did not have a method of ensuring equal health status, thus, the variance in the health status of this study's subjects existed. On the positive side, this variability made it more likely that the population of this study portrayed "normal" health, rather than what would be considered "healthy." However future research should investigate what specific types of older adult (e.g., "healthy," "sedentary," or "normal") would benefit from an EMST exercise program. Further, if future research can show significant, positive changes in other voice and swallowing measures in older adults, will people have a desire to use the device? Future studies can investigate the perceived cost/benefit ratio from the perspective of the consumer and answer the following question: Are older adults willing to participate in an EMST exercise program to help alleviate age-related voice and swallowing changes given the cost and time required to complete the exercise? All of these questions can be addressed in future research to determine what role EMST devices will have for the older adult.

## *Conclusion*

The purpose of this study was to add to the existing literature regarding expiratory muscle strength training and begin to evaluate the device's potential as a preventative instrument to be used by healthy older adults. In particular, the present study investigated tongue strength and function and voice production tasks in adults ages 65 to 79. It was found that the upper limit of available intensity range ($AIR_{UL}$) and maximum expiratory pressure (MEP) significantly increased following four weeks of EMST exercises in the Treatment group when compared to the Control group. No significant differences were noted for the following variables: maximum phonation time (MPT), conversational intensity level (CIL), lower limit of available intensity range ($AIR_{LL}$), maximum isometric pressure (MIP), and mean swallowing pressure (MSP).

Previous literature also noted an increased MEP for older adults, which was an expected outcome since the EMST exercises directly target expiratory pressure. Functionally, the results of this study show that older adults can increase vocal volume by following an EMST exercise program. Further research is needed to determine if EMST use can alter posterior aspects of tongue function, including bolus propulsion. Additionally, the effects of detraining should be investigated with older adults to determine if MPT gains are made following cessation of EMST use.

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APPENDIX A

Initial Interest Flier

# Functional Outcomes of Respiratory Exercises

## Be a part of an important speech and language-based research study!

*Are you:*

- Between 65 and 79 years of age?
- A non-smoker for at least the past ten years?
- Relatively in good health?

*Do you have NO:*

- History of respiratory problems?
- History of speech and/or language problems?
- History of swallowing problems?

**If you answered YES to these questions, you may be eligible to participate in the study.**

The purpose of this research study is to examine the effects of an expiratory muscle strength trainer (EMST) device. The device has been proven to increase maximum expiratory pressure – but does that translate into any function al gains in speech or swallowing functions? That is what we want to find out. We will be evaluating changes to voice intensity and tongue strength. Half of the participants will receive an EMST device and be asked to complete a 4 week exercise program (exercise takes approximately 30-40 minutes a day and is performed 5 days a week). The other half will simply be tested at the start and the end of the 4-week period. Group assignment will be random.

If you can help us out by participating, please contact:

**Adam Follmer -- (920) 296-5482 -- afollmer@uwm.edu**
**Dr. Marylou P. Gelfer -- (414) 229-6465 -- gelfer@uwm.edu**

**THANK-YOU!!**

# APPENDIX B

## Personal Contact Interview Questions

- “What is your current age?”
    - Response:
- “On a scale of one to five, with one being excellent health and five being very poor health, how would you rate your current health status?”
    - Response:
- “Do you have any of the following: untreated hypertension, cardiac abnormalities, asthma, emphysema, chronic obstructive lung disease (or COPD), history of collapsed lung, head/neck surgery, or untreated gastroesophageal reflux disease (GERD)?”
    - Response:
- “Are you currently a smoker or have you smoked in the past ten years?”
    - Response:
- “Do you have any past history of voice disorders? If so, could you explain?”
    - Response:
- “Do you have any past history of speech and/or language disorders? If so, could you explain?”
    - Response:
- “Do you have any past history of swallow difficulties (medical term is dysphagia)? If so, could you explain?”
    - Response:
- “If selected to participate, would you be willing to complete a thirty minute exercise, five days a week for four weeks? The exercise is meant to increase expiratory muscle strength but should never cause extreme breathing effort or fatigue.”
    - Response:
- Would you be willing to return to this location on the same day for three additional weeks in order to adjust the exercise device?
    - Response
- “If selected to participate, would you be willing and able to be re-tested approximately four weeks after the initial testing?”
    - Response:

APPENDIX C

Consent Form

# UNIVERSITY OF WISCONSIN – MILWAUKEE
# CONSENT TO PARTICIPATE IN RESEARCH
## PARTICIPANT CONSENT

**THIS CONSENT FORM HAS BEEN APPROVED BY THE IRB FOR A ONE YEAR PERIOD**

## 1. General Information

**Study title:** The effects of expiratory muscle strength training on swallowing and voice measures in healthy older adults

**Person in Charge of Study (Principal Investigator):**
My name is Adam Follmer. I am a graduate student in the Department of Communication Sciences and Disorders at UWM. I am conducting this study as part of my Masters Degree thesis research. My supervisor, Dr. Marylou Pausewang Gelfer, will also be involved in this study, as well as Dr. Caryn Easterling, a lecturer in the department.

## 2. Study Description

You are being asked to participate in a research study. Your participation is completely voluntary. You do not have to participate if you do not want to.

**Study description:**
The purpose of this study is to see if exercises for your breathing muscles can affect your voice and tongue. Previous studies have suggested that this might be the case. Our plan is to use a particular device called the Expiratory Muscle Strength Trainer (EMST). The device was developed as an exercise tool to help the muscles involved in breathing get stronger. This study will help us determine whether or not the EMST is useful in changing voice and tongue strength measures in healthy older adults. If the EMST improves functions other than breathing, it may be possible to use it to help older adults who have speech and swallowing disorders.

This study will be conducted in multiple places, including the Speech and Language Clinic on the 8th floor of Enderis Hall, various senior centers and churches, or (if necessary) your home. Approximately 20 healthy older adults (67-77 years of age) will participate in the study.

This study will have two groups: a Treatment group and a Control group, or a group that uses the device and a group that does not. For both groups, participation will take about 1 hour and 30 minutes in total, over the course of two days which will be four weeks apart.

If you are selected for the Treatment Group, you must also agree to do daily breathing exercises with the EMST device for four weeks, five days per week. The exercises will take about 30-40 minutes per day, for a total of 2.5 - 3 hours per week. One of the investigators will do a weekly follow-up meeting to re-test your breathing strength and adjust your device for any changes that occurred.

## 3. Study Procedures

**What will I be asked to do if I participate in the study?**
If you agree to participate you will be asked to meet with me at one of the study locations (Speech and Language Clinic at UWM, other approved location). You will be asked to do tasks that involve using your voice, measuring your tongue strength, and forcefully exhaling. You will perform each task twice, once when we first meet and a second time four weeks after the first meeting. The tasks are detailed below.

- **Mini-Mental Status Examination.** This is a group of about 12 questions that will look mainly at your memory. It should only take about five minutes and it is a widely used test to look at your ability to remember things and follow directions.
- **Maximum Phonation Time** (How long you can use your voice). You will take in a deep breath and say “ah” for as long as you possibly can. I will provide a model for you so you can better understand the task. I will audio record your speech so that I can see the exact time length. This activity will take about five minutes and will happen during the first time we do the tests and four weeks after that.
- **Conversational Intensity Level** (How loudly or quietly you speak in a typical conversation). This task involves reading a paragraph at the loudness level you would use for conversation with a person that is three feet away. I will audio record this measurement so that I will be able to find the exact level of loudness during the reading. This activity will take about five minutes and will happen during the first time we take measurements and four weeks after that.
- **Available Intensity Range** (The loudest and quietest you can make your voice). This task involves reading two sentences, first as quietly as you can, and a second time loudly as you can. I will provide a model for you so you can better understand the task. I will audio record this measurement so that I will be able to look at the exact range of loudness in reading. This activity will take about five minutes and will happen during the first time we take measurements and four weeks after that.
- **Maximum Isometric Pressure** (How strongly your tongue can push against the roof of your mouth). This task involves pushing an air-filled bulb against the roof of your mouth as hard as you can for three separate trials. I will have to perform

a specific distance measurement in your mouth to place the bulb correctly. You will have to open your mouth similar to saying “ah” during a doctor’s visit. You will be allowed to rest in between trials, if you wish. This activity will take about five minutes and will happen during the first time we take measurements and four weeks after that.

- **Mean Swallowing Pressure** (How strongly your tongue pushes against the roof of your mouth during a swallow). This task involves swallowing three separate times as you normally would, except an air-filled bulb will be resting on your tongue. I will have to perform a specific distance measurement in your mouth to place the bulb correctly. You will have to open your mouth similar to saying “ah” during a doctor’s visit. You will be allowed to rest in between trials and take drinks of water, if you wish. This activity will take about five minutes and will happen during the first time we take measurements and four weeks after that.
- **Maximum Expiratory Pressure** (How strongly you breathe out). This task involves breathing out as hard as you can into a mouthpiece after you have taken a deep breath. Your nose will be closed off throughout this task by a nose clip to direct air through your mouth. You will do this activity until you have three numbers that are within +/- 5% of each other or 10 breaths total, whichever comes first. You will be allowed to rest in between trials. This activity will take about five minutes and will happen during the first time we take measurements and four weeks after that.
- **For the treatment group participants**: First, we will determine the level you will train at with the EMST device. Your nose will be blocked throughout this task by a nose clip to direct air through your mouth. This involves you taking a large breath in and breathing out into the EMST. If the threshold is met, you will be able to hear air passing through the device. We will continue to increase the level of the EMST until you can no longer meet the given level. At this point, we will dial back the device 25%, or so that you are training at 75% of your maximum ability to breathe out.
    - Treatment involves you performing exercises once a day. Your nose will be closed throughout the exercises by a nose clip to direct air through your mouth. You will perform five sets of five breaths. To clarify, you will take a breath in and then exhale through the device until you reach the level your device is set at. You will do four more breaths to complete one set. You will then take a short break (approximately one minute) and perform four more sets of five breaths. You will do the exercise program five times per week for four weeks. You will be given a log to track the times you perform the exercises. We will also contact you by phone each week to make sure that things are going well with the daily exercises, and that you have no questions.
    - One of the investigators will visit you each week to re-test your maximum expiratory pressure (how strongly you breathe out) so that your EMST device can be adjusted to the 75% training level

**4. Risks and Minimizing Risks**

**What risks will I face by participating in this study?**
The potential risks for participating in this study are minimal. The tasks that you will be performing are similar in physical activity to light housework or gardening.

1. Physical: There is a small possibility that you may feel tired or the need to catch your breath after some of the voice or breathing activities. If necessary, you will be allowed to take breaks in between the different tasks. The questions that were put on the flier and asked during the interview for this study were partially selected so that those involved in this study would be considered healthy enough to participate in these tasks.
    a. For treatment group participants, you will be performing an exercise that involves you breathing out as hard you can. The level of physical activity is relatively low, similar to light housework. Therefore any potential risks are minimal. Your performance on pre-test measures will indicate if you are healthy enough to complete the exercise program.
2. Psychological: You may feel embarrassed if anyone knew you were in the study, or what your voice and swallowing measures were. We will protect your confidentiality by having only a limited number of people with access to your data (the Student Principle Investigator and the Faculty Advisor). We will keep your personal information in a locked filing cabinet in the Faculty Advisor's office. In publications or presentations resulting from this research, we will never identify you by name or personal information. All of your data from this study will be destroyed after we have completed our presentations and publications.

## 5. Benefits

**Will I receive any benefit from my participation in this study?**
For control participants, there are no direct benefits to you other than to further research.

For treatment participants, you will be participating in an exercise program for expiratory muscle strength, or the muscles used for breathing out. You may see improvements in swallowing, voice, and breathing ability.

## 6. Study Costs and Compensation

**Will I be charged anything for participating in this study?**
You will not be responsible for any of the costs from taking part in this research study.

**Are subjects paid or given anything for being in the study?**
If grant funding comes through, participants will receive a $10 gift certificate to a local restaurant upon completion of the post-test (4 weeks from the first test).

Participants in the treatment group will be allowed to keep the EMST device they used during their exercise program.

**7. Confidentiality**

**What happens to the information collected?**
All information collected about you during the course of this study will be kept confidential to the extent permitted by law. We may decide to present what we find to others at scientific conferences, or publish our results in scientific journals. Information that identifies you personally will not be released. Only the PI and supervisor (Dr. Marylou Gelfer ) will have access to your personal information. However, the Institutional Review Board at UW-Milwaukee or appropriate federal agencies like the Office for Human Research Protections may review this study's records.

You will be assigned a number that identifies your experimental records. Your name will not appear anywhere on the data collection forms. Your name and contact information will be stored in a locked cabinet that only Dr. Gelfer has access to. Upon completion of the study, your data will be retained until the study and all publications and presentations are completed. Your contact information will be shredded at that time, and your voice recordings will be erased.

**8. Alternatives**

**Are there alternatives to participating in the study?**
There are no known alternatives available to you other than not taking part in this study.

**9. Voluntary Participation and Withdrawal**

**What happens if I decide not to be in this study?**
Your participation in this study is entirely voluntary. You may choose not to take part in this study. If you decide to take part, you can change your mind later and withdraw from the study. You are free to not answer any questions or withdraw at any time. Your decision will not change any present or future relationships with the University of Wisconsin Milwaukee.

If you withdraw early from the study, we will use the information collected to the point at which you withdrew.

## 10. Questions

**Who do I contact for questions about this study?**
For more information about the study or the study procedures or treatments, or to withdraw from the study, contact:

Marylou Pausewang Gelfer, Ph.D.
Department of Communication Sciences and Disorders
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201-0413
(414) 229-6465

**Who do I contact for questions about my rights or complaints towards my treatment as a research subject?**
The Institutional Review Board may ask your name, but all complaints are kept in confidence.

Institutional Review Board
Human Research Protection Program
Department of University Safety and Assurances
University of Wisconsin – Milwaukee
P.O. Box 413
Milwaukee, WI 53201
(414) 229-3173

## 11. Signatures

**Research Subject's Consent to Participate in Research:**
*To voluntarily agree to take part in this study, you must sign on the line below. If you choose to take part in this study, you may withdraw at any time. You are not giving up any of your legal rights by signing this form. Your signature below indicates that you have read or had read to you this entire consent form, including the risks and benefits, and have had all of your questions answered, and that you are 18 years of age or older.*

_______________________________________________
Printed Name of Subject/ Legally Authorized Representative

_______________________________________________ ______________________
Signature of Subject/Legally Authorized Representative Date

**Research Subject's Consent to Audio/Video/Photo Recording:**

It is okay to audiotape me while I am in this study and use my audiotaped data in the research.

Please initial: ____Yes ____No

**Principal Investigator (or Designee)**
*I have given this research subject information on the study that is accurate and sufficient for the subject to fully understand the nature, risks and benefits of the study.*

________________________________________ _______________________
Printed Name of Person Obtaining Consent Study Role

________________________________________ _______________________
Signature of Person Obtaining Consent Date

# APPENDIX D

## Order of Voice Sampling Procedures and Participant Instructions

**Maximum Phonation Time** (Neiman and Edeson, 1981, p.287)

"We will now measure how long you can hold the sound 'ah'. You need to keep your voice steady at a soft to moderate level of loudness. . Like this (demonstrate)."

"Please do not stop until you completely run out of air. I want you to get to your absolute longest prolongation. We're going to do this three times. Let's get started! Begin as soon as you hear me click the mouse."

After each subsequent trial: "Good! Now try to prolong the sound longer this time."

**Conversational Intensity Level** (Gelfer and Young, 1997)

"Please read this passage to yourself."

"Now I want you to read this passage aloud. Use this string to help you maintain a constant distance away from the sound level meter. Put the knot of the string in between your fingers. Put your thumb against your chin like this [model]. Keep the string pulled tight for the entire reading. I want you to speak in a conversational tone that would be appropriate for a person that is two or three feet away from you - the same distance away from you as I am. Please begin when you are ready and please start with title"

**Available Intensity Range** (Gelfer and Young, 1997 p. 181)

"I want you to read just the first two sentences of the same passage, but this time read them as quietly as possible without whispering. Like this [model].Now you try it. Use the string to maintain the same constant distance as the previous task. Please begin when you are ready."

"Now I want you to read the same two sentences as loudly as possible without high-pitched screaming. Like this [model]. This will take a little bit of effort, so make sure you take a good breath and get prepared.  Use the string to maintain the same constant distance as the previous task. If there's any problem, I'll stop you before you get too far. Go ahead and begin when you are ready."

Order of Tongue Strength Measurements and Patient Instructions

**Maximum Isometric Pressure** (Robbins et al., 1995)

"When I place the bulb in your mouth, I want you to press it against the roof of your mouth with your tongue as hard as you possibly can. We'll do this three times. Please let me know when you are ready to begin. If you need to rest or take a drink of water between trials, just let me know."

**Mean Swallow Pressure** (Robbins et al., 1995)

"This time when I place the bulb in your mouth, I want you to swallow your saliva as you normally would. We'll do this three times.  Try to work up a little saliva first, like this (demonstrate).  If you need to rest or take a drink of water, just let me know. Go ahead when you are ready."

Maximum Expiratory Pressure Patient Instructions

**Maximum Expiratory Pressure**

"Now I want you to breathe in as much air as you possibly can. You will need to breathe through your mouth, because I will need to close off your nose with this clip. Then, create an airtight seal around the mouthpiece of this device and exhale as forcefully as possible. Let's try some practice breaths prior to using the device. [practice] We'll be performing multiple trials of this measurement. If you need to rest in between breaths just let me know. You can start whenever you're ready."

APPENDIX E

Rainbow Passage

# Rainbow Passage

**When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. A rainbow is the division of white light into many beautiful colors. These take the shape of a long, round arch, with its path high above and its two ends apparently beyond the horizon.**

**There is, according to legend, a boiling pot of gold at one end. People look but no one ever finds it. When a man looks for something beyond his reach, his friends say he is looking for the pot of gold at the end of the rainbow.**

APPENDIX F

Rainbow Passage – Two Sentences

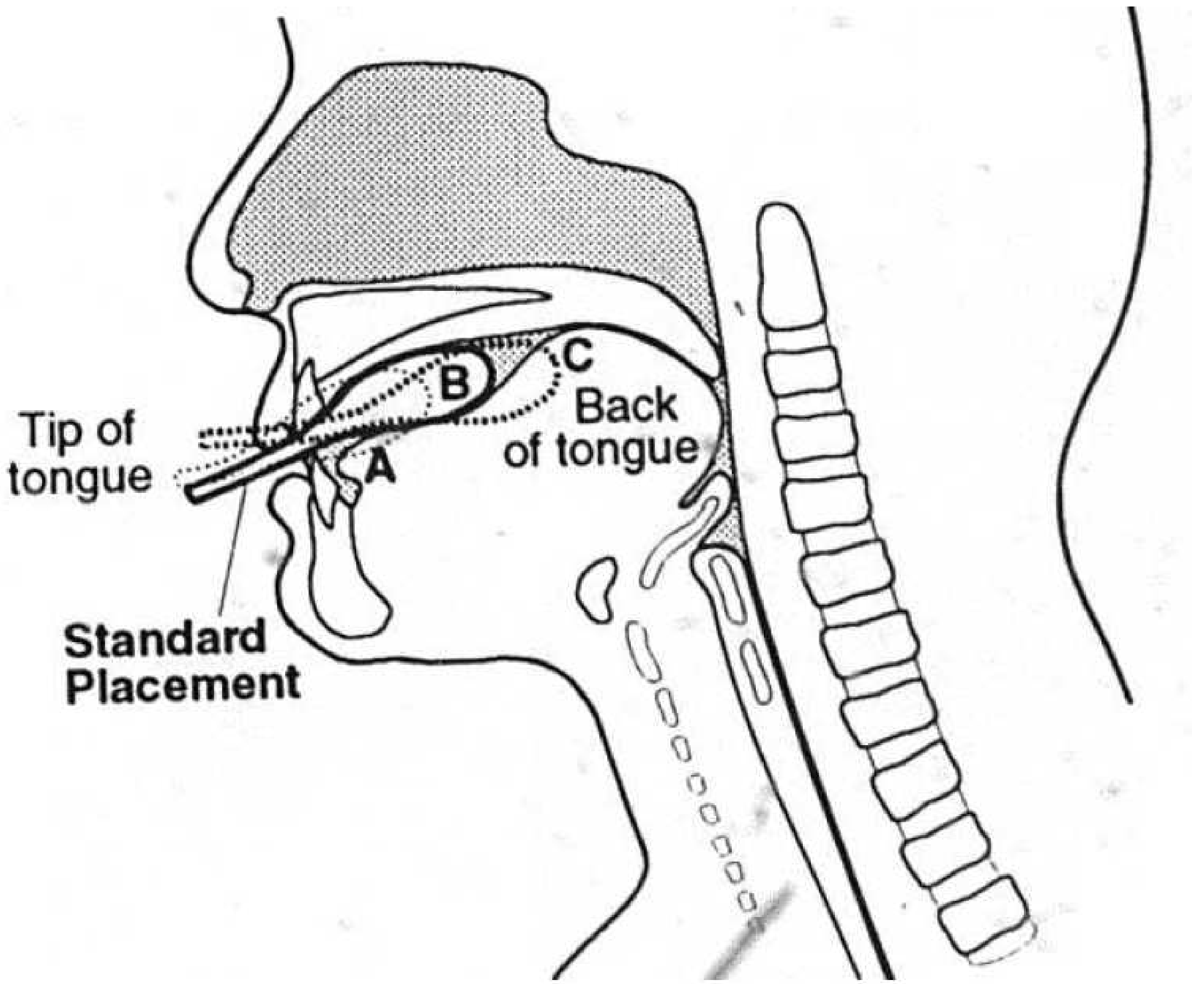
# Rainbow Passage – Two Sentences

**When the sunlight strikes raindrops in the air, they act like a prism and form a rainbow. A rainbow is the division of white light into many beautiful colors.**

APPENDIX G

IOPI Tongue Placement Diagram (Robbins et al., 1995)

Placement B – Standard Placement



# APPENDIX H

## Expiratory Muscle Strength Training Instructions
(adapted from Sapeinza and Troche, 2012)

1. Sit in a comfortable position and place a nose clip on your nose so that all of your breathing is done through the mouth.

2. Practice placing your device: Open your mouth and place lips around the mouthpiece; make sure mouthpiece sits behind the front teeth. When you are sure you know where the device belongs, and can place it there quickly, take your device out of your mouth.

3. Take a deep breath in and quickly place your device in your mouth. Then blow out into your device as hard as you can until you hear and feel air flowing through the device. Keep exhaling for as long as you can. Doing this may be a little tiring, but should not be exhausting. If you feel excessively tired or light-headed, discontinue the exercise, and let us know when we call to check in.

4. Take the device out of your mouth and rest for 30-60 seconds.

5. Repeat Steps 3and 4 four more times

6. Each breath through the device valve is considered one *trial* of training. Five trials performed in a row is *one set*. The protocol is 25 trials (or 5 sets) per sitting, completed 5 days per week.

7. Take a one to two minute break between sets (each five trials or breaths).

- Try to do the training at the same time every day.
- Make sure to fill out the training log as you go.

# APPENDIX I

## Expiratory Muscle Strength Trainer Exercise Log

Use this log to help you keep track of how often you complete the exercise. Circle the day of the week as you go. Place a check or an “x” in each box to mark that you completed a trial.

**Week ____ ( ___________ to _____________)**

<table>
<tr><td>Day __</td><td>Trial number</td><td>Set 1</td><td>Set 2</td><td>Set 3</td><td>Set 4</td><td>Set 5</td></tr>
<tr><td rowspan="5">Monday<br>Tuesday<br>Wednesday<br>Thursday<br>Friday<br>Saturday<br>Sunday</td><td>1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>4</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Notes:</td><td colspan="6"></td></tr>
</table>