EFFECTS OF THE HEAD LIFT AND THE RECLINE EXERCISES ON THE NEUROMUSCULAR CONTROL OF SWALLOWING: AN ELECTROMYOGRAPHY STUDY IN OLDER ADULTS

by

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Dedicated to my sisters.

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ABSTRACT

Rehabilitative exercises are commonly used to strengthen the submental muscles and improve swallowing function in older adults; however, the underlying neuromuscular mechanisms that lead to these improvements have not been delineated and could be important in determining what types of deficits or patients may benefit most from these exercise regimens. This project focused on two well-known head/neck exercises, the Head Lift Exercise (HLE) and the Recline Exercise (RE).

A randomized clinical trial with 2 arms - a 6-week RE or HLE regimen - was conducted. Data were collected on 18 older adults (age range 60-82; RE n=9; HLE n=9) pre-treatment, post-treatment, and at 6-weeks follow-up, and included a VFSS and a surface electromyography (sEMG) study. Results of the VFSS showing hyolaryngeal excursion gains post both regimens have been published (Fujiki et al., 2019). This study focuses on the sEMG data. Surface EMG activity was collected from submental muscles during swallows of self-administered standardized volumes of liquids and solids. We evaluated neuromuscular control through the following outcome measures: normalized mean amplitude, burst duration, and time to peak amplitude.

None of the outcome measures significantly changed across time for either exercise group. However, additional exploratory analysis examining the relationship between the percent change of all outcome measures from pre- to post-exercise revealed two interesting findings. A strong negative relationship was found between percent change of normalized amplitude and time to peak amplitude in thin liquids ($r = -0.925$, $p = 0.0001$) and pudding ($r = -0.901$, $p = 0.0001$).

In this sample of participants, this work shows biomechanical swallowing gains post-exercise but no changes in neuromuscular effort and timing to achieve those gains. These paired results could suggest that these participants exhibited improved function of their swallowing mechanism without the need of the underlying musculature to produce significantly more effort. Interestingly, additional exploratory analysis further revealed a strong negative relationship between percent change in normalized amplitude and time to peak amplitude. This could indicate that two different mechanisms were used to achieve the documented biomechanical gains. That is, some participants may have required decreased effort during a functional swallow, while other participants may have achieved these gains with increased effort but decreased reaction time. To our knowledge this is the first study that offers insights on differential neuromuscular mechanisms

that older adults use to achieve gains in swallowing with therapeutic exercise, and upon future validation could have important implications on how and when we prescribe these exercises in patients with swallowing disorders in clinical settings.

INTRODUCTION

Swallowing involves a series of complex motor and sensory processes and is necessary for sustaining life. A safe, normal swallow requires more than 30 pairs of muscles of the oral cavity, pharynx, larynx, and esophagus (Shaw & Martino, 2013). Of all the muscles involved in swallowing, the role of the submental muscles (i.e., the mylohyoid, geniohyoid, stylohyoid, and anterior belly of the digastric) is considered rather critical as they contract to protect the airway and assist in opening the upper esophageal sphincter (UES) during the pharyngeal stage of a swallow (Pearson et al., 2012; Cook et al., 1989). The function of the submental muscles can physiologically decline with healthy aging (Kim & McCullough, 2007; Aydogdu et al., 2007) and as a result of disease or injury (Hellemans et al., 1981). Such decline can lead to difficulty swallowing (a.k.a. dysphagia), increasing the risk for aspiration (that is, when food or liquid enters the airway) and therefore, respiratory compromise (Logemann, 1998).

Rehabilitative exercises such as the Head Lift Exercise (HLE) (a.k.a. the Shaker exercise) are commonly used to strengthen these muscles and improve hyolaryngeal excursion and UES opening during swallowing (Shaker et al., 1997; Shaker et al., 2002; Logemann et al., 2009). The HLE has been shown to improve anterior laryngeal excursion and anteroposterior diameter of UES opening in both healthy older adults and patients with dysphagia (Shaker et al., 1997; Shaker et al., 2002). In a small-scale clinical trial, the HLE was also shown to decrease aspiration events post-exercise, allowing patients with dysphagia to resume oral feeding (Logemann et al., 2009). However, limitations of the HLE have also been extensively documented. Specifically, it often results in high dropout rates due to difficulties achieving the isokinetic and isometric goals of the exercise (Easterling et al., 2005). Further, the frequency and intensity of the regimen and the required supine position are not ideal for those with a history of cervical or spine surgery or neck and back problems, which are common in older adults (Yoshida et al., 2007; Fujiki et al. 2019a). Patients have also reported dizziness, fatigue, and neck/back pain and stiffness following the exercise (Easterling et al., 2005; Fujiki et al., 2019a). Therefore, our team developed the novel Recline Exercise (RE) as an alternative to the HLE (Mishra et al., 2015; Fujiki et al., 2019a). The RE is identical in frequency and intensity to the HLE but has two important differences. First, the RE is performed while seated at a 45-degree angle and uses gravity for isometric resistance, therefore using eccentric, instead of concentric, muscle contraction (Mishra et al., 2015; Fujiki et al., 2019a).

The RE has been shown to elicit similar biomechanical swallowing outcomes to the HLE in healthy older adults, i.e., improved superior and anterior hyoid excursion (Fujiki et al., 2019a). However, the potential effects of these exercises on the underlying neuromuscular control of swallowing are not known. Previous studies using electromyography have shown increased activation of the targeted submental muscles while performing the HLE, and increased fatigue resistance of the submental, infrahyoid, and sternocleidomastoid muscles post-exercise (Yoshida et al., 2007; White et al., 2008). However, these studies investigated neuromuscular activity of the targeted submental muscles ***during*** active HLE exercise completion and not during functional swallowing. Importantly, although both the HLE and the RE were developed to target submental muscle function during swallowing, their effects on neuromuscular control of swallowing have not been extensively investigated. Better understanding of these neuromuscular effects may provide clarity on the underlying physiological mechanisms that these regimens are theorized to target. A clear understanding of these underlying mechanisms is important because it may help clinicians determine the patient types and/or deficits that may benefit most from these regimens.

To start addressing this gap and comparing the effectiveness of these two exercises, we conducted a randomized clinical trial in a group of healthy older adults randomly assigned to a 6-week Head Lift Exercise or Recline Exercise regimen. This larger study focused on comparing biomechanical swallowing outcomes, perceived effort, and detraining effects of the HLE and RE, and these findings have been published (Fujiki et al., 2019a). In the current study, we will now investigate the effects of the HLE and RE exercises on the neuromuscular control of swallowing, by examining submental muscle activity during swallowing at baseline and post-exercise. Our aim is to compare the effects of the two exercises on neuromuscular control during functional swallows in the two study groups. First, we discuss fundamental knowledge on swallowing physiology and muscle contributions to hyolaryngeal excursion. Then, we discuss the HLE and RE as commonly used exercise regimens for hyolaryngeal and UES dysfunction, and how we expect rehabilitative exercises to impact neuromuscular control during functional tasks. Then, the aims and hypotheses are detailed. Finally, results are presented, followed by a discussion section.

LITERATURE REVIEW

Normal Swallowing Physiology

To provide a framework for this thesis, normal swallowing physiology will be briefly discussed first. Swallowing begins with the placement of food in the mouth and ends with the material entering the stomach through the lower esophageal sphincter (Logemann, 1998). The entire process is artificially broken down into four sequential and partly overlapping phases: oral preparatory, oral transport, pharyngeal, and esophageal.

The swallow begins with the oral preparatory phase, during which food or liquid is manipulated and masticated so that it is ready to be swallowed (Robbins et al., 2006). During the oral transport phase, the tongue pushes the bolus posteriorly towards the pharynx, where the pharyngeal phase begins through an event known as the triggering of the pharyngeal swallow (Kahrilas et al., 1993).

During the pharyngeal phase, the bolus moves inferiorly from the oropharynx through the upper esophageal sphincter (UES) into the esophagus (Perlman and Christenson, 1997). Five important events are required for the bolus to move safely through the pharynx. One important event is velopharyngeal port closure, which seals off the nasal cavity from the oral cavity. The second important event is movement of the tongue base and pharyngeal walls to narrow the pharynx (McConnel, 1988; Dodds et al., 1975). These first two events work together to build up the pressures required to move the bolus inferiorly through the pharynx. The third important event is laryngeal vestibule closure, which seals off the entrance to the airway at three levels: the true vocal folds, false vocal folds, and epiglottis (Shaker et al., 1990). The fourth important event is hyolaryngeal excursion. The entire hyolaryngeal complex, including the hyoid bone, laryngeal cartilages, laryngeal muscles and membranes, is displaced anteriorly and superiorly (Logemann, 1998; Pearson et al., 2012) to further enable airway closure during the swallow. The fifth and final important event of the pharyngeal phase is upper esophageal sphincter (UES) opening, which is achieved through the relaxation of the cricopharyngeus muscle, through gravity and pressure of the oncoming bolus, and the anterior movement of the hyoid bone (Ertekin & Aydogdu, 2002; McConnel, 1988).

The fourth and final phase of the swallow is the esophageal phase, which begins with the bolus passing through the UES into the esophagus and ends with the bolus passing through the lower esophageal sphincter into the stomach, which is also considered the end of the swallow (Miller, 1987). Of all the events described above, hyolaryngeal excursion is one of the most critical for a safe swallow because it moves the airway out of the direct pathway of the oncoming bolus (Matsuo & Palmar, 2008). Reductions in this excursion are often linked to pharyngeal dysphagia in several patient populations (Hellemans et al., 1981; Logemann, 1998; Shaker et al., 2003), and its improvement is frequently a therapeutic target. We will next discuss how this excursion is achieved.

Hyolaryngeal Excursion & Submental Muscles

Hyolaryngeal excursion involves the anterior and superior movement of the entire hyolaryngeal complex (Pearson et al., 2013), and is achieved primarily through contraction of the submental muscle group with contributions from the longitudinal pharyngeal muscles and the thyrohyoid muscle intrinsic to the hyolaryngeal complex (Pearson et al., 2019).

The submental muscles include the suprahyoid muscle group and the stylohyoid muscle, as seen in Image 1. The suprahyoid muscle group includes three important muscles: the anterior belly of the digastric, geniohyoid, and mylohyoid. The anterior belly of the digastric and mylohyoid are believed to contribute to the superior movement of the hyoid bone, while the geniohyoid mostly contributes to the anterior movement of the hyoid bone (Pearson et al., 2011; Pearson et al., 2013). The final muscle of the submental muscle group is the stylohyoid muscle, which contributes to elevating the hyoid bone (Pearson et al., 2011). The submental muscles are considered the primary contributors of hyolaryngeal complex excursion; however, the thyrohyoid muscle and longitudinal pharyngeal muscles also assist in this excursion by contributing to laryngeal elevation (Meng et al., 2008; Pearson et al., 2012).

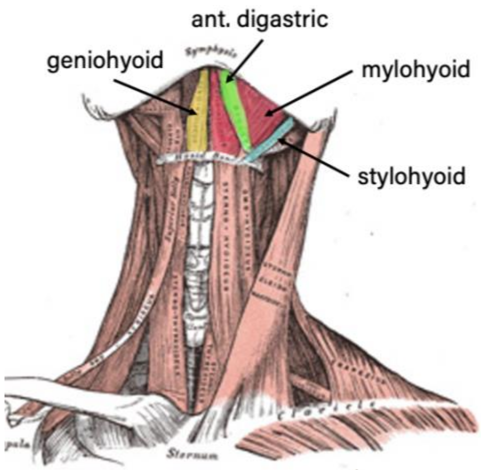

Figure 1. The submental muscles. Taken from: Gray, H. (1918). Muscles of the neck. Anterior view. [Image].

Of all these muscles, the submental muscles are easiest to study and targeted in evaluation and treatment because they are relatively superficially located and their activity can be measured with the use of noninvasive technology, such as surface electromyography (sEMG). Therefore, it is not surprising that many swallowing exercises target this muscle group. In order to better understand the contribution of the submental muscles to swallowing physiology, the next section describes general and head and neck muscle anatomy and physiology.

Insights into Muscle Anatomy and Physiology

The submental muscles are striated skeletal muscles. Skeletal muscles are composed of many muscle fascicles, which are bundles of many muscle fibers. There are two types of skeletal muscle fibers: Type I and Type II, also known as slow-twitch and fast-twitch (McComas, 1998; Moritani et al., 2004). Type I fibers (slow-twitch) contract slowly, are fatigue resistant, and are often used for small movements, but do not require large amounts of energy. Type II fibers (fast-twitch) contract quickly and produce larger, more forceful movements while fatiguing more quickly. Additionally, hybrid muscle fibers are a blend of type I and type II fiber makeups. Most human skeletal muscles contain both types in varying proportions depending on the function of the muscle, age, and amount of exercise (McComas, 1998; Moritani et al., 2004).

Exercise alters the makeup of skeletal muscles and can produce changes in muscle performance. The number of skeletal muscle fibers in each muscle is genetically determined and does not change over time. However, changes in muscle function are reflective of the number of myofibrils and sarcomeres within each muscle fiber (Gabriel et al., 2006; Hedayatpour & Falla, 2015; Moritani et al., 2004). With increased muscle use, there is an increase in the number of myofibrils and sarcomeres, resulting in muscular hypertrophy. Hypertrophy is increased bulk and mass of a skeletal muscle. Conversely, with decreased muscle use, there is a decrease in the number of myofibrils and sarcomeres, resulting in muscular atrophy.

Different types of exercise can result in different types of structural changes in muscle fibers. There are two types of skeletal muscle contraction: isometric and isotonic. Isometric contraction occurs when the muscle produces tension without changing the length of the muscle (Enoka, 2002; Remaud, 2013). Isotonic contractions occur when the muscle tension stays constant and the length of muscle changes. Isotonic contractions can be broken down further into two types of contractions: concentric and eccentric contraction (Enoka, 2002; Remaud, 2013). Concentric contraction occurs when the muscle is shortened, while eccentric contraction occurs when the muscle lengthens (Enoka, 2002; Remaud, 2013). One difference between eccentric and concentric contraction is that fewer motor units are required to perform the same action eccentrically as concentrically, so less effort is required (Hedayatpour & Falla, 2015; Moritani et al., 2004). Additionally, eccentric contractions have a greater effect on type II fibers compared to concentric contractions (Hedayatpour & Falla, 2015; Moritani et al., 2004).

Exercise can result in changes in the structure and function of skeletal muscles; however, it is important to consider the differences between the musculature of the limbs and the head/neck, including the submental muscles. Muscles of the head/neck are different from muscles of the limbs in structure and function. Overall, muscles of the head/neck have more complex patterns of innervation and greater number of motor units compared to limb muscles as well as differing proportions of muscle fiber types (Kent, 2004; McComas, 1998). However, there is even great variability of morphology within the muscles of the head/neck (Kent, 2004; McComas, 1998). Specifically, the submental muscles have similar amounts of type I and type II muscle fibers, but fewer hybrid muscle fibers (Kent, 2004). Insights into muscle structure and function can be gained through techniques, such as surface electromyography.

The surface electromyography signal provides information about muscle activity and insight into the underlying muscles. During muscle contraction, nerve impulses travel to the neuromuscular junction. These nerve impulses propagate through the muscle fibers that are innervated by that neuron to create a motor unit action potential. This creates an electrical field in the muscle, which is detected as the surface EMG signal (Moritani et al., 2004; Stepp, 2012). Thus, the surface EMG signal is a collection of the motor unit action potentials and provides information about motor unit recruitment, firing frequency, and the synchronization of motor impulses, and as mentioned earlier, is frequently used in evaluation and treatment of swallowing. Surface EMG can further be useful in detecting changes in neuromuscular control measures that impact muscle function (Aydogdu et al., 2007; Sella et al., 2014; Stepp, 2012).

Aging Muscle Physiology

Age-related changes that occur in the striated skeletal muscles are thought to primarily result from sarcopenia (Cartee, 1995; Faulkner et al., 1995). Sarcopenia is defined as age-related declines in muscle composition, including decreased muscle mass, cross-sectional area, and number of selective muscle fibers (Evans, 1995). These anatomical changes result in decline in overall muscle function, with decreases in muscle strength, power, and force (Skelton et al., 1994). Additionally, functional tasks require relatively more effort (Hortobagyi et al., 2003; Ploutz-Snyder et al., 2002).

Sarcopenia has been found to affect the submental muscles, and can result in declines in function (Yarasheski, 2002). Previous studies have shown age related decreases in surface electromyography (sEMG) activity of submental muscles during swallowing, including decreased peak and mean amplitude, increased duration, and increased variability (Aydogdu et al., 2007; Sella et al., 2014; Vaiman et al., 2004). These changes in submental muscle composition and function may explain the reductions in hyolaryngeal excursion seen in healthy aging and age-related disease. Indeed, decreased anterior excursion of the hyolaryngeal complex and a delay in the initiation of maximal hyolaryngeal excursion have been frequently documented in older adults (Kim & McCullough, 2007; Namasivayam-MacDonald, et al., 2017; Robbins et al., 1992), and may result in aspiration (Steele et al., 2011) and/or reduced UES opening (Shaker et al., 2002).

Exercises Targeting the Submental Muscles & Hyolaryngeal Excursion: The Head Lift (Shaker) and the Recline Exercises

Several exercise protocols have been designed to improve hyolaryngeal excursion and subsequently UES opening by targeting the submental muscles in older adults and patients with dysphagia. Herein we will briefly discuss the two exercises of interest, the HLE and the RE.

The Head Lift Exercise, also known as the Shaker Exercise, is a well-established rehabilitative exercise for dysphagia aimed at improving hyolaryngeal excursion and UES opening by targeting the submental muscle group. The daily repetitive exercises of the HLE target increased submental muscle strength, which may result in improved hyolaryngeal excursion.

The Head Lift Exercise (HLE) consists of 6-weeks of isometric and isokinetic exercises performed while the patient is in a supine position (Shaker et al., 1997). Isometric exercises involve resistance without movement, thus the isometric portion of the HLE involves three head lifts held for 60 seconds with 60 seconds rest in between. Isokinetic exercises involve resistance with movement, thus the isokinetic portion of the HLE involves 30 consecutive head lifts without holding. The HLE uses concentric contraction, meaning that the muscle shortens to generate force. The full exercise protocol of the HLE is described in detail in the methods section of this study and in prior literature (Shaker et al., 1997).

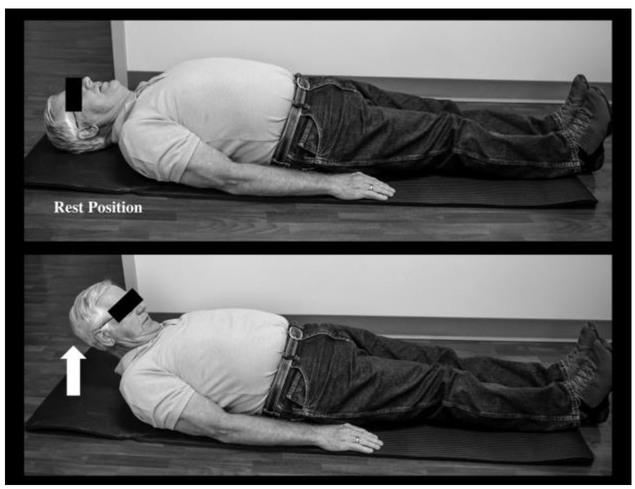

Figure 2. A participant performing the HLE. The rest position is shown in the top picture and the position while performing the exercise is shown in the lower picture. Republished with permission of American Speech-Language-Hearing Association, from "The Recline and Head Lift Exercises: A Randomized Clinical Trial Comparing Biomechanical Swallowing Outcomes and Perceived Effort in Healthy Older Adults", by Robert Brinton Fujiki, Abby J. Oliver, Jaime Bauer Malandraki, Dawn Wetzel, Bruce A. Craig, and Georgia A. Malandraki, Volume 62, Issue 3, 2019; permission conveyed through Copyright Clearance Center, Inc.

The first study published on the HLE included 19 healthy older adults (Shaker et al., 1997). Results revealed that the HLE improved anterior laryngeal excursion and maximum anteroposterior diameter of UES opening during 5 ml thin liquid bolus trials post-exercise (Shaker et al., 1997) in this group, suggesting that the HLE improves biomechanical swallowing function in healthy older adults post-exercise. Several studies have found similar results in older adults and have further shown increases in superior hyoid excursion (Easterling et al., 2005; Easterling et al., 2008, Fujiki et al., 2019a). Studies involving patients with dysphagia have also shown positive outcomes. In a small clinical trial with 27 patients post-stroke, Shaker and colleagues found significantly improved anterior laryngeal excursion and anteroposterior diameter of UES opening post-exercise during 5 ml thin liquid swallows (Shaker et al., 2002). Another small clinical trial with 14 patients with dysphagia compared the effects of two traditional exercises (the supraglottic swallow and tongue strengthening) and the HLE (Logemann et al., 2009). Results showed that the HLE group had fewer aspiration events compared to the two other exercise groups post-exercise, which allowed some patients with dysphagia to resume oral feeding (Logemann et al., 2009). However, the improvements in aspiration events were not fully supported by the biomechanical results; no significant changes were seen in hyolaryngeal excursion and significant increases were only seen in UES opening width during the 3-ml pudding swallows post-HLE. Another study with 11 patients with dysphagia showed that the HLE also augments thyrohyoid muscle shortening (Mepani et al., 2009). Despite these positive results, these small-scale clinical trials had small sample sizes, included few bolus types (primarily thin liquid), and many of the participants with dysphagia had varying diagnoses.

Previous sEMG studies suggest the HLE activates the submental muscles, the infrahyoid muscles, and the sternocleidomastoid (Ferdjallah et al., 2000; White et al., 2008). During the HLE, the sternocleidomastoid has been shown to fatigue faster than the submental and infrahyoid muscles, which may play a limiting role in achieving exercise goals. However, White and colleagues found that the sternocleidomastoid muscle had increased fatigue resistance after completing the HLE regimen (White et al., 2008). Therefore, the sternocleidomastoid may initially limit patients from completing the full exercise regimen, but this limitation may resolve as the sternocleidomastoid strengthens as a result of the regimen.

Despite these promising findings, the HLE can be challenging. Non-dysphagic older adults completing the HLE regimen have reported neck soreness/stiffness, dizziness, fatigue, need for encouragement, and discontinuation of the exercise regimen (Easterling et al., 2005; Fujiki et al., 2019a). The physical and time demands are impractical for many participants (Fujiki et al., 2019a; Yoshida et al., 2007). For example, in a study with healthy older adults, only 50% of participants reached the prescribed isometric goals and 70% of participants reached the prescribed isokinetic goals of the exercise regimen over 6 weeks due to reports of muscle discomfort and time constraints (Easterling et al., 2005). Additionally, the same study reported high dropout rates (Easterling et al., 2005). Further, the physical demands and supine position for the HLE may be impractical for aging and medically fragile patients, especially for patients with pre-existing back pain or stooped posture (Yoshida et al., 2007). These studies support the need for less strenuous rehabilitative exercises targeting the submental muscles that are just as effective as the HLE. Less strenuous options may also help improve patient adherence.

Therefore, the Recline Exercise (RE) was developed as an alternative to the HLE (Mishra et al., 2015; Fujiki et al., 2019a). In the RE, the patient sits in a 45-degree reclined position using a modified wedge pillow. The RE also contains an isometric and an isokinetic portion. However, in the isometric portion, the neck is held against gravity (eccentric contraction), which results in widespread muscle activation (Sutthiprapaporn et al., 2008).

Figure 3. A participant performing the RE. The rest position is shown in the left picture and the position while performing the exercise is shown in the right picture. Republished with permission of American Speech-Language-Hearing Association, from “The Recline and Head Lift Exercises: A Randomized Clinical Trial Comparing Biomechanical Swallowing Outcomes and Perceived Effort in Healthy Older Adults”, by Robert Brinton Fujiki, Abby J. Oliver, Jaime Bauer Malandraki, Dawn Wetzel, Bruce A. Craig, and Georgia A. Malandraki, Volume 62, Issue 3, 2019; permission conveyed through Copyright Clearance Center, Inc.

Mishra and colleagues (2015) investigated the neuromuscular effects and perceived exertion of the HLE and RE regimens in a group of 40 healthy young adults. Their outcome measures included surface electromyography (sEMG) parameters during swallowing, maximum lingual isometric pressures, and Borg scale ratings of perceived exertion (Mishra et al., 2015). Results showed that duration and peak amplitude of submental muscle activity during swallowing did not significantly change in both exercise groups. Improvements were seen in maximum lingual isometric pressures in both groups, but only reached statistical significance in the RE group. The authors suggested that the similar results for sEMG and maximum lingual isometric pressures for both exercise groups suggest the RE and HLE result in similar neuromuscular effects in healthy young individuals. The exertion ratings showed that perceived exertion decreased during the exercise regimen; however, there were no differences between exercise groups. These preliminary findings showing similar results in both exercise groups are promising; however, more research is needed in healthy older adults, who are more typical of patient populations.

Our lab conducted a Randomized Phase II Clinical trial with 22 healthy older adults randomized to complete the HLE or RE regimen for 6-weeks (Fujiki et al., 2019a). Subjects participated in a videofluoroscopic swallow study (VFSS) assessment, completion of post-exercise satisfaction and health surveys, and a surface electromyography (sEMG) study at three visits (baseline, post-treatment, and at 6-weeks follow-up). The results of the biomechanical swallowing outcomes and the surveys have been published (Fujiki et al., 2019a), and showed that the HLE and RE produce similar gains in biomechanical swallowing outcomes in healthy older individuals. Specifically, significant increases were seen in superior and anterior hyoid excursion in both groups post-exercise and there were no differences between exercise groups. Although fewer participants returned for the 6-week follow up visit (18 out of 22 participants), post-exercise biomechanical gains in hyoid excursion were partially preserved for most participants. A secondary outcome measure included was the Borg scale exertion ratings. Results from the exertion ratings revealed the RE requires significantly less effort than the HLE. Overall, this study found that the RE is perceived as easier to perform for healthy older individuals while still resulting in similar biomechanical swallowing improvements, and thus could be used as a valuable treatment alternative for adults who have difficulty with the HLE. The currently proposed study is part of this larger clinical trial and focuses on the sEMG methods and results in order to help us better understand the underlying neuromuscular effects of both exercises.

Effects of Rehabilitative Exercises on Neuromuscular Control during Functional Tasks

Although the effectiveness of the HLE and RE in improving hyolaryngeal excursion during swallowing have been demonstrated by the aforementioned studies, what is not known is how the underlying neuromuscular control of swallowing is affected as a result of these exercise regimens. Understanding how these exercises affect the underlying neuromuscular control of swallowing is important because it may provide clarity on the underlying physiological mechanisms and musculature that these regimens are theorized to target. This contribution will be significant because it may help specify the patient types and/or deficits most likely to benefit from these regimens.

In general, research investigating whether and how the underlying neuromuscular control of swallowing is affected as a result of rehabilitative exercises is scarce. Previous studies involving the HLE and the use of sEMG looked at muscle activity while performing portions of the exercise regimen, not during a swallow. Although this provides important information about which muscles are active during exercise completion, it would be useful to understand how the function of these muscles during swallowing change post-exercise because they were designed to improve swallowing function. Although little is known about the changes in neuromuscular control of swallowing post-exercise, physical therapy literature provides insight into how muscle activity changes during functional tasks post-exercise. Most of this literature focuses on participants experiencing pain or injury and rarely include healthy controls. However, the following two studies investigated the neuromuscular effects of daily rehabilitative exercises on functional arm movement in young adults with shoulder pain as well as in healthy controls.

First, in a study by Seitz and colleagues (2019), young participants (mean age: 30 years +/- 9 years) with shoulder pain during movement performed a horizontal abduction exercise daily for 3 weeks (Seitz et al., 2019). After completing this exercise regimen, significant reductions in normalized EMG amplitude of the targeted lower trapezius muscle activity were seen post-exercise during a functional arm elevation task. Reductions in normalized amplitude were also observed in the healthy control group post-exercise but did not reach statistical significance. Similar results were seen in a study by Tsang and colleagues (2018). Participants (age range: 20-54) with neck-shoulder pain underwent a 12-week intervention including motor control training and general exercises (Tsang et al., 2018). After completing the 12-week exercise regimen, results showed significant reductions in EMG amplitude for the targeted upper trapezius muscle activity and improved kinematics during functional tasks (i.e., moving an object forward, backward, upward, downward) post-exercise completion. The control group showed observable increases in muscle activity post-exercise, but these increases did not reach significance. Overall, results from these studies suggest neuromuscular adaptations with improved kinematics, and specifically mostly decreases in mean amplitude of muscle activity during functional tasks post-exercise for patient groups. According to the authors, these decreases in mean amplitude may be an indication of decreased muscular effort required to complete the same functional task post-exercise completion for these patients (De May et al., 2012; Seitz et al., 2019). For the control groups, however, functional kinematic gains post-exercise were seen without being accompanied by significant neuromuscular changes during these tasks (Seitz et al., 2019; Tsang et al., 2018). Thus, healthy controls showed kinematic gains during functional tasks post-exercise without increased muscular effort.

These studies focused on the upper limb musculature, and, as we described earlier, the musculature of the head and neck is different from that of the limbs. Therefore, different changes may be observed in swallowing muscle activity post-exercise. To our knowledge, only one prior study has investigated how the HLE affects swallowing muscle activity during functional swallowing tasks with sEMG.

Specifically, Poorjavad and colleagues (2019) recently compared the electrophysiological effects of neuromuscular electrical stimulation and the HLE regimen during functional swallows using sEMG in 23 healthy older adults (Poorjavad et al., 2019). Surface EMG recordings of the submental muscles were collected during one swallowing task (a swallow of a 13.5ml water) pre- and post-exercise. After completing the exercise regimen, results showed reduced duration of muscle activation during the swallowing task. Mean amplitude (area under the curve) and time to peak did not significantly change post exercise. According to the authors, these results suggest that participants could swallow a thin liquid bolus faster post-exercise. However, it is important to note that subjects were only asked to swallow one bolus type, i.e., 13.5 ml of thin liquid, which is not representative of all bolus types.

This study provides some first but limiting support for changes in the neuromuscular control of swallowing (thin liquids) after performing the HLE regimen in healthy older adults. Further investigation of these potential changes in swallowing additional bolus volumes and types would offer stronger evidence of these effects. In addition, the effects of the RE on the neuromuscular control of swallowing have not been investigated. Therefore, additional research is needed to investigate how these exercises affect swallowing muscle activity during a wider range of functional swallowing tasks.

Aims and Hypotheses

To address this gap, the main goal of the present investigation is to examine and compare the effects of the two exercises on the neuromuscular control of swallowing in a group of healthy older adults randomly assigned to a 6-week Recline or Head Lift Exercise regimen. Our specific aims are:

Aim 1: To determine the effects of the HLE and RE in the neuromuscular control of swallowing post-exercise completion. The specific outcome measures include burst duration of sEMG activity, normalized mean amplitude, and time to peak amplitude during swallows (detailed in the outcome variables section of the Methods, pages #20-22). Based on prior literature (Poorjavad et al., 2019), we hypothesize that subjects in both groups will show significant reductions in burst duration of sEMG activity during swallowing, and no significant changes in mean amplitude and time to peak amplitude.

Aim 2: To determine differences in the neuromuscular control of swallowing between the two exercise groups. Based on our preliminary data and previous literature (Fujiki et al., 2019a; Mishra et al., 2015), we hypothesize that neuromuscular effects will be similar for both exercise groups.

Next, we discuss the methods used for this study, including the exercise protocol and sEMG data collection and analysis procedures.

METHODS

Design

This was a Randomized Phase II Clinical trial with two arms: HLE and RE groups. The design has been described in detail previously (Fujiki et al., 2019a; Fujiki et al., 2019b). In short, data was collected at three time points (baseline, post-exercise, and follow-up). Baseline data was collected one day before initiating the 6-week training period. Post-exercise data was collected within five days of the end of the 6-week training period. After the post-exercise visit and before the 6-week follow up visit, participants were instructed to not perform any portion of the exercise regimen. Follow-up data was collected six weeks after exercise completion. For this study, only two time points (baseline, post-exercise) were included (See Statistical Analysis for details).

Participants

Recruitment focused on the greater Lafayette, IN area. Inclusion criteria included age (between 60 and 85 years), intact cranial nerve and clinical swallowing function as determined by a cranial nerve exam and a clinical swallowing assessment, normal cognition as measured using the Cognitive Linguistic Quick Test (CLQT; Helm-Estabrooks, Psychological Corporation, & Pearson Education, 2001), and ability to exercise daily. Exclusion criteria included history of swallowing, voice, or neurological disorders, cervical spine surgery, smoking, or injury/surgery/radiation to head/neck.

Participants who qualified were randomly assigned to either the RE or HLE group (Figure 6). Participants were required to demonstrate their ability to perform their assigned exercise during the initial baseline visit but were not excluded if they could not execute the entire exercise protocol. Based on previous literature, gains in swallowing function can still be achieved with the HLE even when participants gradually reach the full exercise regimen (Easterling et al., 2005). However, participants were required to complete the full exercise protocol by the end of the second week to be included in the final analysis.

Exercise Regimens

The protocol for both exercise regimens has also been documented in detail in the literature (Fujiki et al., 2019a; Mishra et al., 2015; Shaker et al., 1997, 2002). The HLE regimen consisted of both an isokinetic and an isometric portion. Participants were instructed to first complete the isometric portion, which included three 1-minute head lifts (concentric contraction) with 1-minute rest between trials. Then, participants completed the isokinetic portion, which included 30 consecutive head lifts without holding. Participants performed both portions laying with shoulders touching the floor (supine position). Participants completed the protocol 3 times a day, every day, for 6-weeks.

Similar to the HLE, the RE also contains an isometric and isokinetic portion. However, participants assigned to the RE sat in a chair (without a head rest) at a 45-degree angle. Additionally, participants received a 45-degree wedge pillow to place on the chair to ensure correct form while performing the exercise. During the isometric portion, participants leaned their head back to be aligned with their trunk/body (eccentric contraction) at a 45-degree angle, resisting gravity, for 1 minute three times with 1-minute rest between trials. During the isokinetic portion, participants leaned their head back to the 45-degree angle and then brought their chin to their chest 30 consecutive times. The HLE and RE was performed at the same frequency and intensity; participants completed the exercise protocol 3 times a day, every day, over a 6-week period.

All participants were trained on their respective exercise protocol through an instructional video and were given written and pictorial instructions to reference at home (instructional videos in the supplemental materials from Fujiki et al., 2019a available here: https://asha.figshare.com/articles/media/The_Recline_and_Head_Lift_Exercises_Fujiki_et_al_2019_/7742897). Participants were contacted weekly to encourage adherence to the exercise protocol. Participants were also supplied with a home exercise log, on which they were required to record their exercise activity, which was collected upon completion of the 6-week regimen.

Data Collection

All data collection procedures were identical at the three time points (baseline, post-exercise, and follow-up). All data was collected by two trained research assistants.

Subjects participated in a comprehensive swallowing evaluation at each visit, including a VFSS assessment, completion of post-exercise satisfaction and health surveys, and a surface electromyography (sEMG) study. The results of the kinematic analysis of the VFSS assessment and of the survey responses have been published (Fujiki et al., 2019a). The present proposed study aims to examine the comparative effects of the two exercises on the neuromuscular control of the swallowing in this sample, and therefore will focus on the sEMG portion of this larger study. Additionally, only two time points (baseline, post-exercise) were included in the preset analysis (See Statistical Analysis for details).

Surface Electromyography

Muscle activity of the submental muscle group (mylohyoid, geniohyoid, anterior belly of the digastric) was measured using surface electromyography (sEMG) during swallowing tasks and a maximum voluntary contraction task. As discussed earlier, these muscles were selected because they have been shown to contribute to hyolaryngeal excursion during swallowing (Pearson et al., 2012).

Recordings were completed using a data acquisition device (PowerLab 8/35, ADInstruments, Inc., Colorado Springs, CO), data acquisition software (LabChart 8), and the Trigno Wireless EMG system (Delsys Inc.) including wireless sEMG sensors (Trigno™ Mini Sensors). The techniques used for sEMG acquisition and processing were consistent with previous literature (Kantarcigil et al., 2020; Stepp, 2012).

Following skin cleansing with an alcohol swab, two double differential electrodes (Trigno™ Mini Sensors) were positioned on the left and right of the submental region over the platysma and aligned with submental muscle fibers as seen in Figure 3. The inter-electrode distance was approximately 1.5 centimeters from the medial edge of the left electrode to the medial edge of the right electrode (Hermens et al., 2000; Hermens & Freriks, 2017). Two corresponding ground electrodes were placed on the mastoid process of the left and right temporal bone. The data acquisition system was calibrated to record sEMG signals from the electrodes at a 2 kHz-sampling rate with a 550-microvolt range. A band pass filter of 10-500 Hz was used during signal acquisition to enable optimal detection and resolution of the signal (Stepp, 2012). A mains filter was also used to attenuate extraneous noise in the environment in order to increase signal to noise ratio.

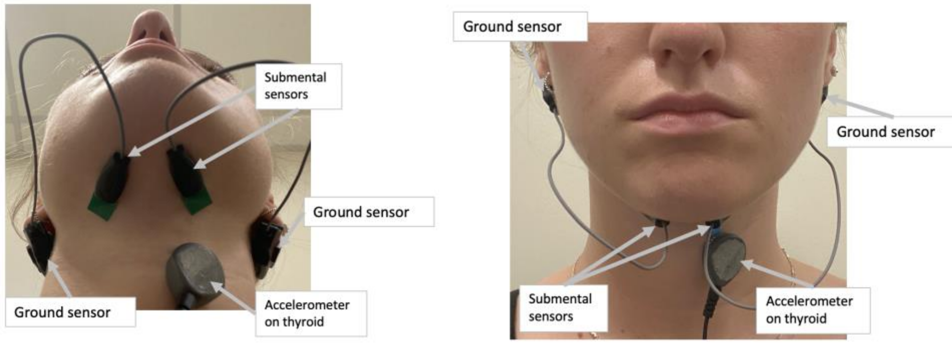

Figure 4. Placement of double differential electrodes on the submental area, ground electrodes on the mastoid process of the temporal bone, and an accelerometer on the side of the thyroid cartilage on participants for sEMG data collection. An inferior view of the submental area is shown on the left and a frontal view is shown on the right.

To confirm the swallow events, we used three complementary methods: respiratory inductance plethysmography to identify the swallow apnea events, an accelerometer signal from the neck (thyroid notch area), and a manual user trigger button. The respiratory signal was recorded with a respiratory inductance plethysmography band with piezoelectric sensors (Great Lakes NeuroTechnologies) placed directly inferior to the ribs via the PowerLab system at a 2 kHz-sampling rate with a 100-microvolt range (Wheeler Hegland et al., 2009). The respiratory signal was used to identify apnea events, which are flat lines in the respiratory signal corresponding to cessation of breathing during a swallow (McFarland et al., 2016). In addition, movement of the thyroid notch during a swallow was identified with an accelerometer sensor placed on the side of the thyroid cartilage via the PowerLab system at a 2 kHz-sampling rate with a 500-microvolt range. This signal provided information about the movement of the larynx as a rough indication of hyolaryngeal excursion during the swallow (Takahashi et al., 1994). Finally, an event marker button pressed by a research assistant during data collection at the first sign of laryngeal elevation was used to indicate a swallow event. This manual trigger marker helped identify the general location of swallow events that were counted as trials while the information provided from the accelerometer and respiratory signals helped confirm these events. Both methods were used for confirmation because of the inherent difficulty in confirming swallow events in the sEMG signal (Charbonneau et al., 2005; Kantarcigil et al., 2020; McFarland & Lund, 1995); however, during analysis, the accelerometer sensor more consistently provided a clear signal during the swallow (see the accelerometer response and overlap in timing with submental sEMG signal in Figure 4).

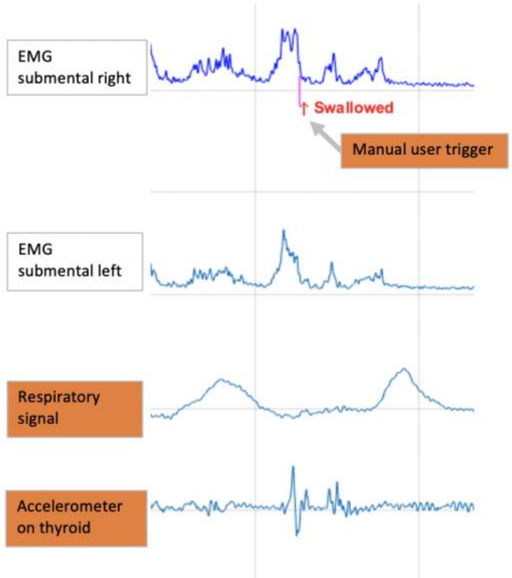

Figure 5. The three methods used to identify and confirm swallow events during data analysis in highlighted orange boxes.

Procedure

Data collection began with a 1-minute rest period to establish a clean baseline signal. Then, participants were instructed to complete a criterion-referenced task (maximum lingual press) using the Iowa Oral Performance Instrument (IOPI) three times (Kantarcigil et al., 2020; Robbins et al., 2005; Stepp, 2012). The IOPI device includes an air-filled bulb, which is connected to a pressure transducer, and measures isometric tongue strength in kPa. Investigators positioned the bulb at the front of the tongue and asked the subject to press the bulb up to the roof of their mouth as hard of they can. Three maximum anterior lingual pressure values (in kilopascals) that differed by less than 5% were recorded (Robbins et al., 2005). This task was used to elicit the maximum voluntary contraction (MVC) of the submental muscles during sEMG (Stepp, 2012). EMG amplitude values were later normalized to the highest of three MVC value and are reported as percent of MVC (Smith et al., 1996).

Then, participants were instructed to swallow 3 trials of each of the following boluses: dry swallow, 5 ml water, 10 ml water, self-administered cup sip, sequential cup sips, 5 cc pudding via spoon, and ¼ cookie. Boluses were presented in the same sequence for all participants and were not randomized. The bolus presentation sequence was not randomized to remain consistent with sequence of boluses during VFSS data collection. All participants were self-fed. All tasks were analyzed and if participants swallowed more than once per bolus trial, only the first swallow was used for analysis.

Data Analysis

Following signal acquisition, the raw signal files were exported as MATLAB files (MATLAB Inc., Natick, MA) while maintaining sampling rates. MATLAB files were loaded in MATLAB R2017a through custom-written MATLAB scripts that generated a graphic user interface. These scripts include all necessary pre- and post-processing EMG analysis steps (Kantarcigil et al., 2020; Smith et al., 1996; Stepp, 2012; Walsh & Smith, 2013). Artifact identification (defined as high and sudden signal spikes in amplitude that could not be attributed to muscle activity or large variations in slope width time) was completed automatically by the MATLAB script through predefined criteria determined from prior pilot data analysis. All automatically identified artifact was reviewed by a trained experimenter to ensure accuracy and if correctly identified, then removed. After artifact removal, the signal was bandpass filtered between 20-300 Hz and notch filtered at 60 Hz. The raw signal was full wave rectified and smoothed with an 80-millisecond window. A trained research assistant analyzed all data files and was blinded to exercise group, but not time point.

Outcome Variables

The following sEMG outcome variables were investigated: burst duration of sEMG activity during swallows, normalized mean amplitude of sEMG muscle activity, and time to peak amplitude. Each is described in detail below.

Burst Duration of sEMG Activity during Swallows

The burst duration of sEMG activity during a swallow indicates the total activity time of the submental muscles during the pharyngeal phase. Significant temporal relationships have been shown between the duration of the submental EMG signal and the total duration of hyoid movement (Crary et al., 2006) and laryngeal elevation (Ding et al., 2002) during swallowing.

Previous studies have shown increased duration of submental activity in healthy older adults compared to young adults (Ding et al., 2003), which aligns with studies using VFSS showing increased duration of the pharyngeal swallow in older healthy adults (Cook et al. 1994; Robbins et al., 1992). Changes in burst duration of sEMG activity during swallows may provide insight into how the HLE and RE affect the timing of muscle activity producing hyolaryngeal excursion during the pharyngeal swallow and are important to delineate.

In this study, each swallow was first identified visually by looking at the sEMG signal as well as the respiratory, accelerometer, and manual trigger signals. The exact onset and offset of the muscle activity during each swallowing event were defined as a change greater than 2 standard deviations (SDs) from the baseline of the sEMG signal and were selected using the custom-written MATLAB script (Kantarcigil et al., 2020). An automatic algorithm searched for a change in baseline that was greater than 2 SD within the user-identified window and marked the time of this amplitude as the onset and offset of the sEMG activity. If the algorithm did not identify the onset and offset of the swallow trial (most likely due to noise), the onset and offset were marked manually. Duration was calculated by subtracting the swallow onset time from the swallow offset time, as seen in Figure 5. For each swallowing task/bolus type, duration was averaged from the three recorded trials.

Normalized Mean Amplitude (Area Under the Curve)

As percentage of maximum voluntary contraction, normalized mean amplitude is an indication of muscular effort. Although this measure does not provide direct information about strength, it is thought to indicate the extent of muscle contraction (Oh, 2016). Swallowing is a submaximal task for healthy adults (Steele, 2013; Youmans et al., 2008); the HLE and RE are intended to strengthen the submental muscles, which may affect the muscular effort required during swallowing for healthy older adults. Changes in normalized mean amplitude may provide information about how the RE and HLE affect submental muscular effort required during swallowing.

The area under the curve (AUC) between the swallow onset and swallow offset as defined above was generated through a custom-written MATLAB script (Kantarcigil et al., 2020; Smith et al., 1987). The AUC value for the three trials of a maximum voluntary contraction task was also generated. Then, the AUC value for each swallow event was normalized against the highest AUC value of the maximum voluntary contraction task (IOPI) to allow for comparison of values across time points and across subjects (Smith et al., 1987; Weber & Smith, 1987). Therefore, all AUC values are a percentage of the maximum voluntary contraction. For each swallowing task/bolus type, AUC values were averaged from three recorded trials.

Time to Peak

Time to peak indicates how quickly the submental muscles can reach their maximum level of activation (Crary and Baldwin, 1997). The peak amplitude of sEMG signal is associated with the pharyngeal triggering of the swallow (Crary et al., 2006). Healthy older adults have been shown to have delayed pharyngeal triggering and increased duration of the pharyngeal swallow (Logemann et al., 2000; Aydoğdu et al., 2007). Changes in time to peak may provide insight into effects on timing and reaction of submental muscle activation during the swallow.

The latency between the onset of muscle activity and the peak amplitude was calculated for each swallowing event, as seen in Figure 5. For each participant, these latency values were averaged from the three recorded trials.

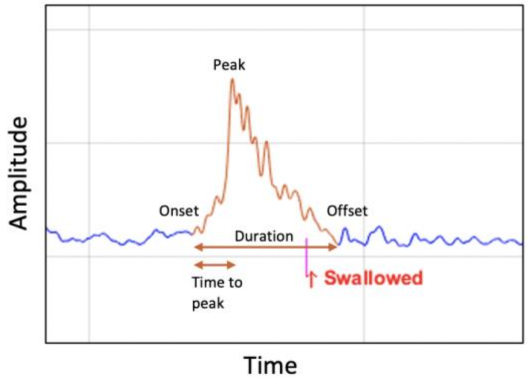

Figure 6. The processed and rectified EMG signal of the left sEMG channel during a single liquid swallow showing the onset and offset of a swallow, the peak, burst duration, and time to peak amplitude measures.

Statistical Analysis

Statistical analysis was completed through SAS Studio (Version 3.8, 2018). All data were tested for normal distribution with the Shapiro-Wilk test of normality and when data were not normally distributed, a log transformation was performed. Linear mixed-effects models were used to compare outcome measures across time points, exercise groups, and bolus types. To reduce the number of factors in this small sample and account for dropouts at the final follow-up time point, only three boluses (5- and 10-ml thin, 5cc pudding) and two time points (baseline, post-exercise) were included in statistical analysis. Time (baseline, post-exercise), exercise group (HLE or RE), and bolus (5- and 10-ml thin, 5cc pudding) were fixed factors and subject was included as a random factor to account for variation among individuals. All interactions were included, and a Tukey adjustment was made on all post hoc *t* tests to correct for multiple comparisons. When post hoc analyses were significant, Cohen's *d* for repeated measures was calculated through a repeated-measures Cohen's *d* calculator (https://www.psychometrica.de/effect_size.html; Lenhard & Lenhard, 2016).

RESULTS

Demographics

As seen in the Consort Diagram (Figure 6), of the 93 older adults screened, 27 met the eligibility requirements (17 women and 10 men) for the larger clinical trial. From these 27 eligible adults, 15 were randomly assigned to the HLE group and 12 were randomly assigned to the RE group. After the initial visit, 2 subjects (one from each group) withdrew from the study due to work conflicts and 3 subjects withdrew from the HLE group due to difficulty with the exercise protocol. Of the 11 subjects left in each group, 2 subjects in each group did not return for the final follow up visit (visit 3) due to scheduling conflicts or dislike for the taste of barium. Additional subjects were excluded from the present analysis due to missing EMG files at the baseline visit (1 subject; missing data file), follow up visit (1 subject; resistance to shave facial hair), or both the post-exercise and follow up visit (2 subjects; resistance to shave facial hair, preference to abstain from sEMG). Overall, EMG files from 10 subjects in the HLE group and 9 subjects in the RE group who completed the baseline and post-exercise EMG recording sessions, were analyzed. Detailed subject demographics are shown in Table 1.

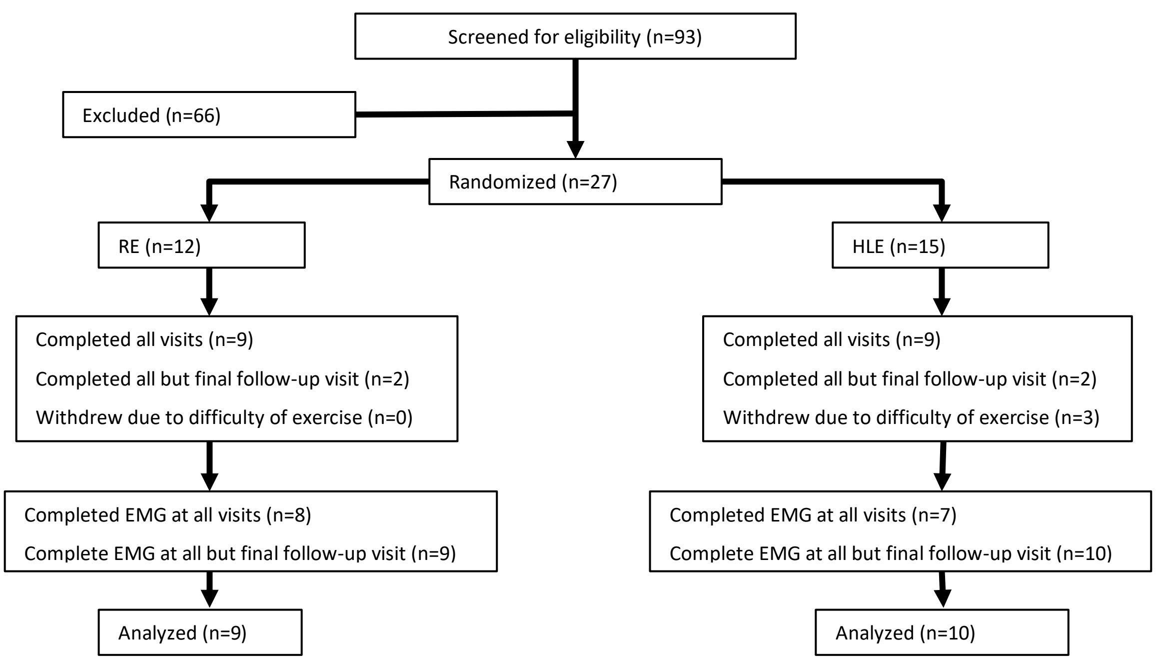

Figure 7. Consort flow diagram

Table 1. Subject Demographics for Subjects completing sEMG protocol

Recline Exercise Group			
Gender	**Age**	**% Body Fat**	**BMI**
Female	74	47.4	34.7
Female	82	39	22.5
Female	67	46.7	35.2
Female	60	41.7	27.8
Female	60	40.1	28.3
Female	70	48.5	36.8
Male	66	44.3	38.8
Male	65	24.1	25.8
Male	66	27.6	27
Head Lift Exercise Group			
Gender	**Age**	**% Body Fat**	**BMI**
Female	66	37.4	27
Female	60	32	21.6
Female	60	40	42
Female	76	45.7	27.8
Female	65	29.7	19.5
Male	68	31.2	29.1
Male	61	29.2	28.6
Male	65	25.1	22.5
Male	62	26.1	24.2
Male	67	30.7	30.3

Group Averages				
	Gender (female/male)	**Age, M (SD)**	**% Body Fat, M (SD)**	**BMI, M (SD)**
RE	6/3	68 (6.9)	39.9 (8.7)	30.8 (5.7)
HLE	5/5	65 (4.8)	32.7 (6.4)	27.3 (6.3)

Surface EMG Outcomes

Burst Duration of sEMG Activity during Swallows

Means and standard errors for burst duration of sEMG activity during swallows across all evaluation time points and boluses are plotted in Figure 7 and listed in Table 2. Mean burst duration appeared to descriptively decrease for thin liquids in the RE group, while slightly increasing or remaining the same in the HLE group (Figure 7); however, no significant main effect of exercise group ($F(1, 16) = 0.001$, $p = .9453$), time, ($F(1, 16) = 0.67$, $p = .4263$), or bolus type was observed ($F(2, 32) = 1.60$, $p = .2184$); and there were no significant interactions.

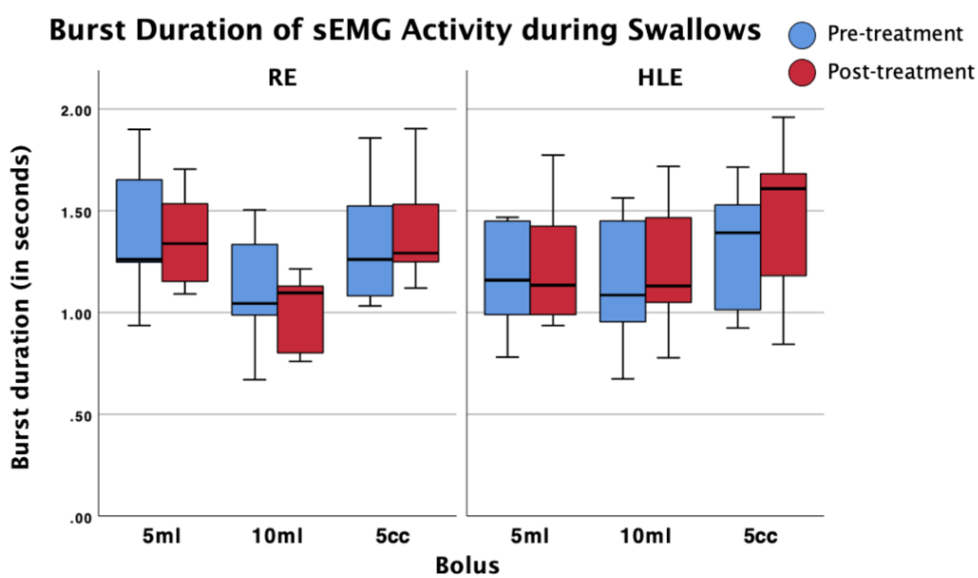

Figure 8. Burst duration of sEMG activity during swallows in seconds for each bolus presented.

Normalized Mean Amplitude

Normalized mean amplitude was not normally distributed and required a log transformation to meet normality assumptions. Means and standard errors for normalized mean amplitude are plotted in Figure 8 and listed in Table 2. No significant interactions between time or group were observed. The effect of group did not reach significance, suggesting no difference between groups across time, ($F(1, 16) = 0.38$, $p = .5455$). Although we observed a slight increase in normalized amplitude post-exercise across time, there was great variability (Figure 8) and this was not statistically significant $F(1, 16) = 2.24$, $p = .1542$. A significant main effect of bolus was observed for normalized mean amplitude, F(2, 32.3) = 9.67, p = .0005. Specifically, amplitude was higher for more viscous boluses (pudding) compared to thin liquid boluses, (t(2, 32.5) = −3.38, p = .0019, Cohen's d = 2.226).

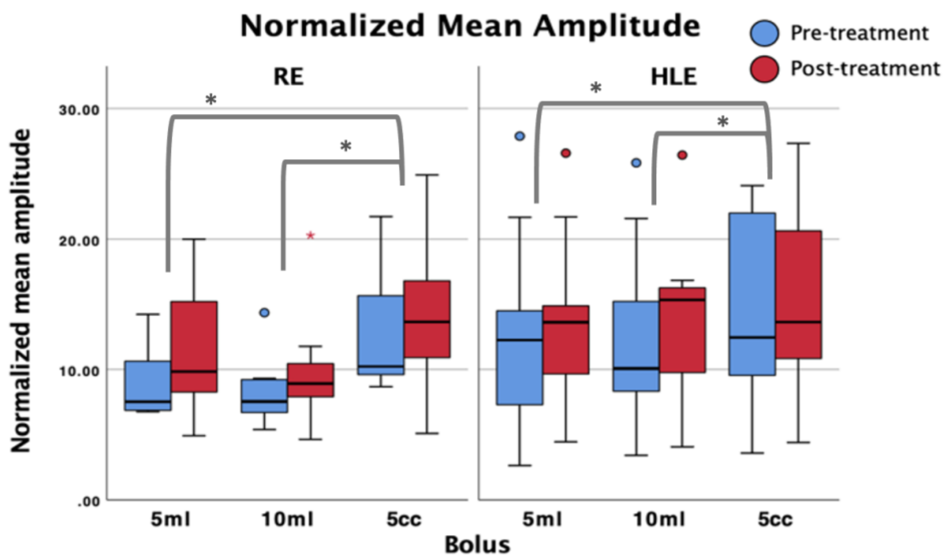

Figure 9. Normalized mean amplitude as a percentage of area under the curve of a maximum voluntary contraction task for each bolus presented.

Time to Peak Amplitude

Time to peak amplitude was not normally distributed and required a log transformation to meet normality assumptions as well. Means and standard errors for time to peak amplitude are plotted in Figure 9 and listed in Table 2. No significant interactions between time or group were noted. The effect of group was also not significant, suggesting no difference between groups across time, (F(1, 16) = 0.28, p = .6034). Additionally, no significant effect of time was observed, (F(1, 16) = 0.02, p = .8764). A significant main effect of bolus type was observed for time to peak amplitude, F(2, 27.4) = 4.16, p = .0264. Specifically, time to peak amplitude was longer for more viscous boluses (pudding) compared to thin liquid boluses, (t(2, 27.5) = −2.18, p = .0382, Cohen's d = 0.689).

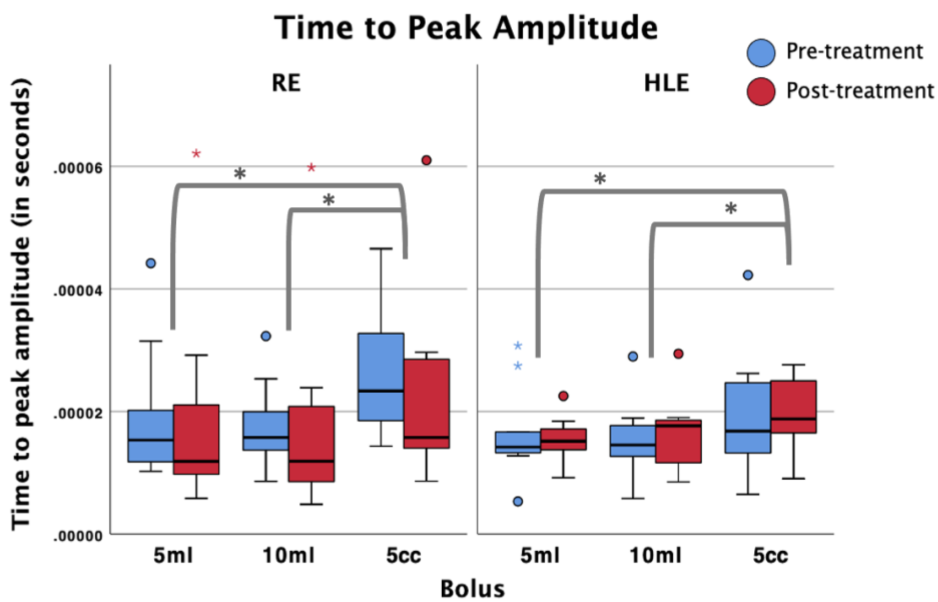

Figure 10. Time to peak amplitude during swallows in seconds for each bolus type.

Table 2. Means and standard deviations of surface electromyography outcome measures divided by time and exercise group

	RE Group					
	Pre-treatment			**Post-treatment**		
	5ml thin liquid	**10ml thin liquid**	**5cc pudding**	**5ml thin liquid**	**10ml thin liquid**	**5cc pudding**
Burst duration (in seconds)	1.21 (0.27)	1.27 (0.21)	1.16 (0.37)	1.35 (0.41)	1.32 (0.31)	1.27 (0.34)
Normalized mean amplitude (% MVC)	8.95 (2.61)	8.29 (2.64)	12.67 (4.60)	11.44 (5.02)	9.93 (4.62)	14.46 (6.28)
Time to peak amplitude (in milli-seconds)	0.020 (0.01)	0.017 (0.01)	0.026 (0.01)	0.019 (0.02)	0.018 (0.02)	0.023 (0.02)
	HLE Group					
	Pre-treatment			**Post-treatment**		
	5ml thin liquid	**10ml thin liquid**	**5cc pudding**	**5ml thin liquid**	**10ml thin liquid**	**5cc pudding**
Burst duration (in seconds)	1.32 (0.21)	1.26 (0.31)	1.23 (0.37)	1.27 (0.30)	1.29 (0.33)	1.18 (0.25)
Normalized mean amplitude (% MVC)	12.93 (7.92)	12.77 (7.10)	15.01 (7.50)	13.51 (7.11)	13.49 (6.68)	15.37 (7.45)
Time to peak amplitude (in milli-seconds)	0.017 (0.01)	0.016 (0.01)	0.020 (0.01)	0.016 (0.004)	0.016 (0.01)	0.019 (0.01)

Additional Exploratory Analysis

Given the large variability in this sample, additional exploratory analysis was completed to investigate any patterns explaining these findings. Percent change of each sEMG outcome measure was calculated as post-exercise value minus pre-exercise value, divided by pre-exercise value, and multiplied by 100. Pearson correlations were then calculated between percent change of all sEMG outcome measures to determine if these relationships would help identify patterns of activity.

Correlations Between Percent Change of Surface EMG Outcomes

Percent change of normalized amplitude and percent change of time to peak amplitude for thin liquids and pudding are plotted in Figure 10. As seen in these graphs, there is a strong negative relationship between these two variables for both thin liquids ($r = -0.925$, p-value = 0.0001) and pudding ($r = -0.901$, p-value = 0.0001). Specifically, participants who had post exercise increases in normalized amplitude tended to have decreases in time to peak amplitude post-exercise and vice versa. Participants who post exercise had decreases in normalized amplitude had increased time to peak amplitude post-exercise. This likely indicates that there were two patterns that participants fell into. Either into a pattern where they needed more effort to complete a swallow post-exercise but were able to reach that effort level (their peak amplitude) faster; or a pattern where they needed less effort post-exercise to complete a functional swallow but took a longer time to reach that effort (their peak amplitude).

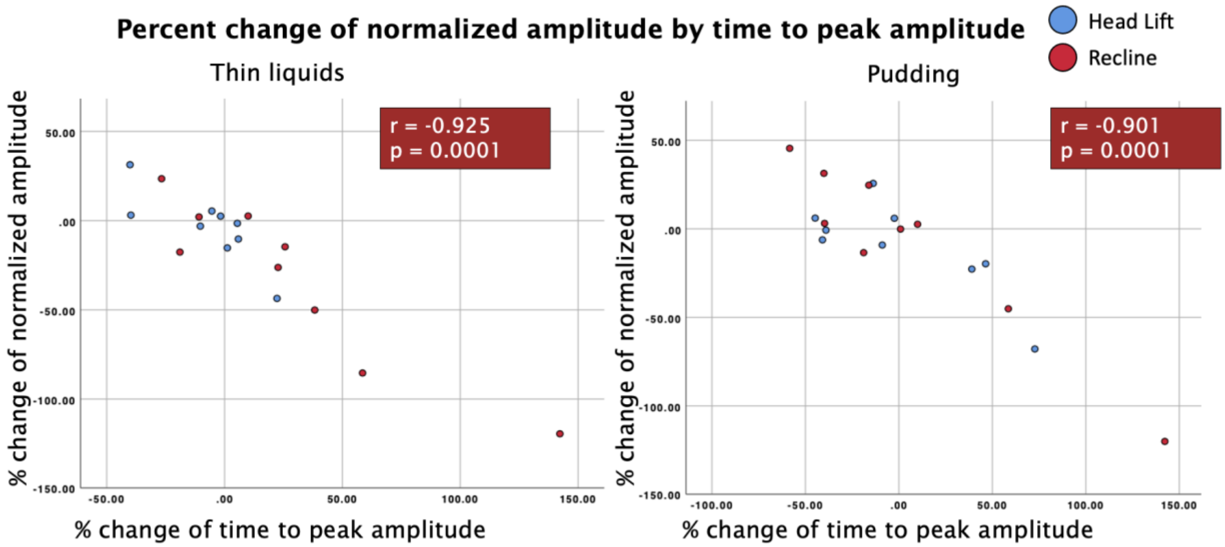

Figure 11. Percent change of normalized amplitude by percent change of time to peak amplitude in thin liquids on the graph on the left and pudding on the graph on the left.

DISCUSSION

Rehabilitative exercises such as the HLE and RE are commonly used to strengthen the submental muscles and improve hyolaryngeal excursion during swallowing (Shaker et al., 1997; Shaker et al., 2002; Logemann et al., 2009). The HLE and RE have been shown to elicit similar gains in hyoid excursion post-exercise in healthy older adults (Fujiki et al., 2019a). However, the potential effects of these exercises on the underlying neuromuscular control of swallowing are not known. These effects are important to understanding in order to help clinicians best determine the patient types and/or deficits most likely to benefit from these exercises.

To start addressing this gap, we investigated the effects of the HLE and RE exercises on the neuromuscular control of swallowing, by examining submental muscle activity during swallowing at baseline and post-exercise. Our first aim was to determine the effects of the HLE and RE on the neuromuscular control of swallowing post-exercise completion. Based on prior work in this area, we hypothesized that subjects in both groups would show significant reductions in burst duration of sEMG activity during swallowing, and no significant changes in mean amplitude and time to peak amplitude.

Our results revealed no significant changes post-exercise in any of our three outcome variables. This may sound surprising as biomechanical gains have been shown in this sample post-exercise (Fujiki et al., 2019a); however, these findings align with the results of prior studies in physical therapy literature. In these studies, young adults with neck-shoulder pain as well as healthy control groups performed daily exercise and neuromuscular control measures during functional tasks were compared pre- and post-exercise (Seitz et al., 2019; Tsang et al., 2018). Similar to our findings, results from the healthy control groups showed that sEMG amplitude during functional tasks did not significantly change post-exercise (Seitz et al., 2019; Tsang et al., 2018). However, kinematic and biomechanical improvements, such as increased force and velocity of arm movement for functional tasks, were seen in the control groups (Tsang et al., 2018). To our knowledge, only one prior study has investigated how the HLE affects swallowing muscle activity during functional swallowing tasks with sEMG in older adults. Poorjavad and colleagues (2019) found reduced duration of muscle activation during swallowing with thin liquids. Although trends were observed, time to peak amplitude and mean amplitude did not significantly change post-exercise. Similar to Poorjavad and colleagues, we found no differences in time to peak amplitude and mean amplitude in our sample. However, we also found no differences in duration of submental muscle activity post exercise and we overall saw increased variability among subjects.

There are several possible interpretations of our results. First, our findings, paired with the improvements seen in biomechanical measures in this sample (Fujiki et al., 2019a) may suggest improved swallowing function without the need of the underlying musculature to produce more effort (Fujiki et al., 2019a; Seitz et al., 2019; Tsang et al., 2018). This aligns with results from previously discussed studies from the physical therapy literature (Seitz et al., 2019; Tsang et al., 2018). However, given the large variability seen within subjects another possible explanation could be that different mechanisms were used across participants to achieve the established biomechanical gains (e.g., decreased effort or decreased reaction time, etc.) (Gabriel et al., 2006; Sale, 1988). To further explore this possibility, we completed correlation analysis between the percent change values of all sEMG outcome measures from pre- to post-exercise time points. As seen in the correlation analysis, there was a strong negative relationship between percent change in normalized amplitude and percent change in time to peak amplitude (Figure 10). This suggests that participants who required less effort post-exercise needed more time to reach that effort (peak amplitude). However, participants who required more effort post-exercise were faster to reach that effort (peak amplitude). This inverse relationship may indicate that participants use differential neuromuscular mechanisms to achieve biomechanical gains post-exercise (Gabriel et al., 2006; Sale, 1988) and warrants further investigation.

Finally, it is also likely that the muscles investigated in this study are not the sole muscles driving the biomechanical gains. Although these exercises were developed to target the submental muscles, other muscle groups also contribute to hyolaryngeal excursion. Pearson and colleagues showed no differences in the ability of the submental muscles and long pharyngeal muscles to displace the hyolaryngeal complex (Pearson et al., 2012). However, the submental muscles paired with the stylohyoid and posterior digastric muscles have a greater potential to displace hyolaryngeal complex (Pearson et al., 2012). In this study, activity was limited to the submental muscles based on the placement of sEMG sensors and thus may not appropriately capture changes in other muscles contributing to hyolaryngeal excursion. Additionally, individual muscles within the submental muscle group contribute to hyoid excursion differently and may be differently targeted by the current exercise protocols (Pearson et al., 2011). Surface EMG recordings collect information from the submental muscles as a group and may miss detailed information about how each submental muscle is affected by these exercise protocols.

Our second aim was to determine differences in the neuromuscular control of swallowing between the two exercise groups. We hypothesized similar neuromuscular effects across both exercise groups (Fujiki et al., 2019a; Mishra et al., 2015), and our findings supported this hypothesis. Specifically, no differences in sEMG outcome measures were seen between exercise groups in this sample of participants. This finding is in agreement with our prior work showing similar neuromuscular effects of both exercises in healthy young adults (Mishra et al., 2015) and similar biomechanical gains in healthy elders (Fujiki et al., 2019a). Our results align with these prior studies and provides further support that the RE and HLE affect these muscle groups similarly.

To better understand the present results, changes in neuromuscular control measures should further be correlated with changes in biomechanical measures post-exercise. Additionally, future studies should investigate changes in additional muscle groups, for example through morphometric analysis, post-exercise to elucidate mechanisms contributing to biomechanical gains beyond the submental muscles. Finally, a larger randomized clinical trial including patients with dysphagia should be conducted in the future to further elucidate both neuromuscular and biomechanical changes post-exercise in patient populations.

Limitations

This study has limitations, which should be considered when interpreting the results. We acknowledge that this is a small-scale randomized clinical trial with a small sample size and even smaller sample size at the final follow-up time point. Additionally, this study did not include a control group. Although sEMG measures are not likely influenced by the placebo effect, this should still be considered, and a control group should be included in future studies. Finally, this sample only included healthy older adults. Although age-related changes in swallowing and neuromuscular control have been established, the sample was healthy, and effects of these exercises need to be better understood in patients as well.

Conclusion

In this study our main aim was to determine the effects of the HLE and RE on the neuromuscular control of swallowing post-exercise completion in order to help clinicians best determine the patient types and/or deficits most likely to benefit from these exercises. Our findings showed that in our sample of healthy older adults, there were no significant differences in surface electromyography measures during functional swallowing tasks after the HLE and/or the RE regimens. These results paired with the biomechanical gains that have already been documented for this sample (Fujiki et al., 2019a) could suggest that these participants exhibited improved function of their swallowing mechanism (i.e., biomechanical gains) without the need of the underlying musculature to produce significantly more effort. However, the large variability seen within subjects and the strong negative relationship we found between percent change in normalized amplitude and percent change in time to peak amplitude from pre-to post-exercise time points could further indicate that differential mechanisms were used across participants to achieve the documented biomechanical gains. That is, some participants may have produced decreased effort post-exercise while making biomechanical gains, while some other participants may have been able to achieve these gains with increased effort but decreased reaction time. Finally, since hyolaryngeal excursion is only partially achieved by contraction of the submental muscles future work on investigating other muscle groups important to this event is warranted. Although these findings provide some first insights into the underlying neuromuscular effects of these two exercise regimens in healthy older adults, further research is needed to further elucidate these findings.

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