THE EFFECTS OF TWO REHABILITATION EXERCISES ON SUBMENTAL HYOLARYNGEAL MUSCULAR ACTIVITY

by

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THE EFFECTS OF TWO REHABILITATION EXERCISES ON SUBMENTAL HYOLARYNGEAL MUSCULAR ACTIVITY

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by

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This thesis is dedicated to my grandfather,
who showed me that the pursuit of knowledge lasts a lifetime.

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CHAPTER I

INTRODUCTION

Dysphagia, an impairment of the swallowing mechanism due to physiological weakness, deficits of structure or neurological function, is a disorder affecting a significant portion of the population of persons who have experienced a stroke, traumatic brain injury (TBI), head and neck cancer, head and neck surgery, or as a natural process of aging (Ekberg, 1982, 1986; Ekberg & Hilderfors, 1985; Perlman et al., 1994; Park et al., 2012; Shaker et al., 2002; Johnson et al., 2014). Dysphagia can adversely impact the quality of life, as well as negatively impact the person's ability to maintain adequate hydration and nutrition (Logemann, 1998; Nilsson et al., 1998). Much research has been conducted on rehabilitation of patients with dysphagia using compensatory strategies such as postures, swallowing maneuvers, and with rehabilitative exercises designed to facilitate a physiological change in the impaired laryngeal musculature. Recent studies (Yoon et al., 2013; Watts, 2013) have focused on creating new rehabilitative exercises targeting the submental hyolaryngeal musculature, specifically the suprahyoids that are involved in hyolaryngeal excursion. Both Yoon and Watts tested the concurrent validity of their exercises against the well-researched and supported Shaker exercises (Shaker et.al, 2002; Logemann et al., 2009; Yoon et al., 2013; Watts, 2013), and both researchers reported positive results for increased muscular activation of the suprahyoids during isometric contraction in comparison to Shaker.

The development of an effective, efficient resistive rehabilitation exercise for dysphagia would have significant implications for clinical practice in management of patients with pharyngeal stage dysphagia caused in part by reduced hyolaryngeal excursion; an ideal exercise would increase the displacement of the hyoid during the pharyngeal stage of the swallow, thus improving reduced airway protection and upper esophageal sphincter (UES) expansion, both major impairments contributing to aspiration in the pharyngeal stage of the swallow. The purpose of this study was to compare the exercises published by Watts and by Yoon and colleagues to determine whether they elicit significant hyolaryngeal muscle contractions and whether a difference exists between these two exercises.

CHAPTER II

Review of the Literature

Hyolaryngeal Elevation and Excursion

Vertical and anterior displacements of the hyoid bone are markers for the initiation of the pharyngeal stage of swallowing (Kim & McCullough, 2008; Yokoyama et al., 2000; Paik et al., 2006). The pharyngeal stage begins with the horizontal and vertical movement of the hyoid bone caused by contraction of the digastric, geniohyoid, and mylohyoid muscles. This pattern, called laryngeal excursion, is responsible for both airway protection and expansion of the upper esophageal sphincter (UES). The hyolaryngeal excursion anteriorly and superiorly in conjunction with posterior tongue base retraction physically approximates the base of the epiglottis to the arytenoid cartilages in the posterior larynx. In a healthy person, these movements effectively seal off the laryngeal vestibule and protect the larynx from penetration or aspiration; additionally, the relaxation of the UES allows for smooth bolus transit into the esophagus.

In studies that have examined vertical and anterior hyoid bone displacement trajectories in normal subjects, excursion characteristics have been shown to vary markedly depending on age, bolus type, and bolus size (Kim & McCullough, 2008; Ishida et al., 2002; Dodds et al., 1998; Cook et al., 1989; Paik et al., 2006). Consequently, the contributions of each trajectory may not be equivalent as they relate to airway protection and UES dilation; analyses of displacement will yield different anterior and vertical trajectories depending on the combination of variables mentioned above. Ishida et al. (2002) posited that while vertical excursion was variable across different food trials, anterior hyoid excursion was "highly consistent in amplitude regardless of food consistency and swallow order," and was therefore a more essential part of the pharyngeal swallow. While vertical displacement is responsible for epiglottic tilt and partial airway protection, anterior excursion is primarily responsible for pulling open the UES (Logemann, 1998; Yokoyama et al., 2000). Characteristics of hyolaryngeal movements during swallowing can change with age (Yokoyama et.al, 2000). Studies have shown that bolus transit times were significantly increased in the elderly, and that increased resistance to bolus entry at the level of the UES was caused by delayed anterior laryngeal movements (Yokoyama et al., 2000; Paik et al., 2006).

Kim and McCullough (2008) showed that younger subjects had greater anterior excursion than older subjects on liquid trials, although differences in vertical excursion were not significantly different, nor were effects of gender. Those authors suggested that reduced anterior excursion with preserved vertical excursion in the elderly may be explained by the recruitment of more motor units for vertical displacement. This theory may support the use of clinical interventions which target rehabilitation of hyolaryngeal excursion through muscle reeducation (neuromuscular adaption) exercises in individuals with reduced movement of the hyoid and larynx during swallowing. Exercises which increase muscle function during swallowing specific to airway protection and swallow effectiveness may be especially important in elderly populations. Potentially, if the submental hyolaryngeal muscles can increase contraction strength and sustain contraction over time, therefore increasing hyolaryngeal excursion, they could overcome the effects of aging on pharyngeal bolus transit and decrease the chance of consequent laryngeal penetration and/or aspiration.

Laryngeal Dysfunction in Dysphagia

Defective closure of the laryngeal vestibule occurs in 43 percent of patients with dysphagia (Ekberg, 1982). Reduced laryngeal closure can occur from a delayed closure that allows entrance of the bolus into the laryngeal vestibule (penetration); it can also occur from an inability to close the glottis—via inadequate vocal fold adduction—throughout the duration of swallowing, allowing the bolus to penetrate and be potentially aspirated or expelled by vigorous coughing (Ekberg & Hilderfors, 1985). Some researchers have attributed delayed airway closure to an inaccuracy in the “subtle normal timing of the swallowing act,” which occurs in typical human aging (Ekberg & Hilderfors, 1985). Delayed laryngeal closure can also manifest secondary to neuromuscular injury, such as stroke.

Reduced laryngeal closure can result in penetration or aspiration and puts an individual at risk for lung infection, decreased eating satisfaction, and increased safety risks during meals. Reduced laryngeal closure can lead to residual bolus material remaining at the entrance of the laryngeal vestibule after the swallow as a result of vallecular pooling; if the residual material cannot be cleared by the pharyngeal contraction or laryngeal excursion, penetration or aspiration occurs when the larynx is opened to inhale following the swallow as the remaining bolus residue passes into the airway (Shaker et al., 2002). Inadequate laryngeal elevation can increase the risk for penetration as a result of reduced laryngeal closure. Penetration can also be caused by inadequate vocal fold adduction that leaves the airway entrance opened during swallowing. The ability of an individual to clear penetrated or aspirated material will depend on sensory function and the ability to generate muscular forces when material triggers sensory modulated reactions.

Reduced hyolaryngeal elevation can create insufficient epiglottic inversion and UES opening, resulting in post-swallow pooling and/or aspiration (Perlman et al., 1994; Bartolome & Neumann, 1993; Kim & Han, 2009). The degree of hyolaryngeal elevation influences to a large degree the extent of UES opening. This influence is applied through traction placed on the UES by the larynx as it elevates. Muscles primarily responsible for this elevation are the suprahyoid muscles, including the geniohyoid and mylohyoid (Kim & Han, 2009). The thyrohyoid muscle is also active for hyolaryngeal excursion during swallowing, pulling the larynx superiorly towards the hyoid bone.

Kim and Han (2009) found in their study that surface electrical stimulation of the suprahyoid muscles can induce the elevation and anterior excursion of the hyoid and larynx. Through trial and error placements of electrodes for muscle stimulation, Kim and Han also discussed the thyrohyoid muscle’s role in hyolaryngeal elevation. During typical swallow function, the thyrohyoid muscle pulls the larynx upward.

However, atypical movements due to poor thyrohyoid function can result in a larger laryngeal vestibule and an increased risk of penetration and subsequent aspiration. Kim and Han observed the previous phenomenon when stimulating specific muscle groups in isolation, supporting the assertion that the swallowing mechanism is a complex combination of timed muscle contractions from multiple muscle groups, and the dysfunction of even one small part can negatively impact the entire system's function.

Perlman and colleagues (1994) analyzed videofluoroscopic examinations of patients with dysphagia from strokes, TBI, Parkinson's disease, or head and neck cancer. They found that adult dysphagic patients displayed prolonged transition times between the oral and pharyngeal stages of swallowing, or the initiation of pharyngeal swallow; this transition delay was identified as a predictor of aspiration in patients with pharyngeal dysphagia (Perlman, et al., 1994). Bartolome and Neumann (1993) found in their study of 28 patients with impaired UES opening that 90 percent of the patients showed improvements in their dysphagia as a result of swallowing therapy.

Between 30 and 50 percent of all individuals who suffer a stroke from cerebrovascular accidents (CVAs) have swallowing problems; dysphagia resulting from a stroke is considered a major cause of respiratory complications such as aspiration pneumonia, as well as dehydration, and malnutrition (Logemann, 1998). Nilsson, Ekberg, and colleagues (1998) conducted a prospective study of 100 consecutive stroke patients. Within twenty-four hours post-onset 14 out of 72 patients (19 percent) had self-reported complaints of dysphagia. When evaluated these patients were observed to have prolonged stages of swallowing, as well as decreased suction pressures[1], bolus volumes, and swallowing capacities (Nilsson et al., 1998). Over the period of one month, the prevalence of swallowing incoordination and abnormal feeding-respiratory patterns increased; after 6 months, 7 of the original 100 patients had persistent dysphagia (Nilsson et al., 1998).

Hyolaryngeal elevation and the opening of the UES are integrally related: traction is applied to the UES by the superior and anterior movement of the hyoid and thyroid (defined as hyolaryngeal excursion); excursion occurs secondary to the activation of the hyolaryngeal musculature—the mylohyoid, geniohyoid, anterior digastric, and thyrohyoid (Cook, 1993; Cook, 1989; Logemann, 1998; Huckabee & Pelletier, 1999; Groher & Crary, 2009). In both reduced laryngeal closure and reduced hyolaryngeal elevation, rehabilitative exercises targeting the hyolaryngeal elevators—the geniohyoid, mylohyoid, anterior digastric muscles—aim to facilitate neuromuscular adaption to change the structural and functional properties of the weakened muscles through use of some form of stimulation and/or principles of strength training (Watts, 2013; Steele, 2012; Lieber, 2002).

Exercises for Laryngeal Dysfunction in Dysphagia

Clinicians have multiple options for treating reduced hyolaryngeal excursion in dysphagia. These include neuromuscular electrical stimulation, the Shaker exercise,

[1] The term “suction pressure” as used by Nilsson and colleagues (1998) is referring to subglottic bolus pressure.

the tongue press, the Mendelsohn maneuver, chin tuck against resistance (CTAR), and a chin-to-chest exercise (CtC).

Neuromuscular electrical stimulation (NMES). NMES is used to stimulate nerves to achieve a therapeutic response in muscles (Herbert, 2003), causing nerves to fire by generating an electrical current which flows through body tissues to depolarize sensory and motor neurons. This modality can be used clinically to retrain the neuromuscular function that is lost after surgery or upper motor neuron injury. Denegar et al. (2006) stated that the goal of NMES is to elicit a strong muscle contraction through stimulation of the alpha motor nerve. The patient is taught to contract the affected muscle(s) in synchrony with the stimulation to overcome the natural muscle inhibition produced by the injury or surgery. Denegar et al (2006) suggested that NMES is so named because “the goal is to retrain the neuromuscular component to achieve an improved ability to produce muscle force.” NMES was originally developed to increase muscle strength in trained athletes. Kots (1977) stated that NMES combined with intense training resulted in greater strength gains than training alone. In order for a muscle to become stronger, a load must be placed on the muscle and adaption/accommodation must occur. Maximal contractions require the recruitment of type II muscle fibers. According to Henneman et al. (1965), muscle fibers are recruited via a “size principle.” In physiological muscle contractions type I muscle fibers (slow twitch) are activated first, and type II fibers (fast twitch) are recruited only after the muscle requires a greater contraction. In order to reeducate the muscle, NMES contraction reverses the recruitment order used in physiological muscle contractions. Type II fibers have larger motor neurons and the depolarization threshold is lower; therefore these fibers respond more quickly to electrical currents when exposed than type I fibers. The recruitment of type II fibers via NMES promotes maximal muscle contractions, ultimately creating more adaption and increased muscle strength and function in the targeted area.

Shaker (Head Lift). The clinical effectiveness the Shaker head-lift exercise has been extensively researched. During the Shaker exercise, the participant performs isometric and isokinetic head lift exercises three times a day while lying in the supine position (Shaker et al., 2002). The main goal of the Shaker head-lift exercise is to cause adaptation in the suprahyoid muscles. The strategy of this exercise is that contracting the suprahyoid muscles "contributes to the upward and forward movement of the larynx and hyoid bone, resulting in the opening of the UES" (Goyal, 1984). Therefore, by strengthening the suprahyoid muscles through exercise, patients would increase the opening of their UES (Logemann et al, 2009; Shaker et al., 1997). The Shaker exercise has reduced post-swallow aspiration in patients with dysphagia (Logemann et al., 2009), increased anterior laryngeal excursion (Shaker et al., 2002), and increased the anterior-posterior diameter of the UES in elderly populations both with dysphagia and without (Shaker et al., 1997; Easterling et al, 2005). These results are attributed to the improved strength of the suprahyoid muscles after completing the Shaker exercise regimen (Shaker et al., 2002; Mepani et al., 2009). A major contraindication often cited against use of the Shaker exercise is the degree of physiological rigor required to complete the head-lifts. As with the

Mendelsohn maneuver, the Shaker exercises are thought to be “too physically demanding for elderly patients with chronic disease” (Yoshida et. al, 2007).

Mendelsohn maneuver. The Mendelsohn maneuver has been widely used as a compensatory strategy to improve UES opening and bolus flow (McCullough & Kim, 2012). Mendelsohn and McConnell (1987) define the Mendelsohn maneuver as “a voluntary prolongation of hyolaryngeal elevation at the peak of the swallow.” As a compensatory strategy, the Mendelsohn maneuver increases laryngeal elevation and maximal hyoid superior displacement as well as the duration of UES opening (McCullough & Kim, 2012). A major drawback of the Mendelsohn maneuver is the fatiguing of the Type II muscle fibers of the oropharynx in elderly populations that would benefit from this strategy (Burkhead et al., 2007). McCullough and Kim (2012) posited that if a patient has to strenuously compensate during a meal, the increased fatigue may in fact worsen the patient’s dysphagia rather than helping it. Several recent studies by McCullough have investigated the Mendelsohn maneuver’s potential as a rehabilitative exercise to improve UES opening and duration of hyoid movement (McCullough & Kim, 2012; McCullough et al., 2012; McCullough, 2014). In a previous study, Kim and McCullough (2010) examined maximal hyoid excursion in post-stroke patients, and stated that decreased hyoid movement was a common cause of insufficient UES opening. McCullough & Kim (2013) showed that the Mendelsohn maneuver employed as a rehabilitative exercise not only improved UES opening and increased the extent of hyoid movement, but that it also yielded improvements in the coordination of structural movements and bolus flow during the swallow. The greatest improvement post-study was observed for hyoid elevation (McCullough, 2013). The authors suggested that results were due to the Mendelsohn maneuver creating a physiological change (neuromuscular adaptation) to strengthen the hyolaryngeal elevators.

Chin tuck against resistance (CTAR). Yoon et al. (2013) claimed that strengthening the suprahyoid muscles elevators through therapeutic exercise is effective in restoring oral feeding for patients with dysphagia resulting from UES dysfunction. Yoon's study contrasted the Shaker exercises with CTAR exercises to compare the activation of the suprahyoid muscles. In CTAR the patient is seated in an upright position and tucks the chin to compress an inflatable rubber ball in both isometric and isokinetic tasks (Yoon et al., 2013). Yoon claimed that the chin tuck is already a widely used compensatory strategy in dysphagia management, and posited that as a therapeutic exercise CTAR would be more effective than Shaker—a rehabilitative regimen already demonstrated to be successful in effecting a positive change in hyolaryngeal musculature—due to increased compliance and decreased strenuousness of the physical exercises. The results of Yoon's study indicated that CTAR yielded greater suprahyoid activation during both isokinetic and isometric exercises compared to the equivalent Shaker exercises for both maximum and mean surface electromyography (sEMG) values. Yoon therefore claimed that CTAR would serve as an effective approach to exercising the suprahyoid muscles in to achieve results comparable to the known effects of Shaker exercises in clinical populations.

Chin-to-Chest (CtC). The chin-to-chest exercise (CtC) is a potential rehabilitative exercise that places maximum overload on the hyolaryngeal muscles during isometric contraction to maximally facilitate adaption and increase muscle strength (Watts, 2013). Watts compared the effects of CtC exercise on hyolaryngeal musculature activation to a head lifting exercise comparable to Shaker exercises. The CtC exercise used a maximal jaw opening posture in which the patient actively pushed against a semi-rigid chin brace for 10 seconds, with the purpose of incorporating a large resistance load against hyolaryngeal muscle contraction (Watts, 2013). The combination of resistance and isometric hyolaryngeal muscle contraction resulted in both significantly greater sEMG measures at peak contraction and a greater difference between rest and peak contraction during the CtC exercise relative to the Shaker exercise (2013). Watts concluded that the CtC resulted in greater activation of the hyolaryngeal muscles responsible for elevating the larynx and moving it forward during swallowing than the isometric head-lift exercise.

Surface Electromyography for measuring Muscle Function during Swallowing

Electromyography is a process which records the electric currents from an active muscle to produce an electromyogram, a graphic representation of the electrical currents associated with muscular action. sEMG is a technique in which electrodes are placed on the skin overlying a muscle to detect the electrical activity of the muscle during a contraction. This is in contrast with intramuscular electromyography (iEMG), where electrodes are inserted into the body of a muscle. sEMG can be used for measuring muscle activity during swallowing. sEMG gives information about motor unit activity associated with groups of activated muscles in the area around the electrode, rather than isolating the activity of specific motor units and muscles as is the case with iEMG. Electromyographic signals obtained through the surface electrodes represent simultaneous muscle activity from multiple muscles in the region of interest (Crary & Groher, 2006). Common temporal measurement parameters used with sEMG are “onset,” “peak,” and “offset” activity in the specified muscles (Crary & Groher, 2006). Onset is defined as the point of upward excursion of the sEMG trace from resting baseline. Offset, conversely, is defined as when the sEMG activity returns to baseline. The signal peak is the highest amplitude point of the sEMG trace during a swallow (Crary & Groher, 2006). Typically the mean sEMG amplitudes across onset and offset points, and amplitude at the peak location, are reported as dependent variables.

Over the past thirty years, sEMG has been used by clinical researchers in multiple ways, including identifying the presence of swallowing activity, analyzing the timing and amplitude of a swallow, and also as a therapeutic biofeedback approach in treating patients with swallowing disorders (Crary & Groher, 2006; Bryant, 1991; Crary et al., 2004; Haynes, 1976; McKewon et al., 2002; Huckabee & Cannito, 1995; Vaiman et al., 2004). Crary and Groher (2006) studied the correlation of sEMG measures with specific biomechanical swallowing activities including hyolaryngeal elevation, pharyngeal constriction, and UES opening and closing. Based on their results, the authors stated that "both hyoid and laryngeal movements are closely related to sEMG signals obtained from the upper anterior neck midline"—the submental area. The conclusions of the study support earlier findings by others, such as Palmer et al. (1999) that concluded after examining specific muscle activity and their associations with sEMG signals during swallowing that the mylohyoid, geniohyoid, and anterior belly of the digastric muscles (the hyolaryngeal elevators) were the greatest contributors to the signal measured from submental sEMG electrodes obtained during a swallow response.

The practice of examining submental muscles via sEMG to assess swallowing is supported by the significant correlation established between laryngeal elevation and submental and cricopharyngeal muscle activity (Ertekin et al., 1995; Ertekin et al., 1997; Ding et al., 2002; Wheeler-Hegland et al., 2008). Laryngeal elevation is significantly related to increased submental sEMG activity (Crary & Groher, 2006). While some measures such as pharyngeal constriction and UES opening/closing slightly precede or follow sEMG activity (McKeown et al., 2002; Perlman et al., 1999; Crary & Groher, 2006), hyolaryngeal elevation has a strong direct temporal correlation to sEMG signals obtained during a recorded swallow (Crary & Groher, 2006). Those results support the use of submental sEMG as a reliable measure of hyolaryngeal muscular activation during swallowing in clinical studies. sEMG provides a modality through which the effectiveness of rehabilitative exercises on muscle adaptation can be demonstrated and visualized via amplitude and duration, e.g. measuring contraction force. When used as a basis of measurement, sEMG traces, specifically submental sEMG measures, can be used to compare the effectiveness of exercises (such as Mendelsohn maneuver versus effortful swallow, or CtC versus CTAR) (Wheeler-Hegland et al., 2008).

CHAPTER III

Purpose

Reduced hyolaryngeal excursion subsequent to aging, stroke, head injury, or medical treatment for head/neck cancer puts an individual at risk for dysphagia. A number of treatments have shown benefits for rehabilitating laryngeal excursion, most notably the Shaker exercise and Mendelsohn maneuver. Two newer exercises, CTAR and CtC, have suggested that hyolaryngeal muscles can be rehabilitated by depressing the chin downward against resistance. These two exercises differ in that CTAR does not actively engage the submental muscles, while CtC does by requiring jaw opening against a resistive brace. Authors of both maneuvers have suggested that hyolaryngeal muscular activity is increased during the exercises and that this activity is equal to or greater than that elicited during the Shaker exercise. However, hyolaryngeal muscular activity during production of CTAR and CtC has never been compared. A comparison is needed to identify which exercise elicited greater contraction force in the targeted muscles.

The purpose of this study was to compare the electrical activity in hyolaryngeal muscles during CTAR and CtC. sEMG was used to measure average and peak contraction amplitude during production of both exercises in a young, healthy sample. sEMG electrodes were placed on the anterior neck to measure activity of the Mylohyoid, Geniohyoid, and Anterior Digastric muscles. The following was designed to answer specific research questions related to 1) Do CTAR and CtC result in greater mean and peak contraction compared to resting baseline, and (2) Do mean and peak contraction during CTAR and CtC differ from each other.

CHAPTER IV

Methods

Participants

Participants were recruited via a convenience sample and included 20 healthy young women between 20 and 30 years of age (mean age 24;1 yrs; range 22;2—30;4 yrs). Each participant completed both counterbalanced experimental exercise conditions, with 10 performing the CTAR as the first exercise and 10 performing the CtC as the first exercise. Inclusion criteria required a negative history of dysphagia, head or neck cancer, cervical spine conditions, neuromuscular or neurological disease, surgery to the anterior neck, or radiation to the anterior neck. All participants signed an informed consent form, which was approved by the Institutional Review Board at Texas Christian University.

Instrumentation

To acquire sEMG signals the Swallowing Signals Lab workstation (Kaypentax, Montvale, NJ) was used, set up in a similar method as Crary, Carnaby, and Groher (2006). This included disposable self- adhesive electrode patches, which were approximately 2.25 in. in diameter. The patches consisted of three electrodes organized in a triangle configuration approximately 0.25 in. from each other. Two of the electrodes served as recording electrodes and a third served as the ground. Signals from the electrodes were processed by the Swallowing Signals Lab, which was connected to a desktop PC. An example of the data collected by the Digital Swallowing Workstation (DSW) is displayed in Figure 1 below. The x axis represented the duration of the sEMG signal in seconds (s) and the y axis represented the amplitude, or intensity of the sEMG signal, in microvolts (µV).

DSW Signal Display

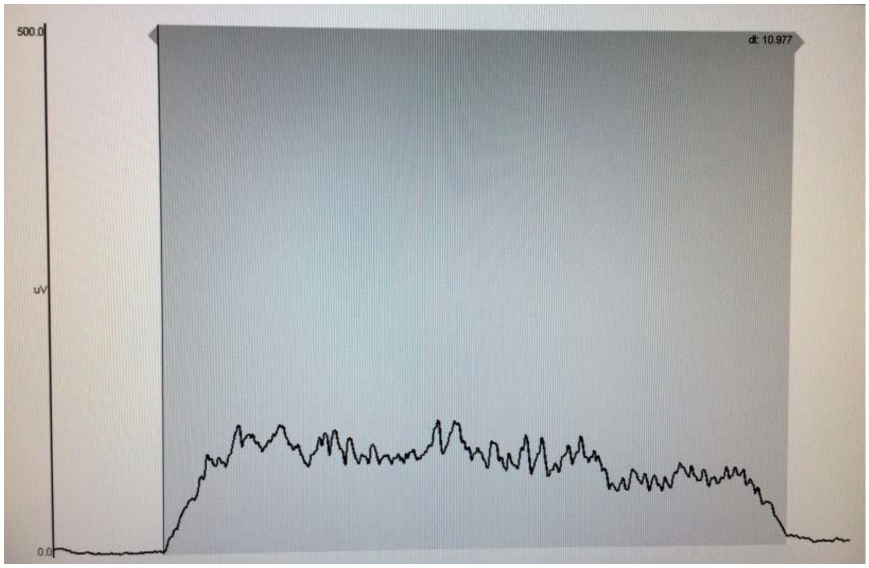

Figure 1. Sample display of sEMG tracing from DSW. Adapted from the Swallowing Signals Lab workstation model (Kaypentax, Montvale, NJ).
Retrieved by the author, March 1, 2015.

The y axis was set at a fixed range of 0 to 500 µV, while the x axis length varied based upon sample duration. Consequently, a shorter recording of 10 s would create a false visual perception of a higher amplitude of sEMG signal (denoting greater muscle activation) displayed in the raw data, as opposed to that of a 30 s recording, where the data was more condense. This sample variance is demonstrated in Figure 2 below. The sample on the top with a 10.985s portion highlighted appears to have greater amplitude than the sample on the bottom, which had a longer period of pre-trial activity included in the total sample length. Therefore, although the sample on the bottom has a highlighted portion of 12.868s, it appears perceptually smaller and shorter than the sample on the top. For this reason, it was essential to exclude extraneous tracings before and after the 10 second contraction when viewing and analyzing sample data.

Variance in DSW signal display with sample duration

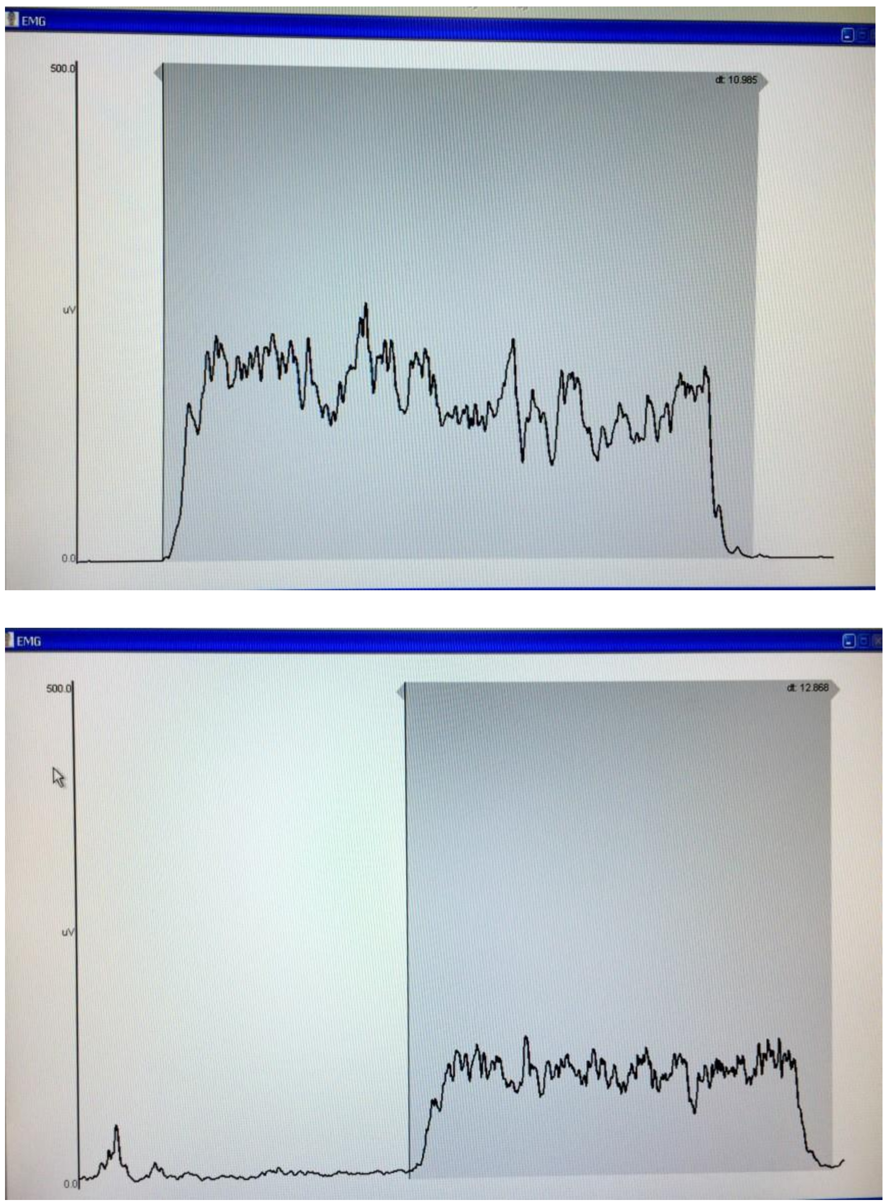

Figure 2. The effects of pre-exercise activity on visual display of signal amplitude. Adapted from the Swallowing Signals Lab workstation model (Kaypentax, Montvale, NJ). Retrieved by the author, March 1, 2015.

Procedures

All participants were asked a set of questions regarding inclusion criteria and provided informed consent prior to participation in the study. Once consent was obtained, participants were recorded in the Laryngeal Function Laboratory in the Miller Speech and Hearing Clinic (MSHC) on the campus of Texas Christian University. Participants were required to participate in one recording session during which all measurements were obtained. After consenting procedures, electrodes were applied to the surface of the skin beneath the mandible. The skin surface was cleansed with an alcohol wipe (MEDI-PAK 70% Isopropyl Alcohol) prior to application to remove skin oils. Electrode heads on the self-adhesive electrode patch were coated with a light film of electrode gel (Signa gel, Parker Laboratories, Fairfield, NJ) to improve signal conduction. The tab of each electrode patch was placed centrally 1 cm below the inferior rim of the mental protuberance of the mandible. This placement was to insure that the electrodes were over the laryngeal elevator muscles, as shown in Figure 3. Electrode cables from the Swallowing Signals Lab were then attached to the electrode patch.

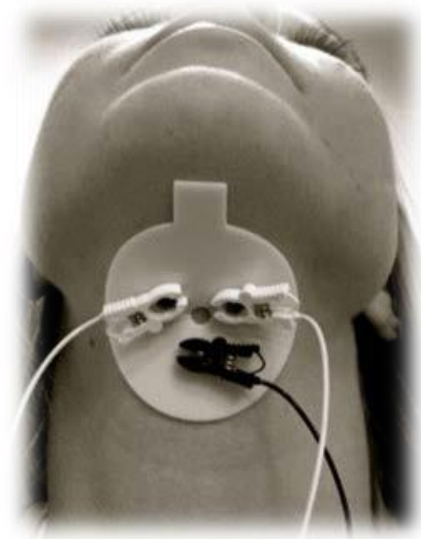

Figure 3. Surface EMG electrode placement and lead orientation. Photo used with permission of Christopher Watts, Ph.D, Texas Christian University.

Baseline Performance Measurements. Neuromuscular activity from sEMG signals can exhibit normal inter-subject variability based on physical characteristics of the individual. To control for natural variability, a baseline recording for hyolaryngeal sEMG activity was obtained from each participant during a minimal effort task. The participant was instructed to "tuck your chin towards your chest and hold for 10 seconds until I tell you to stop," with a visual demonstration by the principal investigator. Five trials were completed with the instructions repeated for each trial to ensure consistent participant technique. Five rest measurements were collected for the baseline condition of each participant. These five resting baseline trials were used to calculate average sEMG measures, which were then used to transform data from CtC and CTAR conditions, as described in the Analysis section below.

Chin-to-Chest (CtC) Exercise. Participants performing the CtC as the first or second exercise were instructed to press their maximally opened jaw into a semi-rigid adjustable plastic chin brace (Restorative Posture Device, Ampcare, LLC; Fort Worth, TX) while sitting upright in a chair. Prior to initiation of the CtC exercise, the purpose and function of the brace as well as exercise instructions were explained to each participant. Participants were fitted with the brace so that it rested under the mandible without eliciting discomfort. The brace provided a platform against which participants could press their chins as they contracted their hyolaryngeal muscles, adding resistance to potentially increase the number of motor units recruited during contraction (Watts, 2013). Figure 4 illustrates the chin brace fitted to an individual at rest, while Figure 5 illustrates the CtC exercise during contraction. As a participant opens their jaw into the brace, a chest plate at the inferior end of the brace prevents compression of the device and provides a semi-rigid resistance to the muscular load. Visual demonstrations of proper exercise form were given by the principal investigator and participants were allowed several practice trials before recording to ensure proper form and consistent technique. To initiate the CtC exercise, each participant was asked to open her mouth maximally while pushing her chin into the brace, and hold for 10 seconds until instructed to stop. Before each CtC repetition, the participant was encouraged to open her jaw into the brace “as hard as you can” for the entire 10 seconds. Hyolaryngeal sEMG activity was measured at rest for 1-2 seconds prior to the initiation of each CtC exercise and after the participant completed the CtC exercise and returned to baseline activity. After the first 10 second trial, participants rested for one minute followed by four additional CtC and rest repetitions. The CtC condition resulted in five paired rest and contraction-against-resistance measurements for each participant.

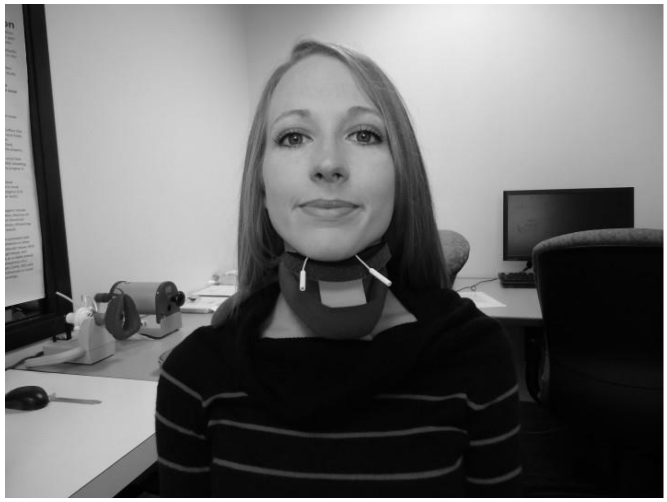

Figure 4. Positioning of the chin brace at rest.*

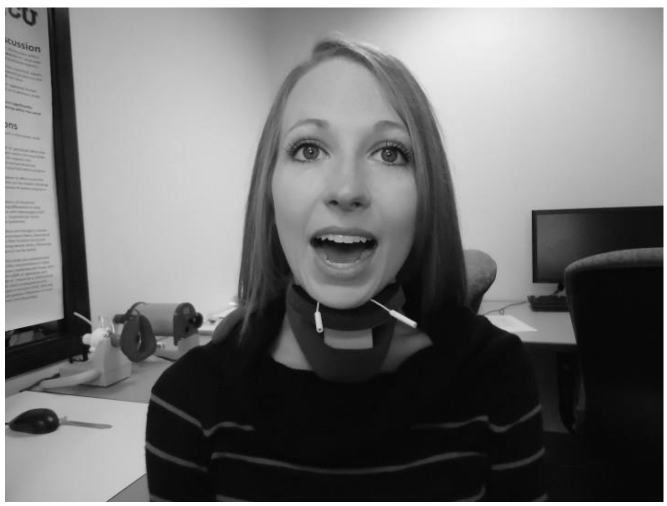

Figure 5. Contraction elicited during the CtC exercise.*

*Note: Photos in Figures 4 and 5 were copied from Watts, C. R. (2013). Measurement of Hyolaryngeal Muscle Activation Using Surface Electromyography for Comparison of Two Rehabilitative Dysphagia Exercises. *Archives of Physical Medicine and Rehabilitation* 94:2542-2548.

Chin Tuck against Resistance (CTAR) Exercises. Participants performing the CTAR as the first or second exercise were instructed to squeeze a rubber ball placed between their chin and manubrium sterni (pictured in Figure 6 below) by maximally tucking their chin towards their chest while sitting upright in a chair. Participants were allowed and encouraged to use one hand to keep the ball in position during the exercise. As with the base performance measures and CtC condition described previously, the purpose of the resistance device (i.e. rubber ball) and explanation of performance expectations was conducted before initiation of the CTAR exercise. Visual demonstrations were provided by the principal investigator and participants were allowed several practice movements prior to recording to ensure proper exercise form and consistent technique. Before beginning the CTAR exercise, the participants were reminded to keep their shoulders stationary, to keep their chin in contact with the ball throughout the entire exercise, and to keep squeezing as hard as possible until instructed to stop.

Similar to Yoon et al. (2013), all participants used the same inflatable rubber ball, “approximately 12 cm in diameter,” to complete the CTAR exercises. The inflatable rubber ball used in this study measured 11.02 cm in diameter. Figure 6 (from Yoon et al., 2013) illustrates the ball placement during the CTAR exercise both at rest (a) and during contraction (b). As with the CtC procedures detailed above, hyolaryngeal sEMG activity was measured at rest for 1-2 seconds prior to the initiation of each CTAR exercise and after exercise completion and return to baseline activity. To initiate the CTAR exercise, the participants were asked to squeeze the rubber ball by tucking their chin “as hard as you can as if you were trying to crush the ball” and hold for 10 seconds until instructed to stop. Before each CTAR repetition, participants were reminded to keep their jaws closed during the exercise and to try to “crush the ball.” After the chin tuck was held for 10 seconds participants rested for one minute, followed by an additional four CTAR and rest repetitions. The CTAR condition resulted in five paired rest and contraction-against-resistance measurements for each participant.

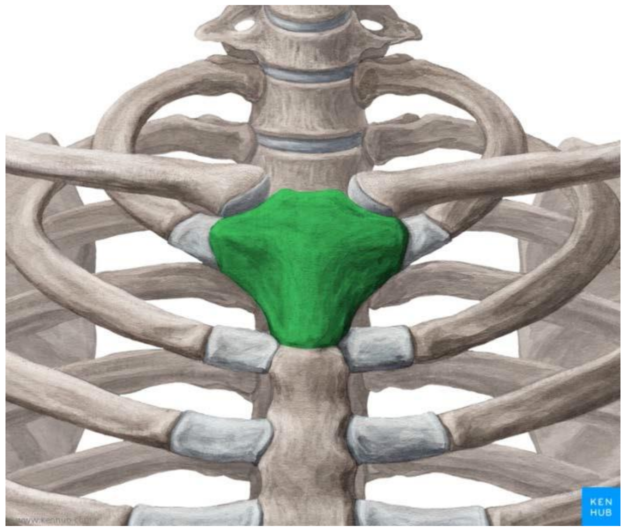

Figure 6. Location of the Manubrium Sterni. Taken from www.bing.com/images, search term “manubrium sterni.”
Retrieved from https://www.kenhub.com/en/atlas/manubrium-sterni

In summary, by the end of each of the participants’ involvement in the study fifteen paired baseline and exercise with (or without) resistance measurements were collected: five trials of resting baseline, five trials of CtC contraction against resistance, and five trials of CTAR against resistance. All participants completed the baseline condition first. Study participants were randomly assigned into two groups for counterbalancing; group one completed first CtC and then CTAR, group two completed first CTAR and then CtC. Counterbalancing was completed to further eliminate any differences in performance due to muscle fatigue in addition to the 60 second rest intervals between trials.

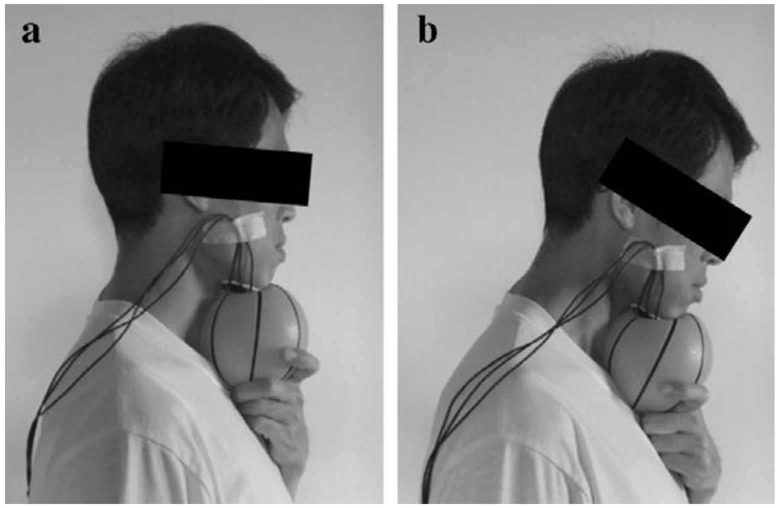

Figure 7. Positioning of the rubber ball a) at rest and b) during the CTAR contraction. Photos were copied from Yoon, et al. (2013). Chin Tuck Against Resistance (CTAR): New Method for Enhancing Suprahyoid Muscle Activity Using a Shaker-type Exercise. *Dysphagia* (2014). 29:243-248.

Analyses

Two dependent variables were obtained from the sEMG recordings: (**1**) peak sEMG (PsEMG - in µV) and (**2**) average sEMG (AsEMG - in µV). PsEMG represented the peak amplitude of the sEMG signal across the entire duration of contraction (in both CtC and CTAR conditions). AsEMG represented the average amplitude of the sEMG signal across the entire duration of contraction. PsEMG and AsEMG values were collected for each of the four conditions for each participant, and an average of the means of all participants was taken for each condition. These averages were used for the following calculations. In order to normalize the data to control for differences in normal sEMG variation, each measurement was transformed via a ratio using each participant's PsEMG and AsEMG measurements compared to the baseline condition. Normalized data was thus calculated as:

- PsEMG = peak sEMG from CtC/CTAR ÷ peak sEMG from baseline
- AsEMG = average sEMG from CtC/CTAR ÷ average sEMG baseline

Paired samples t-tests were applied to the separate dependent variables (PsEMG & AsEMG). The level of significance was set at 0.05 for all statistical tests. Each participant contributed one data point for each variable, which was derived from their average PsEMG, AsEMG and baseline performance over the 5 repetitions of each exercise. To answer the first research question (Does CTAR and CtC result in greater mean and peak contraction compared to resting baseline?) paired t-tests compared raw PsEMG and AsEMG to raw baseline amplitudes. To answer the second research question (Do mean and peak contraction during CTAR and CtC differ from each other?) paired t-tests compared normalized PsEMG and AsEMG measures with condition (CtC and CTAR) as the independent variable.

Reliability

In order to assure consistency of measurements, four study participants were randomly selected and data analysis was repeated by the principal investigator and a second COSD graduate student familiar with data collection protocols. Both raters rescored sEMG amplitude measurements for baseline, CtC, and CTAR exercises as well as sample duration for two of the randomly selected participant's files, totaling 40 separate data points or 10 percent of the total recordings. Copies of the original unmarked DSW files were provided along with the coding guidelines and were re-coded. The purpose of this procedure was to determine measure consistency both within and between data samples through confirmation by comparable agreement rates. The peak sEMG amplitude and average sEMG amplitude measures were compared using a Pearson product-moment correlation.

CHAPTER V

Results

Both intra-rater and inter-rater reliabilities were high (R=ratio, e.g. 0.99), and the comparison revealed a significant correlation for both ($p<0.05$) suggesting that the degree of measured correlation was not due to chance. Results for inter-rater reliability for amplitude were R=1.0 for peak sEMG measurements and R=0.99 for average sEMG amplitude measurements. Intra-rater reliability results were R=0.97 for both peak and average sEMG measurements. Intra- and Inter-rater reliability results are summarized in Table 1 and detailed in Tables 2 and 3 below.

Table 1
Total Reliability Ratios

	Peak sEMG amplitude (µV)	Average sEMG amplitude (µV)
Inter-Rater Reliability	R=1.0	R=0.99
Intra-Rater Reliability	R=0.97	R=0.97

Regarding intra-rater reliability averages listed in Table 2, measurements for peak amplitude were nearly identical to the ten thousandths place (0.0001) and thousandth's place between the original and rescored samples across base, CtC, and CTAR conditions, with the exception of one measure for average peak CtC which differed by 10.28 microvolts. Greater variation was seen with the measurements for average amplitude, but differences mostly occurred at the tenths place for subject 1 and in the ones place value for subject 2. Differences observed in muscle contraction duration measures (S1 Duration, S2 Duration) of 0.10 seconds or greater resulted in larger differences in average amplitude. These small variations in peak and average amplitude were reflective of and dependent upon the differences seen in recorded duration times. It should be noted, however, across all six durations that were rescored, values rarely differed at the ones place value and most often differed by tenths or hundredths of a second.

Table 2

Intra-rater reliability results

Intra-Rater Reliability								
	Subject (S) Averages	S1 Peak (µV)	S1 Avg (µV)	S1 Duration (s)	S2 Peak (µV)	S2 Avg (µV)	S2 Duration (s)
Original Measures	base	28.884	12.8842	10.3082	12.395	4.4988	10.5166
	CtC	56.7436	26.2772	11.8994	119.2402	67.0946	11.4474
	CTAR	55.6804	19.9402	11.613	73.5944	43.5902	10.4714
Retest Measures	base	28.884	12.792	10.39	12.395	6.5364	10.5428
	CtC	56.7436	26.117	11.9768	108.9602	61.0892	11.323
	CTAR	55.6804	20.205	11.2712	73.5944	43.4688	10.5006

Inter-rater reliability was even higher than intra-rater, as seen in Table 1. Mean measurements for peak amplitude were identical to the ten thousandths place value between the original and rescored measures across all three conditions. Variation did not exceed 0.964 microvolts across base, CtC, and CTAR conditions for average sEMG amplitude means. Differences in duration measures ranged from 0.026 to 0.169 seconds. The high degree of concordance of peak and average sEMG reliability can be attributed to the small degree of variation between original and retest duration measures, as evinced in Table 3 below.

Table 3
Inter-rater Reliability Results

Inter-Rater Reliability							
	Subject (S) Averages	S1 Peak (µV)	S1 Avg (µV)	S1 Duration (s)	S2 Peak (µV)	S2 Avg (µV)	S2 Duration (s)
Original Measures	base	16.8842	1.9102	10.6744	14.4454	6.569	10.2024
	CtC	208.4564	122.3782	11.8002	138.1096	90.7492	10.9202
	CTAR	105.91	51.2406	11.1274	89.0304	35.1748	10.8304
Retest Measures	base	16.8842	1.942	10.5052	14.4454	6.621	10.1764
	CtC	208.4564	121.4144	11.8774	138.1096	90.2182	11.0262
	CTAR	105.91	50.6392	11.2238	89.0304	34.856	10.973

At the end of the study the participants were asked to perceptually qualify which exercise was easier, CtC or CTAR; results were equivocal. Some participants felt that the resistive posture device made the CtC exercise more difficult, while others felt that the support from the brace (CtC) was easier than trying to squeeze the inflatable rubber ball (CTAR). Differences in perception of difficulty were also noted to be influenced by tolerance of the adhesive electrode patch and cables, which acted as a barrier between the participant's chin and the resistive device.

Both CTAR and CtC traces showed significantly higher amplitudes of hyolaryngeal muscle activation during 10 seconds of contraction compared to the resting baseline measure of chin tuck without resistance, as seen in Figure 8. Additionally, sEMG traces were notably different between CTAR and CtC exercises. CtC showed greater peaks of activity that were consistently higher across the duration of contraction compared to CTAR. Descriptive statistics for peak and average sEMG amplitude values comparing CtC and CTAR against the baseline are displayed below in Table 4.

Isometric contractions across exercise conditions

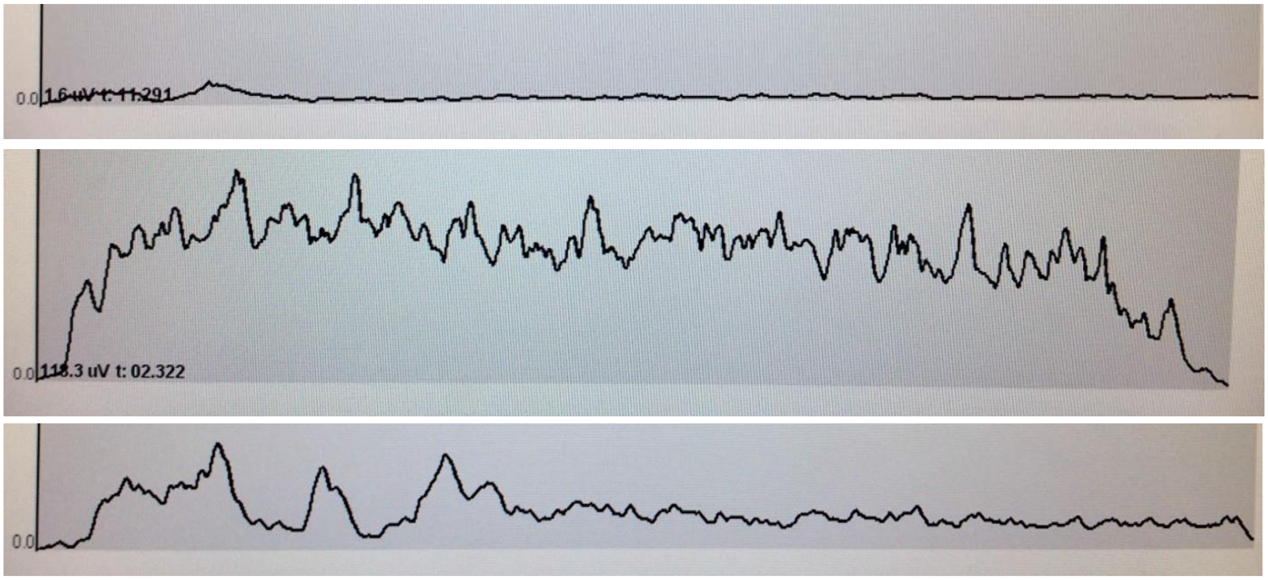

Figure 8. Surface EMG traces during 10 seconds of resting activation and exercise (*Top* Baseline, *Middle* CtC, *Bottom* CTAR).

Note: This figure shows an example of the different recordings obtained for a single participant during the three study conditions. These tracings from the DSW workstation depict sEMG amplitudes of baseline chin tuck as compared to the isometric tasks CTAR and CtC exercises. Adapted from the Swallowing Signals Lab workstation model (Kaypentax, Montvale, NJ). Retrieved by the author, March 1, 2015.

Table 4
Mean Amplitudes and Standard Deviations (in Parentheses) across All Test Conditions

	Means for Peak Amplitude (µV)	Means for Average Amplitude (µV)
Avg. base	24.96 (26.09)	8.89 (15.06)
Avg. CtC exercise	136.64 (75.66)	75.54 (35.61)
Avg. CTAR exercise	106.03 (59.08)	49.39 (25.26)

The averages of all participant data (sum of averages obtained from 5 trials per test condition ÷ total number of participants) indicated that CtC (peak=136.64 µV, average=75.54 µV) and CTAR (peak=106.03 µV, average=49.39 µV) did result in greater mean and peak contraction amplitudes compared to resting baseline (peak=24.96 µV, average=8.89 µV). The means from Table 4 are displayed below in Figure 9, which clearly displays a notable difference in amplitude of both CtC and CTAR compared to baseline amplitude across both peak and average amplitude

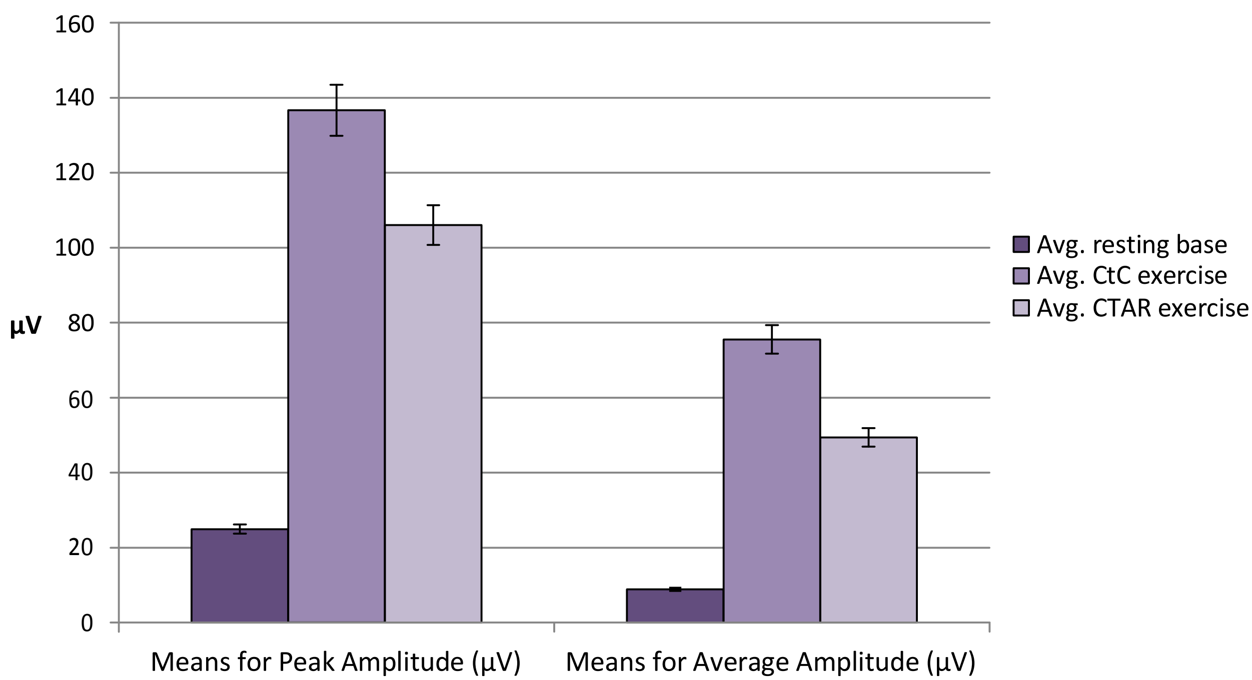

Figure 9. Summary of Mean Chin-to-Chest (CtC) and Chin Tuck Against Resistance (CTAR) Amplitudes Compared to Baseline Amplitude.

Descriptive statistics for peak and average amplitude values across the two exercise conditions are displayed in Table 5 and Figure 9. Inspection of the data comparing CtC and CTAR revealed the following:

Table 5

Means and Standard Deviations (in Parentheses) of Amplitude Values for PsEMG and AsEMG

Exercise	Measure (in µV)			
	rawPeak	rawAverage	normPsEMG	normAsEMG
CtC	136.64 (75.66)	75.54 (35.61)	10.80 (11.37)	45.49 (82.52)
CTAR	106.03 (59.08)	49.39 (25.26)	8.45 (9.42)	32.40 (62.28)

Note: The data are adapted from "raw" averages of summed average CtC and CTAR performance values for all participants; "normalized" measures are the result of the formulas detailed in the Methods section.

Participants' sEMG activity for average peak amplitude during the CtC exercises was noticeably higher than those for CTAR. CtC had greater muscle activation not only for peak amplitude but also across the entire contraction duration with higher average amplitude compared to the CTAR condition. These proportions held true when the raw values were converted to normalized means as well, particularly regarding the difference observed between CtC and CTAR for the normalized average amplitude (AsEMG) of muscle activation across the entire duration of contraction, as seen in Figure 9 above.

Figure 10 below represents the normalized sEMG values detailed in Table 5 (*see* normPsEMG and normAsEMG); the CtC exercise resulted in both greater mean peak amplitude and greater mean average amplitude for the entire hyolaryngeal muscle contractions compared to CTAR. Normalized PsEMG values were slightly higher in CtC compared to CTAR (difference of 2 microvolts on average), but the notable difference occurred with the total mean average sEMG values. CtC AsEMG was an average of 13 microvolts greater than CTAR AsEMG.

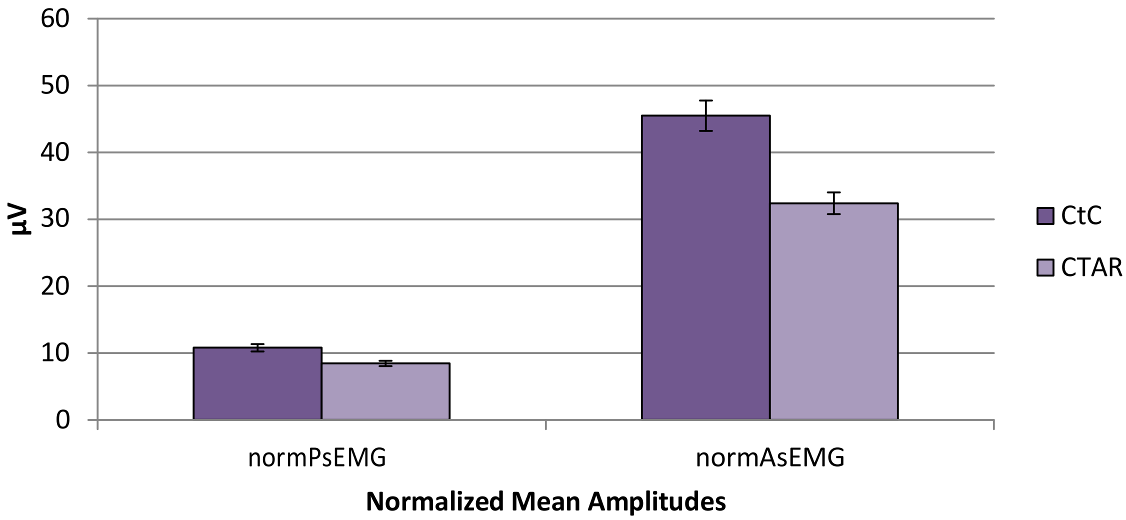

Figure 10. Normalized Means of Chin-to-Chest (CtC) and Chin Tuck Against Resistance (CTAR) Amplitudes. Adapted from data reported in Table 5, *normPsEMG* and *normAsEMG* (2015).

Statistical analysis was completed with a series of paired samples t-tests applied to the normalized and raw peak amplitude and mean amplitude data from the CtC and CTAR exercises and baselines. Table 6 illustrates the results of these analyses. The differences observed in descriptive statistics supported the findings; all results were significant ($p<0.05$). All measures of peak and average CtC and CTAR amplitudes compared to baseline amplitude were significantly different ($p <0.001$). The differences between normalized peak sEMG amplitude (PsEMG) means of CtC and CTAR were also statistically significant ($p=0.011$), as were the differences between the means of normalized average sEMG amplitude (AsEMG) across the entire hyolaryngeal muscle contraction duration ($p=0.018$).

Significant effects were also found for the raw data in both PsEMG (p=0.002) and AsEMG (p<0.001) amplitudes for the CtC vs CTAR conditions. These results signify that the CtC condition resulted in hyolaryngeal muscular activity characterized by stronger peak (PsEMG) contraction levels and temporally stronger contraction levels across the duration (AsEMG) of pharyngeal swallowing. The probability values in the p-value column of Table 6 revealed that the differences observed between the CtC and CTAR exercises did not occur due to chance.

Table 6

Results from Paired Samples T-Tests

Test Pair	**t (df)**	**p-value**	**95% CI**
Baseline vs Raw CtC Peak amplitude (µV)	-7.52 (25)	<0.001	-142.26 to -81.09
Baseline vs Raw CTAR Peak amplitude (µV)	-7.10 (25)	<0.001	-104.57 to -57.56
Baseline vs Raw CtC Average amplitude (µV)	-9.49 (25)	<0.001	-81.12 to -52.18
Baseline vs Raw CTAR Average amplitude (µV)	-8.55 (25)	<0.001	-50.26 to -30.74
Raw CtC vs CTAR PsEMG amplitude (µV)	3.51 (25)	0.002	12.66 to 48.56
Raw CtC vs CTAR AsEMG amplitude (µV)	4.77 (25)	<0.001	14.87 to 37.44
Normalized CtC vs CTAR PsEMG amplitude (µV)	2.74 (25)	0.011	0.58 to 4.10
Normalized CtC vs CTAR AsEMG amplitude (µV)	2.54 (25)	0.018	2.48 to 23.71

CHAPTER VI

Discussion

The purpose of this study was to investigate the effects of two rehabilitative exercises (CtC and CTAR) on measures of hyolaryngeal muscle activity in healthy young adult females. The second purpose of this study was to determine whether there was a difference between the level of electrical activation seen during CtC exercises compared to CTAR exercises across average duration and peak duration as measured by sEMG.

The first research question of this study asked: "Do CTAR and CtC result in greater mean and peak contraction compared to resting baseline?" Results displayed in Table 5 indicated a significant difference ($p < 0.001$) between peak and average CtC and baseline as well as between peak and average CTAR and baseline. The second research question of this study asked: "Do mean and peak contraction during CTAR and CtC differ from each other?" The averages displayed in Table 5 indicated a difference between CtC and CTAR for both peak (136.64>106.03 µV, $p=0.002$) and average (75.54 >49.39 µV, $p<0.001$) amplitudes. The results of the paired samples t-tests showed that the differences between normalized CtC and CTAR amplitude measures were statistically significant (PsEMG p-value=0.011; AsEMG p-value=0.018). CtC resulted in a significantly greater difference than CTAR with regards to sEMG amplitude across PsEMG and AsEMG measures.

There is a present clinical need for effective efficient rehabilitative swallowing exercises. Due to limited length of stay durations in acute care and rehabilitation hospitalizations, more patients are being discharged and transitioning home with persisting dysphagia (Johnson et al., 2014). Johnson and colleagues' (2014) recent compilation of evidence-based compensatory and exercise management strategies underscored the need for effective rehabilitation exercises for patients with an impaired swallow. Several new exercises have been published (Yoon et al., 2013; Wada et.al, 2012; Watts, 2013) but are still undergoing research to demonstrate clinical effectiveness.

In the preliminary studies, both CTAR and CTC reported greater statistically significant differences in muscle activation compared to the Shaker head-lift exercise during isometric contraction conditions. CTAR was found to have an equivalent or greater impact than the Shaker exercise on the suprahyoid muscles (Yoon et al., 2013).Similar to Yoon's findings, in the current study CTAR did have a significantly greater degree of muscle activation compared to the baseline activation, where the participants were instructed to tuck their chin towards their chest and hold for 10 seconds. The following values are summarized in Table 7. The original study yielded mean peak sEMG values of 166.52 microvolts and mean average sEMG values of 103.72 microvolts. The current study yielded slightly lower averages, with smaller sEMG values by approximately 55 microvolts. These variations may be attributed to differences in sensitivity of sEMG recording equipment between studies.

Table 7

Isometric CTAR sEMG Averages with Standard Deviations (in Parentheses)

	Mean Peak sEMG (μV)	**Mean Average sEMG (μV)**
Yoon et al., 2013	166.52 (99.62)	103.72 (64.03)
Hughes & Watts, 2015	106.03 (59.08)	49.39 (25.26)

Note: The data are adapted from the authors, Hughes & Watts (2015), and from Yoon et al. (2013), Table 1 "Maximum and mean sEMG values of isometric and isokinetic tasks obtained during the CTAR exercise and the Shaker exercise," from *Dysphagia* (2014) *p*.246

Much research has been conducted on the accuracy of sEMG signals in measuring hyolaryngeal movement. A study by Crary and Groher (2006) noted a strong positive relationship between hyoid elevation-anterior displacement and the sEMG signal. Work by Ding and colleagues (2002) also showed a significant difference in sEMG activity from the submental muscle group between normal swallowing and the Mendelsohn maneuver, indicating that sEMG recordings from submental muscles can be used reliably to differentiate the level of effort or degree of hyolaryngeal activation between two swallow conditions. We can therefore be confident that the sEMG tracings obtained from the submandibular electrode placement in this study were measuring activity from the suprahyoids, those muscles responsible for laryngeal elevation.

Another difference between the two studies includes sample size and composition; Yoon's study participants included 20 males and 20 females aged 21 to 39 years compared to this study which included only females aged 22 to 30 years. However, differences across gender did not reach significance (Yoon et al., 2013). Additional explanations for Yoon's increased sEMG values could be attributed to cross-talk from the sternocleidomastoid muscles in addition to the hyolaryngeal elevators

(Watts, 2013). The sternocleidomastoid is a large muscle that is recruited to pull the chin down towards the chest; it is possible that the contraction of that muscle during the CTAR exercise could have influenced sEMG readings despite the electrode placement over target muscles (i.e. the suprahyoids) only. Additionally, increased activation from the platysma muscle could have contributed to the sEMG measures.

The Yoon study based CTAR function off of the supposition that head and neck flexion are known to activate the suprahyoid muscles (Forsberg et al., 1985; Falla et al., 2006; Adler, Beckers, & Buck, 2007). Yoon et al. (2013) found CTAR to have significantly greater muscle activation than the comparison exercise, which was inconsistent with the results of this current study where CTAR was found to have significantly less peak and average amplitudes across muscle activations versus the comparison exercise, CtC. The results of this study do not refute Yoon's initial findings of CTAR causing muscle contractions of equal or greater strength than the Shaker exercise, but merely indicate that CtC does the same task with a greater degree of activation; this increased muscle performance could significantly impact the outcome of CTAR as an effective rehabilitation exercise. Further research is needed to determine this effect.

Rehabilitative swallowing exercises should be chosen based on the underlying physiological impairment (Johnson et al., 2014.) The increased muscular activity observed during the CtC exercise supports the need for further studies investigating the possibility of CtC being an effective clinically as a rehabilitative exercise targeting dysphagia induced by decreased hyolaryngeal excursion or decreased UES opening secondary to impaired hyolaryngeal elevation.

The effectiveness of rehabilitative exercises on muscle adaption can be demonstrated and visualized by measuring contraction force via amplitude (uV) and duration (s) (Wheeler-Hegland et al., 2008). As observed in Watts's (2013) initial study, muscular activation during CtC was greater versus the comparison exercise, in this case CTAR. It has been confirmed that the mandibular adductors/depressors, including the mylohyoid, geniohyoid, and anterior digastric muscles, are involved in maximally opening the jaw and maintaining that opened posture (Van Eijden et al., 1997). Furthermore, exercises developed around jaw opening have resulted in positive impacts on the suprahyoid muscles related to their influence on UES function (Wada et al., 2012).

Watts (2013) also stated that the resistance incorporated into the isometric contraction helped facilitate a greater degree of "muscular overload" and he supported the research of Campos and colleagues (2002), whose findings suggested that the greater resistance loads during exercise facilitates remodeling of type I and type II skeletal muscle fibers. These findings have important clinical implications that support developing CtC further as a clinically effective rehabilitative exercise for targeting deconditioned hyolaryngeal elevator muscles to facilitate muscular adaption and more efficient functional recovery through increased resistance (Watts, 2013; Ivey et al., 2006).

Yoon et al. (2014) discussed the lack of compliance in patients prescribed Shaker exercises. In traditional swallowing rehabilitation exercises the physiological rigor may be too demanding for patients with dysphagia who are impaired as a result of chronic disease such as neuromuscular weakness or injury, spinal fusions, radical neck surgery, or radiation of the head and neck; such patients require alternative exercises targeting hyolaryngeal muscles (Watts, 2013; Yoshida et al., 2007; Wada et al., 2012). CtC could serve as one such alternative—patients are positioned upright in a chair and a brace is used, which provides resistance but also influences posture, a known factor that can influence swallowing safety. Another benefit of CtC is that patients are able to use their maximum current strength level; there is no minimum requirement as with the patient needing to be able to lift his or her head and hold it up against gravity during the Shaker exercise. CtC has the same goal of Shaker head-lift exercise, to cause adaptation in the suprahyoid muscles (Watts, 2013; Shaker et al., 2002).

Despite CtC having a greater effect on activation of submental hyolaryngeal muscles than CTAR, potential drawbacks exist with regard to resource availability and feasibility of compliance during home practice. Lack of patient compliance could occur as a result of difficulties associated with obtaining the resistive brace and subsequent application during exercise at home. In comparison, the inflatable rubber ball required for CTAR would be more economical and readily available for patients, potentially increasing exercise compliance and therefore improving patient outcomes. Nevertheless, in choosing between the two exercises CtC would still be the stronger clinical choice in for example an inpatient rehab setting performed under the speech-language pathologist's supervision. One would expect to see greater muscle adaption during contraction against resistance with CtC and therefore quicker improvements in the range and strength of the hyolaryngeal muscles responsible for elevating the larynx and moving it forward during swallowing as compared to the CTAR exercise which purports to target the same set of hyolaryngeal elevator muscles.

Results of this study suggest a possible future beneficial clinical effect. An ideal rehabilitative exercise targets the underlying area of impairment, for example reduced hyolaryngeal excursion. The CtC exercise resulted in increased activity (i.e. contraction strength) sustained over time in the muscles that cause anterior and vertical hyoid movement, the suprahyoids (Goyal, 1984; Palmer et al., 1999; Johnson et al., 2014). Nevertheless, it is important to qualify that these findings were with healthy young adults. While many studies note increased occurrences of slower or delayed swallowing movements in the elderly (Yokoyama et al., 2000; Paik et al., 2006; Dodds et al., 1998; Ishida et al., 2002; Cook et al., 1989), Kim and McCullough (2008) found that younger and older subjects did not have significant differences in vertical excursion of the larynx on liquid trials. This similarity across ages suggests that an exercise that facilitates muscle adaptation of the hyolaryngeal elevators in younger populations could yield similar results in older populations. Additional studies will be needed to determine CtC's effectiveness with impaired and/or elderly populations.

CHAPTER VII

Study Limitations

The results obtained with the CtC exercise are encouraging, but several limitations in the methodology of this study must be acknowledged:

First, this study tested hyolaryngeal muscular activation in healthy young adults without any presence or history of dysphagia or its concomitant impairments such as physiological weakness and structural or neurological deficits as a result of stroke, TBI, head and neck cancer and/or surgery, or as a natural process of aging. CtC has shown to work in theory to increase maximum and sustained muscle contractions in the suprahyoids, as observed in non-disordered healthy populations. To determine the CtC exercise's effectiveness or ability to rehabilitate persons with decreased hyolaryngeal elevation and impaired UES function, further research should extend first to an increased age range including older participants between 70 and 90 years of age, then to a clinical population within that same generation.

Second, sEMG was used to obtain data for muscle contractions instead of iEMG. While studies have demonstrated sEMG to accurately measure submental muscle activity in the muscles primarily involved with swallowing, iEMG would provide more specific information with regards to the degree of specific muscular contractions. iEMG could be used to determine whether a specific muscle within the group of hyolaryngeal elevators benefits most from CtC exercise; additionally other associated muscles, such as the genioglossus and the sternocleidomastoid, could be observed for any side effects or secondary activation from the exercise.

Third, the degree of hyoid excursion was not measured during this study. Although the degree of suprahyoid muscle group activation was inferred from the amplitude of sEMG signal during contraction, the resulting excursion of the hyoid or larynx was not specifically measured. Future studies should incorporate this measure to verify that CtC has a specific effect on hyolaryngeal excursion in both normal and clinical populations across a range of ages.

Finally, it should be noted that the levels of muscle activation and degree of increased amplitude varied from participant to participant. While some had radical differences in the sEMG traces between CtC and CTAR performance, others had CtC and CTAR trials that were closer in peak and average amplitude. Furthermore, while the majority of participants’ tracings appeared similar across exercises, creating a “typical” level of performance, some participants had noticeably smaller muscle activation levels across all exercise conditions. This variation was expected and was controlled for by completing multiple trials and using an average, as micro-variations in peak and average amplitudes occurred between sEMG trials of the same participant on the same exercise. Further research would be beneficial in developing a corpus of data that would assist in visually assessing a “normal” sEMG tracing during CtC (and other exercises) from an “abnormal” reading.

CHAPTER VII

Conclusion

This study compared the electrical activity in hyolaryngeal muscles during CtC and CTAR resistance exercises. sEMG recordings were gathered for five repetitions of three different exercise conditions (baseline chin tuck without resistance, chin-to-chest, and chin tuck against resistance); peak and average amplitudes as well as contraction duration times were recorded for every trial during the control condition and both test conditions. A significant difference was found between mean peak and average contractions during both CtC and CTAR exercises compared to baseline trials, with CtC always having greater amplitudes of sEMG activity. CtC was found to have significantly greater activation levels for both peak and average contractions than those observed during CTAR contractions; CtC and CTAR did significantly differ from each other. Although trace values did vary across individual participants, trends were easily visible even in the raw trace data; this prediction was validated by the statistical analyses and results of the paired samples t-tests and p values, none of which exceeded 0.018 and were well within statistical significance ($p<0.05$).

These results signify that in choosing between CtC and CTAR as a potential rehabilitative exercise, CTC has higher maximum and mean sEMG values, implying greater muscle activation and therefore greater muscle adaption. This muscle overload and adaption over time could facilitate increased suprahyoid muscle function resulting in improved hyolaryngeal elevation and UES opening. Despite study limitations such as testing in a young, healthy population, the results of this study are promising and support the initial findings of Watts (2013). Further research is needed using CtC with clinical populations; moving trials from normal to dysphagic participants is the next step in testing whether CtC will have a clinical effect on patients with swallowing disorders resulting from impaired hyolaryngeal elevation.

REFERENCES

Adler, S.S., Beckers, D., & Buck, M. (2007). PNF in practice: an illustrated guide. Berlin: Springer.

Bartolome, G., & Neumann, S. (1993). Swallowing therapy in patients with neurological disorders causing cricopharyngeal dysfunction. *Dysphagia*, 8:146-149.

Bryant M. (1991). Biofeedback in the treatment of a selected dysphagic patient. *Dysphagia*, 6:140–4.

Burkhead, L., Sapienza, C.M., & Rosenbek, J. (2007). Strength-training exercise in dysphagia rehabilitation: Principles, procedures, and directions for future research. *Dysphagia,* 22:251–65.

Cook, I.J., (1993). Cricopharyngeal function and dysfunction. *Dysphagia*, 8:244-51

Cook, I.J., Dodds, W.J., Dantas, R.O., et al. (1989). Opening mechanism of the human upper esophageal sphincter. *American Journal of Physiology,* 257:G748-59.

Crary, M.A. (1995). A direct intervention program for chronic neurogenic dysphagia secondary to brainstem stroke. *Dysphagia*, 10:6–18

Crary, M.A., Carnaby, (Mann) G.D., & Groher, M.E. (2006). Biomechanical correlates of surface electromyography signals obtained during swallowing by healthy adults. *Journal of Speech Language Hearing Research,* 49:186–93.

Crary, M.A., & Groher, M.E. (2006). Biomedical correlates of surface electromyography signals obtained during swallowing by healthy adults. *Journal of Speech Language and Hearing Research,* 49:186-193.

Crary, M.A., Carnaby, Mann, G.D., Groher, M.E., & Helseth, E. (2004). Functional benefits of dysphagia therapy using adjunctive sEMG biofeedback. *Dysphagia*,19:160-4.

Denegar, Craig R., Saliba, E., Saliba, S.F. (2006). "Clinical Uses of Electrical Stimulation." *Therapeutic Modalities for Musculoskeletal Injuries*. Champaign, IL: *Human Kinetics*:N. pag. Print.

Ding, R., Larson, C. R., Logemann, J. A., & Rademaker, A. W. (2002). Surface electromyographic and electroglottographic studies in normal subjects under two swallow conditions: Normal and during the Mendelsohn manuever. *Dysphagia,17*(1), 1-12.

Dodds, W. J., Stewart, E. T., & Logemann, J. A. (1990). Physiology and radiology of the normal oral and pharyngeal phases of swallowing. *AJR American Journal of Roentgenology, 154*(5), 953-63.

Dodds, W. J., Man, K.M., Cook, I.J., Kahrilas, P.J., Stewart, E.T., & Kem, M.K. (1998). Influence of bolus volume on swallow-induced hyoid movement in normal subjects. *AJR American Journal of Roentgenology,* 150(6):1307-09, 2002.

Easterling, C., Grande, B., Kern, M., Sears, K., & Shaker, R. (2005). Attaining and maintaining isometric and isokinetic goals of the Shaker exercise. *Dysphagia,* 20:133–8.

Easterling, C. S., Bousamra, M., 2nd, Lang, I. M., Kern, M. K., Nitschke, T., Bardan, E., et al. (2000). Pharyngeal dysphagia in postesophagectomy patients:

Correlation with deglutitive biomechanics. *Annals of Thoracic Surgery, 69*(4), 989-92.

Ekberg, O., & Hilderfors, H. (1985). Defective closure of the laryngeal vestibule: Frequency of pulmonary complications. *American Journal of Roentgenology,* 145:1159-64.

Ekberg, O. (1986). The normal movements of the hyoid bone during swallow. *Invest Radiol,* 21:408-10.

Ekberg, O. (1982). Defective closure of the laryngeal vestibule during deglutition. *Acta Otolaryngol,* Mar-Apr; 93 (3-4):309-17

Ertekin, C., Aydogdu, I., Yuceyar, N., Pehlivan, M., Ertas, M., Uludag, B., et al. (1997). Effects of bolus volume on oropharyngeal swallowing: An electrophysiologic study in man. *American Journal of Gastroenterology, 92*(11), 2049-53.

Ertekin, C., Peblivan, M., Aydgodu, I., Ertas, M., Uludag, B., & Celebi, G. (1995). An electrophysiological investigation of deglutition in man. *Muscle & Nerve, 18*, 1177-1186

Falla, D., Jull, G., O'Leary, S., & Dall'Alba, P. (2006). Further evaluation of an EMG technique for assessment of the deep cervical flexor muscles. *Journal of Electromyography and Kinesiology,*16:621–8.

Forsberg, C.M., Hellsing, E., Linder-Aronson, S., & Sheikholeslam, A. (1985). EMG activity in neck and masticatory muscles in relation to extension and flexion of the head. *European Journal of Orthodontics*, 7:177–84.

Goyal, R.K. (1984). Disorders of the cricopharyngeus muscle. *Otolaryngologic*

Clinics of North America Journal, 17(1):115–30.

Groher, M., & Crary M. (2009). Dysphagia: Clinical management in adults and children. Maryland Heights: Mosby; 2009.

Haynes, S.N. (1976). Electromyographic biofeedback treatment of a woman with chronic dysphagia. *Biofeedback and Self-Regulation,* 1:121–126.

Henneman, E., Somjen, G., & Carpenter, D.O**.** (1965). Excitability and inhibitability of motoneurons of different sizes. *Journal of Neurophysiology* 28: 599–620.

Herbert, J. (2003). Consensus document for the use of neuromuscular electrical stimulation. *Nursing Times*, 99(19), 53.

Huckabee, M. L., Butler, S. G., Barclay, M., & Jit, S. (2005). Submental surface electromyographic measurement and pharyngeal pressures during normal and effortful swallowing. *Archives of Physical Medicine and Rehabilitation, 86*(11), 2144-2149.

Huckabee, M.L., & Pelletier, C.A. (1999). Management of adult neurogenic dysphagia. San Diego: Singular; 1999.

Huckabee, M.L., & Cannito, M.P. (1995). A direct intervention program for chronic neurogenic dysphagia secondary to brainstem stroke. *Dysphagia,* 10: 6-18.

Ishida, R., Palmer, J. B., & Hiiemae, K. M. (2002). Hyoid motion during swallowing: Factors affecting forward and upward displacement. *Dysphagia, 17*(4), 262-272.

Johnson, D.N., Herring, H.J.& Daniels, S.K. (2014). Dysphagia management in stroke rehabilitation. *Current Physical Medicine and Rehabilitation Report,* 2:207-218

Kim, S.J. & Han, T.R. (2009). Effect of surface electrical stimulation of suprahyoid muscles on hyolaryngeal movement. *Neuromodulation: Technology at the Neural Interface,* 12:2; 134-140

Kim, Y., & McCullough, G.H. (2010). Maximal hyoid excursion in post-stroke patients. *Dysphagia*, 25(1):20–5.

Kim, Y. & McCullough, G.H. (2008). Maximum hyoid displacement in normal swallowing. *Dysphagia*, 23:274–279.

Kots, Y.M. (1977). Electrostimulation. Paper presented at the Canadian-Soviet Exchange Symposium on Electrostimulation of Skeletal Muscles. Concordia University, Montreal.

Ivey, F.M., Hafer-Macko, C.E., & Macko, R.F. (2006). Exercise rehabilitation after stroke. *NeuroRx*, 3:439-450.

Lieber, R.L. (2002). Skeletal muscle structure, function, & plasticity. Philadelphia: Lippincott Williams & Wilkins.

Logemann, J.A., Rademaker, A., Pauloski, B.R., Kelly, A., Stangl-McBreen, C., Antinoja, J., Grande, B., Frquharson, J., Kern, M., Easterling, C., & Shaker, R. (2009). A randomized study comparing the Shaker exercise with traditional therapy: A preliminary study. *Dysphagia*, 24:403-411.

Logemann, J.A. (1998). Evaluation and Treatment of Swallowing Disorders, (2nd ed.). Austin, TX: Pro-Ed.

McCullough, G.H. (2014). One step back and two steps up and forward: The superior movements of research defining the utility of the Mendelsohn maneuver for improving UES function. *Perspectives on Swallowing and Swallowing Disorders*, 23:1.

McCullough, G.H., & Kim, Y. (2013). Effects of the Mendelsohn Maneuver on Extent of Hyoid Movement and UES Opening Post-Stroke. *Dysphagia*, 28:511-519.

McCullough, G.H., Kamarunas, E., Mann, G.C., Schmidley, J.W., & Robbins, J.A., Crary, M. (2012). Effects of Mendelsohn maneuver on measures of swallowing duration post-stroke. *Top Stroke Rehabilitation,* 19:234–43.

McKeown, M.J., Torpey, D.C., & Ghem, W.C. (2002). Non-invasive monitoring of functional distinct muscle activations during swallowing. *Clinical Neurophysiology,* 113:354- 366.

Mepani, R., Antonik, S., Massey, B., et al. (2009). Augmentation of deglutitive thyrohyoid muscle shortening by the Shaker exercise. *Dysphagia*, 24:26-31.

Neumann, S. (1993). Swallowing therapy with neurologic patients: Results of direct and indirect therapy methods in 66 patients suffering from neurological disorders. *Dysphagia, 8*(2), 150-153.

Nilsson, H., Ekberg, O., Olsson, R., & Hindfelt, B. (1998). Dysphagia in stroke: A prospective study of quantitative aspects of swallowing in dysphagic patients. *Dysphagia, 13*(1), 32-38.

Paik, N.J., Kim, S.J., Lee, H.J., Jeon, J.Y., Lim, J.Y., & Han, T.R. (2008). Movement of the hyoid bone and the epiglottis during swallowing in patients with dysphagia from different etiologies. *Journal of Electromyography and Kinesiology,* 18:329–335.

Palmer, P. M., Luschei, E. S., Jaffe, D., & McCulloch, T. M. (1999). Contributions of individual muscles to the submental surface electromyogram during swallowing. *Journal of Speech Language Hearing Research, 42*(6), 1378-1391.

Park, J.W., Kim, Y., Oh, J., & Lee, H. (2012). Effortful swallowing training combined with electrical stimulation in post-stroke dysphagia: A randomized controlled study. *Dysphagia,* 27:521-527.

Perlman, A. L., Palmer, P. M., McCulloch, T. M., & Vandaele, D. J. (1999). Electromyographic activity from human laryngeal, pharyngeal, and submental muscles during swallowing. *Journal of Applied Physiology, 86*(5), 1663-1669.

Perlman, A. L., VanDaele, D. J., & Otterbacher, M. S. (1995). Quantitative assessment of hyoid bone displacement from video images during swallowing. *Journal of Speech and Hearing Research, 38*(3), 579-585.

Perlman, A.L., Booth, B.M., & Grayhack, J. P. (1994). Videofluoroscopic Predictors of Aspiration in Patients with Oropharyngeal Dysphagia. *Dysphagia*, 9:90-95

Shaker, R., Easterling, C., Kern, M., Nitschke, T., Massey, B., Daniels, S.… Dikeman, K. (2002). Rehabilitation of swallowing by exercise in tube-fed patients with pharyngeal dysphagia secondary to abnormal UES opening. *Gastroenterology*, 122:1314–21.

Shaker, R., Kern, M., Bardan, E., Taylor, A., Stewart, E.T., Hoffmann, R.G.… Bonnevier, J. (1997). Augmentation of deglutitive upper esophageal sphincter opening in the elderly by exercise. *American Journal of Physiology*, 272(6):G1518–1522.

Steele, C.M. (2012). Exercise-based approaches to dysphagia rehabilitation. *As cited in* Watts (2013); originally from *Nestle Nutr. Inst. Workshop Ser.*, 72:109-117.

Vaiman, M., Segal, S., & Eviatar, E. (2004). Surface electromyographic studies of swallowing in normal children, age 4–12 years. *International Journal of Pediatric Otorhinolaryngology,* 68:65–73.

Van Eijden, T.M., Korfage, J.A., Brugman, P. (1997). Architecture of the human jaw-closing and jaw-opening muscles. *Anatomical Record*, 248:464-474.

Wada, S., Tohara, H., Lida, T., Inoue, M., Sato, M., & Ueda, K. (2012). Jaw-opening exercise for insufficient opening of upper esophageal sphincter. *Archives of Physical Medicine and Rehabilitation,* 93:1995-1999.

Watts, C.R. (2013). Measurement of hyolaryngeal muscle activation using surface electromyography for comparison of two rehabilitative dysphagia exercises. *Archives of Physical Medicine and Rehabilitation,* 94:2542-2548.

Wheeler-Hegland, K.M., Rosenbek, J.C., & Sapienza, C.M. (2008). Submental sEMG and hyoid movement during Mendelsohn maneuver, effortful swallow, and expiratory muscle strength training. *Journal of Speech Language and Hearing Reasearch,* Oct;51(5):1072-1087.

Yokoyama, M., Mitomi, N., Tetsuka, K., Tayama, N., & Niimi, S. (2000). Role of laryngeal movement and effect of aging on swallowing pressure in the pharynx and upper esophageal sphincter. *The Laryngoscope,* 110:434-439.

Yoon, W.L., Khoo, J.K.P., & Rickard Liow, S.J. (2013). Chin tuck against resistance (CTAR): New method for enhancing suprahyoid muscle activity using a Shaker-type exercise. *Dysphagia*, 29: 243-248.

Yoshida, M., Groher, M.E., Crary, M.A., Mann, G.C., & Akagawa,Y. (2007). Comparison of surface electromyographic (sEMG) activity of submental muscles between the head lift and tongue press exercises as a therapeutic exercise for pharyngeal dysphagia. *Gerodontology,* 24:111-6.

Appendix A

Consent to Participate in Research form

Texas Christian University

Fort Worth, Texas

CONSENT TO PARTICIPATE IN RESEARCH

Title of Research: The Effects of Two Rehabilitation Exercises on Submental Hyolaryngeal Muscular Activity.

Funding Agency/Sponsor: N/A

Study Investigators: Teresa D. Hughes, B.S.

What is the purpose of the research?
You have been asked to take part in this study to help determine if two different head and neck exercises result in the same or a different amount of muscular activity. One exercise has been used to target the muscles under the chin that lift the larynx (voice box) when you swallow. The second exercise is new but designed to target the same muscles. This study will compare how muscles are activated when performing both exercises.

How many people will participate in this study?
20 people are being recruited to participate in the study.

What is my involvement for participating in the study?
If you agree to participate in the study, you will be asked to perform two different head and neck exercises. The first exercise will require you sit in a chair and hold a rubber ball between your chin and the top of your breast bone, flex your neck muscles into the ball as you make your chin touch your chest and hold it for 10 seconds. The second exercise will require you to sit in a chair with a special brace placed around your neck, and flex your jaw and neck muscles into the brace while holding it for 10 seconds. You will be asked to perform 5 repetitions of each exercise. During each exercise, sensors adhered to the skin under your chin will measure the degree of muscle activation.

How long am I expected to be in this study for and how much of my time is required?
You will be required to attend one measurement session which will last no longer than 45 minutes.

What are the risks of participating in this study and how will they be minimized?
There are no known risks associated with the exercises you will perform in this study. However, you may feel uncomfortable with the feel of sensors attached to the skin under

your chin. If this occurs, you can let me know and I will adjust the sensors. If you still feel uncomfortable you may withdraw from the study at any time. If for any reason you feel soreness or pain anywhere in your body when performing the exercises, you are asked to tell me and you may withdraw from the study.

What are the benefits for participating in this study?
Although participation in this study will not benefit you personally, the information may help improve the future treatment of many people with swallowing difficulties.

Will I be compensated for participating in this study?
You will not be compensated for participation in this study.

What is an alternate procedure(s) that I can choose instead of participating in this study?
None

How will my confidentiality be protected?
All information which is collected about you during the course of the research will be kept strictly confidential. Data used in research publications and presentations will not contain any personal identifying information. Data will be coded prior to analysis. Only the primary investigator, Teresa Hughes, the thesis director, Dr. Christopher Watts, and authorized persons who are approved by the TCU Institutional Review Board will know participants identity. Computer files will be accessible only to the primary investigator. All data and recordings will be kept for 5-7 years and stored in a locked cabinet within the office of Dr. Christopher Watts.

Is my participation voluntary?
Yes. It is up to you to decide whether or not to take part in the study. If you do, you will be given this consent form to sign and will keep a copy of it. Even if you initially participate in the study, you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect any services or opportunities you may be eligible for at TCU.

Can I stop taking part in this research?
You are free to stop participating at any time. Your decision whether or not to participate will not influence any future services with the Texas Christian University or the Miller Speech and Hearing Clinic.

What are the procedures for withdrawal?
You may withdraw at any time after signing this form should you choose to discontinue participation in this study. You can tell the researcher you want to withdraw from the study. You can withdraw verbally or in writing.

Will I be given a copy of the consent document to keep?
Yes

Who should I contact if I have questions regarding the study?

Dr. Christopher R. Watts, Ph.D.
Department of Communication Sciences and Disorders
Texas Christian University 817-257-7620
c.watts@tcu.edu

Who should I contact if I have concerns regarding my rights as a study participant?

Dr. Dan Southard
Chair, TCU Institutional Review Board
817-257-6869
d.southard@tcu.edu

Linda Freed
Director of Sponsored Programs
Telephone 817-257-4877
linda.freed@tcu.edu

Your signature below indicates that you have read or been read the information provided above, you have received answers to all of your questions and have been told who to call if you have any questions, you have freely decided to participate in this research, and you understand that you are not giving up any of your legal rights.

Participant's Name (please print): ____

Participant's Signature_________________________Date__________

Investigator's Signature:________________________Date:_________

ABSTRACT

THE EFFECTS OF TWO REHABILITATION EXERCISES ON SUBMENTAL HYOLARYNGEAL MUSCULAR ACTIVITY

by Teresa D. Hughes, B.S., 2015
Davies School of Communication Sciences and Disorders
Texas Christian University

Thesis Advisor: Dr. Christopher Watts, Professor and Director of COSD

This study compared the electrophysiological activity in hyolaryngeal muscles during performance of two exercises that target the submandibular laryngeal elevators. Twenty-six normal, healthy participants were measured using surface electromyography (sEMG) in three different conditions: (a) performing a baseline chin tuck with no resistance applied to the mandible, (b) performing the Chin Tuck Against Resistance Exercise (CTAR), and (c) performing the Chin-to-Chest Exercise (CtC). Measures of normalized sEMG peak amplitude and mean amplitude across 10 seconds of contraction were obtained. Results revealed a significant effect of condition on measures of peak and mean contraction amplitudes where both exercises were significantly greater than baseline chin tuck ($p < 0.001$ for both). Hyolaryngeal peak contraction amplitude and mean contraction amplitude were significantly greater during performance of the CtC compared to the CTAR exercise ($p = 0.011$ and 0.018, respectively). This study provides supporting evidence for the effect of two published exercises targeting submandibular muscles when compared to baseline. Both exercises incorporated resistance to facilitate an overload to muscle contraction, which likely accounted for baseline differences. The CtC

exercise, which required jaw opening against a rigid brace, resulted in the greatest degree of neuromuscular activity in the submandibular muscles. Potential clinical implications will be discussed.