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Ultrasonography as Biofeedback to Increase Muscle Activation During the Mendelsohn Maneuver in Healthy Adults

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ULTRASONOGRAPHY AS BIOFEEDBACK TO INCREASE MUSCLE ACTIVATION DURING THE MENDELSOHN MANEUVER IN HEALTHY ADULTS

by

Ching-Hsuan Peng

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ABSTRACT

ULTRASONOGRAPHY AS BIOFEEDBACK TO INCREASE MUSCLE ACTIVATION DURING THE MENDELSOHN MANEUVER IN HEALTHY ADULTS

by

Ching-Hsuan Peng

The University of Wisconsin-Milwaukee, 2021
Under the Supervision of Professor Barbara Roa Pauloski, Ph.D., CCC-SLP

The purpose of this study was to examine the effect of applying real-time ultrasound as visual feedback in addition to verbal instruction/tactile feedback to facility the accuracy of learning the Mendelsohn maneuver. The Mendelsohn maneuver is one of the commonly used swallowing exercises targeting hyolaryngeal elevation and prolonging upper esophageal sphincter opening during swallow. It was hypothesized that the additional visual cueing provided by ultrasound would significantly increase sEMG activity which may be associated with increased duration and extent of hyolaryngeal elevation during the Mendelsohn maneuver as compared to the effect of verbal instruction/tactile feedback alone. A total of twenty-four healthy adults aged between 20 and 59 years were randomly assigned into training with ultrasound biofeedback versus training with verbal instruction/tactile cueing groups. Outcomes were measured via sEMG before and after training. Statistical analysis of the data with three-way repeated measures ANOVA revealed both ultrasound feedback and traditional cueing were effective for teaching the Mendelsohn maneuver. However, there were no significant differences between the two groups in maximum amplitude of sEMG, sEMG duration, and the area under the curve of sEMG signal when performing swallows with the Mendelsohn maneuver. Although the findings do not demonstrate that the addition of ultrasound biofeedback in training will significantly increase the electromyographic outcomes when performing the Mendelsohn maneuverer, it is still an effective and feasible tool for learning a new swallowing maneuver.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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Introduction

Normal Swallow Function and Dysphagia

Swallowing is an essential function for human beings to maintain nutrition and hydration. It involves voluntary and reflexive physiologic processes to transport the food from placement in the mouth through the oral cavity, pharynx, upper esophageal sphincter, and into the esophagus. Swallowing is commonly divided into 4 phases: oral preparatory phase, oral phase, pharyngeal phase, and esophageal phase. During the oral preparatory phase, food or liquid is manipulated into a cohesive bolus and prepared for transport to the back of the mouth; this transport is the oral phase. During the pharyngeal phase, the bolus is propelled and transferred through the pharynx and upper esophageal sphincter (UES) into the esophagus. During the esophageal phase, the bolus passes through the esophagus and into the stomach.

There are five crucial physiologic mechanisms that make the pharyngeal swallow efficient and safe: velopharyngeal closure, hyoid bone and laryngeal elevation, laryngeal closure, cricopharyngeal opening, and tongue base to pharyngeal wall contraction (Dodds, Stewart, & Logemann, 1990; Matsuo & Palmer, 2008; O'Kane, Groher, Silva, & Osborn, 2010). The contraction of the suprahyoid muscles exert anterior and superior traction on the hyoid bone. This traction occurs concomitant with laryngeal elevation due to the connection of the thyrohyoid muscle between the hyoid bone and thyroid cartilage. The suprahyoid muscles are the mylohyoid, geniohyoid, anterior and posterior bellies of the digastric, and stylohyoid. Studies have found that these muscles produce the force to elevate the hyolaryngeal complex in anterior and superior dimensions of displacement (Pearson, Hindson, Langmore, & Zumwalt, 2013; Pearson, Langmore, Yu, & Zumwalt, 2012). Jacob, Kahrilas, Logemann, Shah, and Ha (1989) found that the UES relaxed but did not open until substantial anterior and superior laryngeal elevation occurred. The change of the displacement of the laryngeal elevation correlated inversely with UES pressure. These results indicate that hyolaryngeal excursion contributes to UES opening. After the bolus passes through the UES, gravity and peristalsis assist the bolus movement down to the stomach.

Any abnormal structural or functional deficit of the swallowing-related muscles and nerves will result in swallowing problems, also known as dysphagia. It is estimated that about 1 in 25 adults in the United States have swallowing problems annually. Based on the National Health Interview Survey (NHIS) conducted by the National Center for Healthcare Statistics of the Centers for Disease Control, dysphagia affects approximately 9.44 million adults (Bhattacharyya, 2014). Stroke, neurologic disease, and head and neck cancer are common causes of dysphagia. The elderly are more vulnerable to swallowing-related problems (Sura, Madhavan, Carnaby, & Crary, 2012). These problems interfere with swallowing efficiency and safety, which result in individuals with dysphagia having high risk of malnutrition, dehydration, and aspiration pneumonia, which may be fatal. Dysphagia may result not only in physical and functional impairment, but also in psychosocial functioning. Multiple studies have shown that swallowing difficulty negatively impacts quality of life across different populations (Nguyen et al., 2005; Paris et al., 2013; Plowman-Prine et al., 2009; Silveira, Dedivitis, Queija, & Nascimento, 2015; Yi, Oh, Seo, Shin, & Bang, 2019).

Mendelsohn Maneuver

Depending upon the cause and the physiology of the swallowing disorder, several swallowing rehabilitation maneuvers may be implemented to improve impaired swallowing function. The Mendelsohn maneuver is one of the therapeutic strategies that is commonly used in clinical practice, aiming to target reduced laryngeal elevation which may result in reduced UES opening with accompanying pyriform sinus residue which may be aspirated. The maneuver requires an individual to voluntarily prolong the elevation of the larynx at the highest position while swallowing forcefully. The prolonged contraction of suprahyoid muscles pulls the hyoid bone and larynx upward and forward for a longer duration (Kahrilas, Logemann, Krugler, & Flanagan, 1991) and greater displacement (Inamoto et al., 2018). The efficacy of the Mendelsohn maneuver has been tested and analyzed across healthy adults and various patient populations (Lazarus, Logemann, & Gibbons, 1993; McCullough et al., 2012; Prosiegel, Heintze, Sonntag, Schenk, & Yassouridis, 2000). Doeltgen, Ong, Scholten, Cock, and Omari (2017) ultilized surface electromyography (sEMG) and high-resolution impedance manometry (HRM) to investiage the efficacy. They reported an immediate effect of increased peak pharyngeal pressure, faster onset of upper esophageal sphinctor (UES) opening, and increased submental sEMG amplitude. The Mendelsohn maneuver has also been found to reduce upper esophageal sphincter (UES) pressure (Hoffman et al., 2012). A recent study conducted by Inamoto et al. (2018) that used three-dimensional computed tomography to study the Mendelsohn maneuver revealed longer duration of laryngeal vestibule closure, increased hyoid excursion, maximum hyoid displacement, and greater pharyngeal constriction.

Biofeedback Methods

Teaching clients to perform the Mendelsohn maneuver is sometimes difficult, especially for clients with cognitive deficits or receptive language impairments. The Mendelsohn maneuver requires the individual to consciously manipulate laryngeal excursion. Gross and fine movement control relies on proprioceptive signals (internal feedback) from joints, muscles, and skin. Human beings monitor the path of movement by receiving proprioceptive messages, then adjust the force, direction, and position accordingly (Proske & Gandevia, 2012). Verbal instruction and tactile cueing are types of external feedback which are provided by the clinician to enhance the efficiency and effectiveness of learning new skills. External cueing directing attention externally to the targeted muscle, movement, or position may result in better outcomes on accuracy, efficiency, force, and coordination (Wulf, 2013). Biofeedback is known as one type of external feedback using an instrument to provide visual feedback on specific kinematic performance or biomedical variables. The use of biofeedback enhances the awareness of the physical movement which enables the individual to have the possibility of self-control and manipulation of their movement (Mulder & Hulstyn, 1984). Accelerometry, tongue manometry, and surface electromyography (sEMG) are the three main types of biofeedback employed in swallowing rehabilitation (Benfield, Everton, Bath, & England, 2019).

Accelerometry

Accelerometry is used rarely with dysphagia. Li et al. (2016) reported the outcomes of using accelerometry in swallowing therapy. The authors measured the acceleration of laryngeal elevation and displayed real-time outcomes with game-based biofeedback. They reported significantly improved functional diet level and laryngeal elevation in those participants who used the accelerometer biofeedback.

Tongue Manometry

The most common device used for tongue manometry is the Iowa Oral Performance Instrument (IOPI) (Benfield et al., 2019). The IOPI is designed to measure both tongue strength and endurance (Crow & Ship, 1996). The light indicator on the IOPI can be used as additional visual feedback in tongue resistance exercises. A certain level of maximal pressure will be set, and the user will be asked to press hard enough to keep the light lit. Steele et al. (2016) compared tongue resistance exercise with or without utilizing tongue manometry in a randomized controlled study. They found there was no significant difference in tongue strength, reduction in risk of penetration or aspiration, or amount of residue in the valleculae between those who did and did not use the IOPI for biofeedback. Lazarus, Logemann, Huang, and Rademaker (2003) reported similar results: Participants who used the IOPI for biofeedback did not demonstrate significantly greater tongue endurance and amplitude over those who did not use the IOPI for biofeedback. Park, Kim, and Oh (2015) also reported there were no significant differences in tongue strength and swallowing function measured by a videofluoroscopic dysphagia scale after using the IOPI for biofeedback. The data are limited to indicate that tongue manometry can be an effective biofeedback tool to increase swallowing treatment efficacy.

Surface EMG

Surface EMG allows the clinician and the patient to gain immediate information on muscle contraction amplitude by measuring the electrical activity generated by muscle action potentials. Meta-analyses and systematic reviews have shown effectiveness in improving musculoskeletal function using sEMG (Giggins, Persson, & Caulfield, 2013; Wasielewski, Parker, & Kotsko, 2011). Researchers have investigated sEMG biofeedback employed in swallowing rehabilitation. Crary and Groher (2000) introduced a tutorial for using sEMG as biofeedback in dysphagia rehabilitation. The tutorial was based on the findings from the authors’ previous studies in which more than 700 swallows were investigated (Crary, 1995; Crary & Baldwin, 1997). The authors suggested appropriate electrode placement, patient selection, amplifier and filter settings, as well as provided interpretation of normal and abnormal sEMG activity. Some positive outcomes have been demonstrated in patients’ swallowing function using sEMG biofeedback such as improved functional diet level, improved swallowing coordination, increased duration of swallowing (longer duration of myoelectric activity of swallowing muscles), and increased average and peak myoelectric activity (Bogaardt, Grolman, & Fokkens, 2009; Crary, 1995; Huckabee & Cannito, 1999). However, the study designs represented lower levels of evidence (e.g., retrospective case series rather than randomized trials). In addition, most of the studies only reported the functional performance change in terms of diet level instead of showing evidence of physiologic change in the swallow. McCullough and Kim (2013) taught the Mendelsohn maneuver with sEMG biofeedback to participants who were diagnosed with dysphagia secondary to stroke. Archer, Smith, and Newham (2021) also reported significantly greater sEMG amplitude while applying sEMG feedback on healthy older adults. The results support that applying biofeedback during teaching of swallowing exercises and maneuvers is feasible and effective.

Ultrasound

Ultrasound imaging (sonography) uses high-frequency sound waves above 20,000 Hz to visualize structures within the body. Ultrasound has been widely used as a non-invasive and harmless diagnostic imaging technique to capture real-time images of soft tissues such as muscles, circulatory systems, and organs (Hoskins & Kenwright, 2015; Peetrons, 2002; Sigrist, Liau, Kaffas, Chammas, & Willmann, 2017). Lingual movement, submental muscle, and pharyngeal and laryngeal functions are among the most common areas where ultrasound imaging is used for assessing swallowing function (Hsiao, Wahyuni, & Wang, 2013; Leite, Mangilli, Sassi, Limongi, & Andrade, 2014). Peng, Miethke, Pong, and Lin (2007) applied a combination of B-mode and M-mode ultrasonography to assess the speed, duration, and range of motion of the tongue during swallowing in healthy adults. The authors stated that ultrasound provided useful information for evaluating tongue movement. Ultrasound was also found to be an accessible method for measuring the diameter of the UES opening during swallowing (Morinière et al., 2013). In a meta-analysis, Leite et al. (2014) found that hyoid bone movement could reliably be evaluated with ultrasound. Chen, Hsiao, Wang, Fu, and Wang (2017) compared the results observed in the modified barium swallowing study (MBS) to test the reliability and feasibility of evaluating hyoid bone displacement using ultrasonic imaging. The authors reported a high intrarater coefficient and interrater coefficient between MBS and ultrasonography. Kuhl, Eicke, Dieterich, and Urban (2003) used B-mode with a 7.5 MHz linear transducer to capture the distance between hyoid bone and thyroid for measuring laryngeal elevation. The amplitude of laryngeal elevation was found significantly different between healthy adults and people with dysphagia. Another study evaluated hyoid bone elevation during deglutition in different ages (Yabunaka et al., 2010). By capturing dynamic phase images and analyzing the movement of the hyoid bone, the authors found that ultrasonography is a useful tool to visualize hyoid bone movement.

Most studies using ultrasound focus on the evaluation of swallowing function. There are only limited numbers of studies that investigate the efficacy of applying ultrasonography as biofeedback in swallowing rehabilitation. Blyth, McCabe, Madill, and Ballard (2017) conducted a single-case design experimental study using sonography as visual biofeedback in the swallowing treatment for two patients with partial glossectomy. The participants were trained to identify the landmarks and movement of the tongue during swallowing. They were provided visual feedback from ultrasound and verbal feedback from the clinician during swallowing trials. Ultrasound was used for the first 10 trials of each target food consistency to provide additional feedback of the tongue movements so that the patients could adjust oral movement to improve their bolus control. Patients received a modified barium swallowing study pre-treatment and post-treatment to observe parameters such as the duration of bolus transit, frequency of anterior oral spillage, and signs of penetration or aspiration. The authors reported that the participants significantly reduced bolus transit duration and improved Functional Oral Intake Scale scores after training oral tongue movements with biofeedback with ultrasound.

Although studies have proven that ultrasound is a feasible and useful tool for analyzing the laryngeal elevation, pharyngeal wall movement, and UES opening, as well as a tool for biofeedback for oral tongue movements, the utility of ultrasonography biofeedback in swallowing treatment targeting the pharyngeal phase has not yet been examined extensively. A recent study investigated the accuracy of performing the Mendelsohn maneuver after learning and practicing with either sEMG or ultrasound (Kwong, Ng, Leung, & Zheng, 2020). The authors randomly assigned participants into the sEMG group and the ultrasound group. The two groups were all given an introduction and demonstration for performing the

Mendelsohn maneuver and then assigned a biofeedback technique. All participants were required to achieve an 80% accuracy rate performing the Mendelsohn maneuver with their biofeedback technique before they received the post-assessment after a two-week rest period. In the post-assessment, participants performed the Mendelsohn maneuver without biofeedback for ten trials. All trials were recorded via ultrasound and analyzed by a final year graduate speech pathology student who was blind to the participants' training condition. The study found that the ultrasound group had a better level of acquisition of the Mendelsohn maneuver compared to sEMG group.

Purpose of the study

Kwong, et al. (2020) assessed the efficacy of ultrasound as a biofeedback technique after a two-week training period. It would be useful to know whether clients are able to learn the Mendelsohn maneuver using ultrasound as a biofeedback technique within a shorter time frame such as one would have during a swallowing therapy session. The purpose of the present study is to see whether using ultrasonography as biofeedback in support of instruction of the Mendelsohn maneuver increases activation of the submental musculature as measured by sEMG within a single training session. The present study aims to examine the effect of applying real-time ultrasound as visual biofeedback to facilitate the accuracy of learning the Mendelsohn maneuver. It was hypothesized that the additional visual cueing provided by ultrasound would significantly increase sEMG activity which may be associated with increased duration and extent of hyolaryngeal elevation during the Mendelsohn maneuver. The study results will indicate whether ultrasound is an effective and applicable biofeedback tool to assist clinicians in teaching the Mendelsohn maneuver.

This study was designed to answer the following research questions:

Research question 1: Does training with feedback increase the effectiveness of the Mendelsohn Maneuver as assessed by sEMG?

Research question 2: Does feedback with ultrasound increase the effectiveness of the Mendelsohn maneuver as assessed by sEMG more than verbal/tactile feedback?

Methodology

This study is an unblinded prospective mixed design with subjects randomized to two-parallel groups. The standard care group, henceforth called the control group, received verbal instruction, verbal reinforcement, and tactile cueing while practicing the maneuver. The experimental group also received verbal instruction, verbal reinforcement and tactile cueing with additional real-time ultrasound images as visual kinematic biofeedback. Both groups were measured at two time points: baseline and after training while completing saliva swallows and water swallows. Therefore, this study involved four independent variables (IVs): Study Group (control, experimental; a between-subjects IV), Bolus Type (saliva, water; a within-subjects IV), Condition (no maneuver, Mendelsohn maneuver; a within-subjects IV) and Evaluation Point (baseline assessment, post-training assessment; a within-subjects IV). Three dependent variables measured in this study were maximum amplitude of submental sEMG signal during target swallows, duration of the muscle activity captured by sEMG during target swallows, and integrated area under curve (AUC) of the sEMG signal during target swallows.

Subjects and Recruitment

The study targeted enrollment of 24 healthy adults aged from 20 to 65 years. Participants were recruited via multiple methods including posting flyers on the bulletin board at the UWM Student Union, posting the recruitment information on Facebook pages, and sending an email with research recruitment information to a student group in the health sciences. As an incentive for recruitment, participants were offered a $20 Visa gift card upon completion of the study. Interested participants contacted the student principal investigator for additional information concerning the study and to schedule a screening interview.

Eligibility criteria included:

- Age between 20 years and 65 years. Persons older than 60 years of age were considered at higher risk for complications of COVID-19 and were initially restricted from research participation by the UWM Institutional Review Board. The upper age limit was raised due to the loosening of COVID restrictions regarding the age of research participants during the course of this study. The amendment of upper age limit to 65 years was approved by the UWM Institutional Review Board.
- No history of surgery to the head and neck region with the exception of rhinoplasty, tonsil or adenoid removal, or dental extractions.
- No history of swallowing, neurological, or gastrointestinal disorders.
- No self-report of current swallowing problems.
- A score less than 3 in the Eating Assessment Tool (EAT-10) (Belafsky et al., 2008). The EAT-10 was used as a screening tool to exclude participants who have current swallowing problems. EAT-10 is a self-administered instrument which is widely used as a dysphagia screening on a wide variety of patients with dysphagia (Arslan, Demir, Kılınç, & Karaduman, 2017; Plowman et al., 2016). It is a questionnaire

consisting of 10 items rated on a 5-point scale, with each question scoring from 0 (no problem) to 4 (severe). Normative data suggest that individual scores of 3 or above are abnormal (Belafsky et al., 2008).

- Because the Mendelsohn maneuver places some demands on the respiratory system, persons with COPD or other respiratory issues were excluded.
- Persons with graduate-level coursework in the anatomy and physiology of the oropharyngeal swallowing mechanism were excluded because of the potential advantage they may have in understanding the mechanics of the Mendelsohn maneuver.

After passing the screening procedures, participants were provided with an explanation of the study procedures as well as possible risks and benefits. After having an opportunity to ask all questions, participants provided written consent. Individuals with facial hair were informed that they would need to shave the submental area in order to participate so that proper placement of the sEMG electrodes could be achieved.

Sella, Jones, and Huckabee (2014) found age-related differences in sEMG activity of the submental muscles during swallowing but no gender effects on sEMG peak amplitude. Therefore, eligible participants were randomly assigned to either the experimental group or the control group with stratification by age. The participants were divided into two strata: 20

to 39-year-old participants and 40 to 65-year-old participants. Gender was not used as a randomization stratum.

Study Arms

The control group received verbal instruction with verbal feedback and tactile cueing, whereas the experimental group received verbal instruction, verbal feedback, tactile cueing and visual feedback from ultrasound. Details of the training phase for each group are detailed in section titled “Study protocol, Training Phase.”

Study Protocol

Before entering the lab, all personnel and participants engaged in COVID-19 precautions including temperature screening and hand sanitizer use. All laboratory surfaces and equipment were disinfected with university-approved products between data collection sessions. Research personnel wore gloves and face shields while participating in study procedures. All subjects and research personnel wore masks during the entire session.

Each participant completed a single 45- to 60-minute session which consisted of three phases: baseline assessment phase, training phase, and post-training assessment phase.

Baseline Assessment Phase: In the baseline assessment phase, subjects in both arms were instructed to complete five saliva swallows and five 5 ml thin liquid swallows via a straw. For the saliva swallows, participants were given instruction to “swallow as you typically do” on every trial. For the 5 ml thin liquid swallows, participants were given instruction to “Take as sip, hold in your mouth. Don’t swallow until I ask you to do so” on every trial. The student investigator gave the instruction to swallow once the sEMG signal return to resting baseline after sipping the water. Participants were asked to do one swallow every 30 seconds and repeat 5 times each. This protocol was consistent with the one used by Steele et al. (2012). In order to minimize the potential for an order effect of performing the two assessment tasks (saliva swallows and 5 ml thin liquid swallows), the sequence of the tasks was counterbalanced.

Training Phase: During the training phase, all participants in the two study groups were taught the Mendelsohn maneuver with written instruction as provided in Appendix A, as well as verbal instruction and tactile feedback via laryngeal palpation. Participants were asked to feel the upward movement of the laryngeal prominence while swallowing normally. Every participant received the same instruction as indicated below and included in Appendix B:

> "When we swallow, our voice box moves upwards and forward. It is a swallowing mechanism that helps us to clear the food in our pharynx. Now put your fingers on your voice box and feel your Adam's apple lift up as you swallow your saliva. Now, swallow again. When you feel the voice box lift up, squeeze the muscles in the throat to hold the Adam's apple up, and don't let it drop for as long as you can. Did you feel your Adam's apple up for a longer duration compared to your saliva swallow? You can always use your finger to assist you to feel the elevation."

The experimental group received all the instructions that the control group received as well as concurrent biofeedback during the training phase with ultrasonography. The Mindray

Z6 Diagnostic Ultrasound System (Shenzhen Mindray Bio-Medical Electronics, Shenzhen, China) with a 40 mm linear transducer, model 7L4P, set at 7.5 MHz was used in the study. The transducer was placed in the midsagittal plane along the submental area and anterior neck, between the mandibular symphysis and the hyoid bone (Figure. 1). The mandible bone (Figure. 2a) and hyoid bone (Figure. 2b) can be visualized as two distinct hyperechoic plaques with an acoustic shadow and were used to assist in orienting the participant to the ultrasound image. Ultrasound gel (Parker Laboratories, New Jersey) was used to eliminate air and form a bond between skin and transducer to facilitate image quality.

Figure 1. The positioning of the transducer

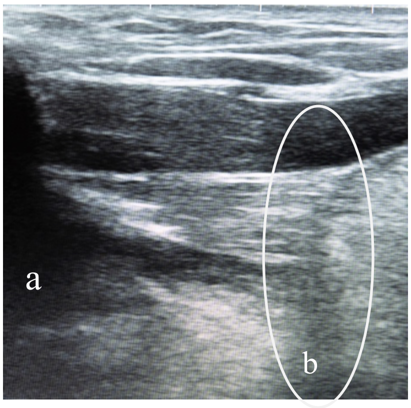


Figure 2a. Shadow cast by the mandible bone shown on ultrasonography image

Figure 2b. Shadow cast by the hyoid bone shown on ultrasonography image

The experimental group was trained to identify the location of the mandible and hyoid bone as well as perceive hyolaryngeal excursion movement on the ultrasound images.

Subjects were instructed to observe and explore the hyolaryngeal displacement difference between the normal swallow and the Mendelsohn maneuver on the ultrasound image. The script for training with ultrasound biofeedback is included in Appendix C.

Both groups were asked to practice the Mendelsohn maneuver for 2 sets of 10 repetitions. Participants were provided verbal cues of whether the kinematics of the maneuver were accurate and verbal reinforcement to encourage the participants to hold the movement for a longer duration. Participants took a 3-minute rest between practice sets. The rest interval was based on the recommendation for muscle resistance training (Freitas de Salles et al., 2009; Willardson, 2008).

Post-Training Assessment Phase: During the post-training assessment, participants in each study arm were instructed to produce five saliva swallows, five swallows of 5 ml water via a straw, five saliva swallows with Mendelsohn maneuver, and five swallows of 5 ml water via a straw with Mendelsohn maneuver. Participants was asked to do one swallow every 30 seconds. Counterbalancing was used to reduce the potential sequencing effect in the post-training assessment.

Outcome Measures

Three dependent variables were measured in this study: sEMG duration, maximum amplitude of sEMG, and area under curve (AUC) of the sEMG signal. Surface EMG was used to quantify submental muscle activity during the baseline and the post-training assessments. sEMG graphic information was collected and stored using the Digital Swallowing Workstation ^{TM} (DSW) (Model 7200) and the KAY Swallowing Signals Lab (Model 7210) (Kay Elemetrics, Lincoln Park, NJ). Azola et al, (2015) indicated that an sEMG sampling rate of 10 kHz may improve hyolaryngeal kinematic and temporal correlation; however, equipment available for this study had a maximum sampling rate of 250 Hz. Because the sEMG signal was not being correlated with other physiologic signals in this study, the 250 Hz sampling rate was considered sufficient. sEMG signals were acquired from two circular Uni-Patch disposable EMG electrodes with 2.25-inch diameter and 3 Ag/AgCl snaps (Model 7500) (Covidien, Mansfield, MA) placed submentally on either side of midline. Each patch contains three electrodes: Two are recording electrodes and the third serves as ground. To ensure that placement was consistent across participants, the ground electrode was placed vertical to the outer edges of the eyes. The two recording electrodes were placed at the submental area parallel to the midline raphe of the mylohyoid muscle

(Figure. 3). The lower recording electrodes were attached above the thyroid cartilage. In order to acquire a reliable sEMG signal, an alcohol pad was used to clean the submental area and ensure the area was dry before the electrode patch was placed. Makeup removing wipes were provided for individuals who wear makeup. Persons with facial hair growth in the area were asked to shave.

Figure 3. The placement of the electrodes

Data were recorded simultaneously for left and right channels and stored in the DSW for analysis. Three dependent variable measurements were collected for each swallow on the DSW. The onset of the swallow was identified as the rapid increase in the sEMG signal above baseline after the researcher's instruction to swallow. The offset point of the swallow was identified where the sEMG signal decreased again to the resting baseline (Figure. 4). Once the swallow event was identified by manually placing the cursors at the onset and offset points, duration of the sEMG signal, the maximum amplitude, and the area under the curve

(AUC) were calculated by the DSW analysis software for both left and right sEMG channels (Figure. 5). The sEMG data obtained from five swallow trials in each swallow task was averaged for statistical analyses. Preliminary testing indicated that values between the left and right channels did not differ significantly, so the researchers chose to average both channels for the final outcome measures used for statistical analysis.

As an assessment of remeasurement reliability, 10% percent of the sEMG data were chosen at random and remeasured by the student principal investigator and thesis advisor. Intra-class correlations coefficients (ICC) were calculated for sEMG duration, peak sEMG activity, and sEMG AUC for both right and left channels on all trials of the randomly selected data sets. ICCs based on absolute-agreement using a 2 way-mixed-effects model with 95% confident intervals revealed excellent intrajudge reliability (Average ICC = 0.994) and interjudge reliability (Average ICC = 1) across all variables including right side and left side measurements of duration, peak sEMG signal, and area under the curve.

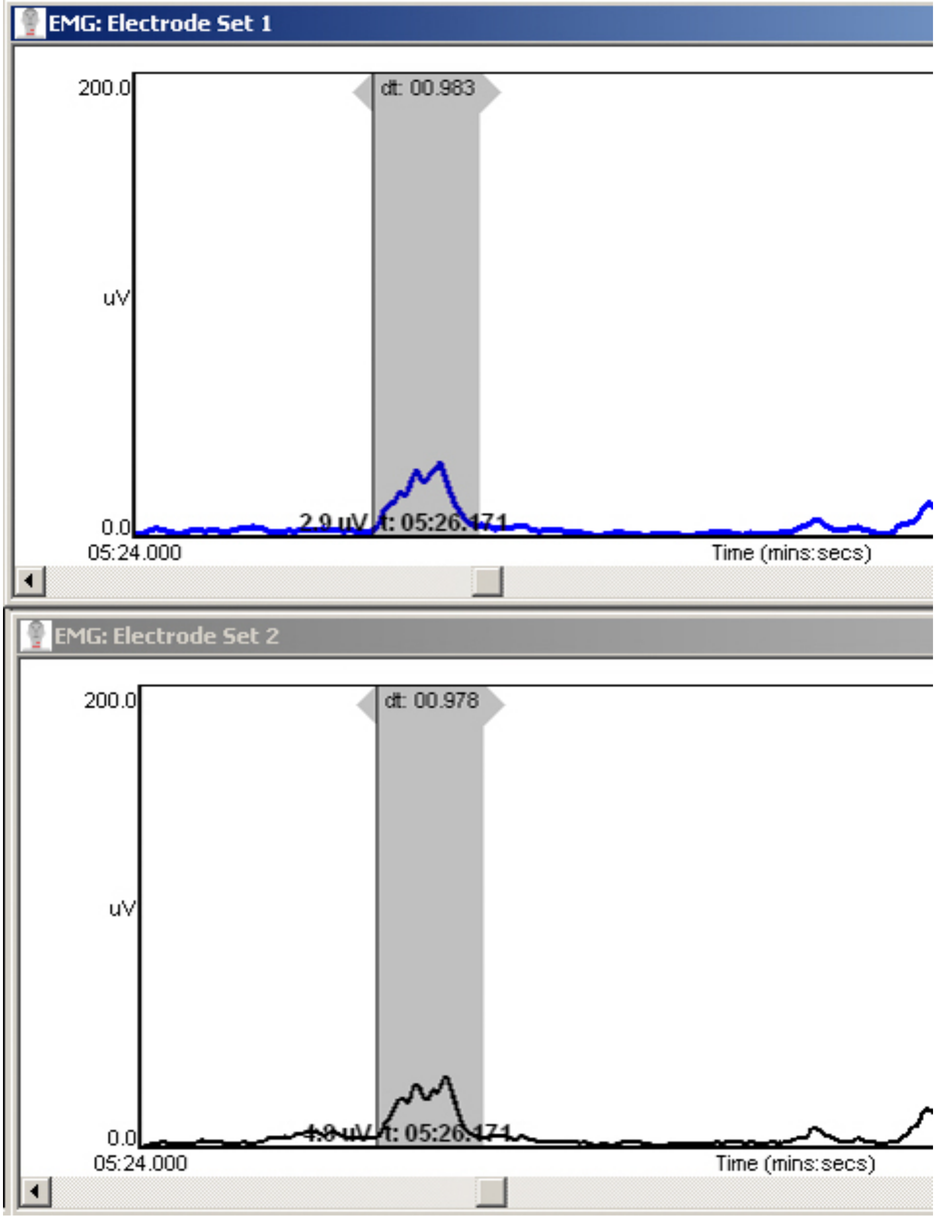
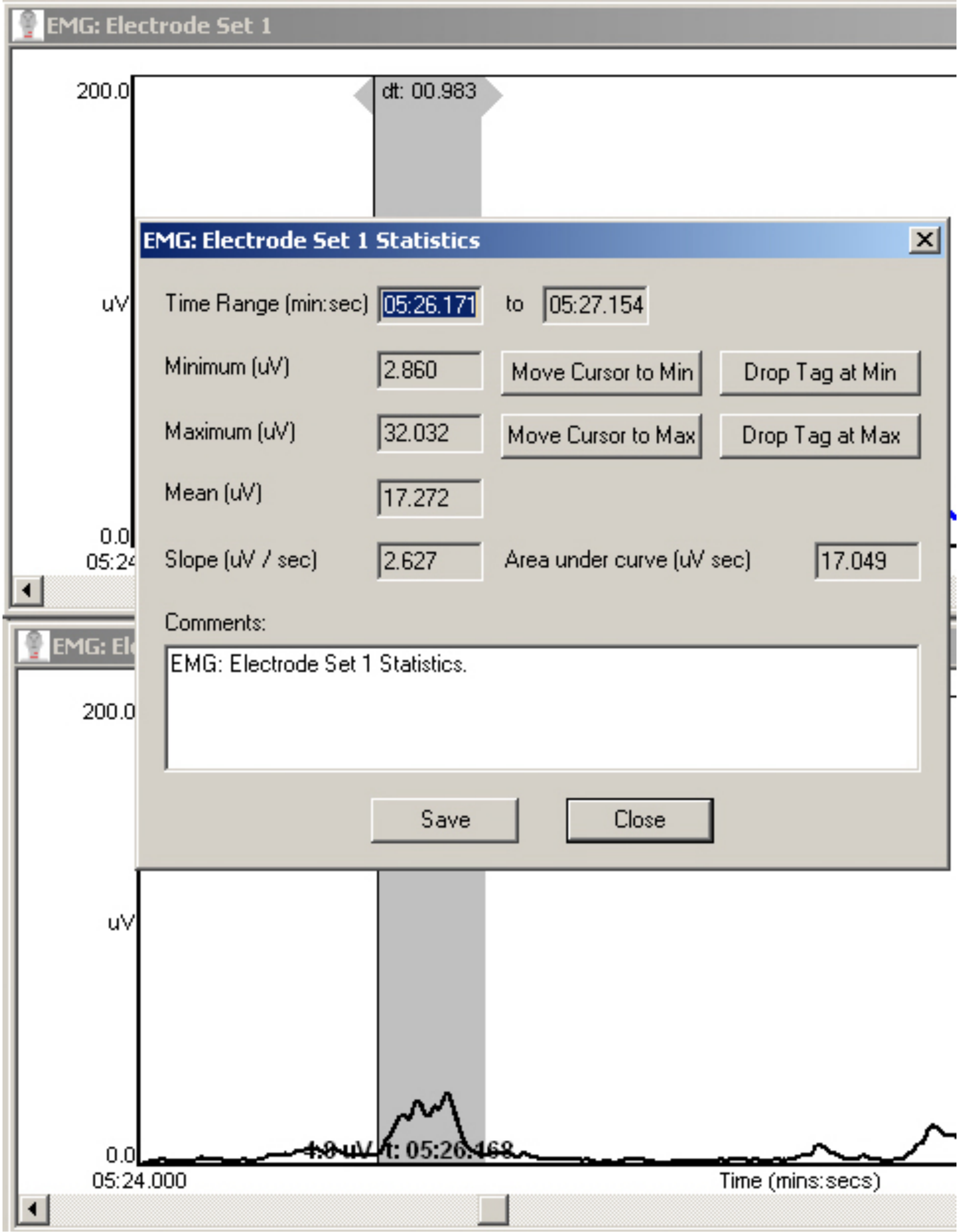


Figure 4. An identified swallow event

(Electrode set 1 = left channel, electrode set 2 = right channel, dt = duration)



Time Range (min:sec) 05:26.171 to 05:27.154

Minimum (uV) 2.860

Maximum (uV) 32.032

Mean (uV) 17.272

Slope (uV / sec) 2.627

Area under curve (uV sec) 17.049

Comments: EMG: Electrode Set 1 Statistics.

Figure 5. The maximum amplitude and area under curve calculated by DSW analysis software

Statistical Analysis

Statistical analysis was completed using SPSS statistical software (SPSS Statistics version 28.0, IBM, Chicago, IL). Descriptive statistics for sEMG maximum amplitude duration, and area under curve were reported with mean and standard deviation. To assess equality of the randomized groups at baseline, subject demographics (age and gender) and baseline sEMG activity were assessed with the appropriate parametric or non-parametric statistic. If any subject demographic or baseline data were significantly different between groups, then an analysis of covariance (ANCOVA) was planned using the significant variable or variables as covariates to adjust for group differences. If there were no significant differences between the two groups on subject demographics or dependent variables at baseline, a three-way mixed model repeated measure analysis of variance (ANOVA) was planned to determine whether training method (verbal/tactile only versus ultrasound) results in differences in sEMG activity when using the Mendelsohn maneuver.

Results

Participants

Twenty-six (26) participants were screened for the study. One participant was excluded due to an EAT-10 score higher than 3. One participant with facial hair in the submental area was consented but declined to shave his hair to continue the study. Twenty-four (24) healthy adults met the eligibility criteria and were randomized into the study. The experimental group consisted of 5 males and 7 females, aged between 20 and 54 years (mean = 28.08 years; SD = 8.618). The control group consisted of 2 males and 10 females, aged between 23 and 59 years (mean = 28 years; SD = 10.072).

Baseline Equivalence of Randomized Groups

An independent t-test was performed on age between the two randomized groups. There was no significant difference between the groups on age (t = .022, df = 22, p = .983). Fisher's Exact Test was used to determine equality of gender distribution between the randomized groups. There was no significant difference between the groups based on gender (p = .371). Therefore, the control and experimental group were equivalent on subject demographics.

To determine equivalence of the randomized groups on the dependent measures prior to training, baseline performance was evaluated as part of a three-way repeated measures ANOVA using evaluation point and bolus type as within-subjects independent measures and training group as the between-subjects independent measure. This approach controls the experiment-wide error rate while permitting interpretation of baseline comparisons in the instance of interactions between evaluation point and the other independent variables.

The results for the ANOVA for peak sEMG are summarized in Table 1 and results for sEMG AUC are summarized in Table 2. There were no significant interactions among group, evaluation, or bolus type and no main effect of group, indicating that peak sEMG activity and sEMG AUC were equivalent between the randomized groups at baseline.

Table 1. Baseline equivalence analysis for maximum amplitude of sEMG

Within-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Evaluation	6.711	1	6.711	.080	.780	.004
Evaluation X Group	8.680	1	8.680	.104	.750	.005
Bolus	15.876	1	15.876	.532	.473	.024
Bolus X Group	17.911	1	17.911	.600	.447	.027
Evaluation X Bolus	137.970	1	137.970	3.841	.063	.149
Evaluation X Bolus X Group	11.511	1	11.511	.320	.577	.014
Between-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	77.421	1	77.421	.101	.754	.05

Table 2. Baseline equivalence analysis for sEMG area under the curve

Within-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Evaluation	24.229	1	24.229	.954	.339	.042
Evaluation X Group	.546	1	.546	.021	.885	.001
Bolus	22.587	1	22.587	1.978	.174	.082
Bolus X Group	19.483	1	19.483	1.706	.205	.072
Evaluation X Bolus	26.998	1	26.998	2.315	.142	.095
Evaluation X Bolus X Group	6.145	1	6.145	.527	.476	.023
Between-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	.748	1	.748	.004	.952	.000

Results for the ANOVA for duration of sEMG are summarized in Table 3. There was a significant interaction between evaluation time and group; therefore in order to assess group equivalence, it was necessary to interpret the paired comparisons between groups separately by evaluation point. The mean difference between groups at baseline assessment or at post-training assessment for duration of sEMG was not significant (Table 4). These results indicated that the randomized groups were equivalent on all subject demographics and on the dependent variables at baseline. Therefore, no ANCOVA analysis was warranted to determine the primary study outcomes. Means and standard deviations for the dependent variables by group and bolus type at baseline are presented in Table 5.

Table 3. Baseline equivalence analysis for duration of swallow (* indicates p<0.05)

Within-Subjects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Evaluation	.067	1	.067	10.130	.004*	.315
Evaluation X Group	.040	1	.040	6.085	.022*	.217
Bolus	.072	1	.072	7.255	.013*	.248
Bolus X Group	.002	1	.002	.156	.697	.007
Evaluation X Bolus	.065	1	.065	3.553	.073	.073
Evaluation X Bolus X Group	.000	1	.000	.006	.941	.941
Between-Subjects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	.073	1	.073	.844	.368	.037

Table 4. Pairwise Comparisons of sEMG duration between groups at different evaluation point. (EG = experimental group, CG = control group)

Evaluation			**Mean difference (EG - CG)**	**Std. Error**	**Sig.**
Baseline	EG	CG	.014	.058	.812
Post-training	EG	CG	.096	.066	.159

Table 5. Mean +/- standard deviation of baseline performance by training group and bolus type. (SS = saliva swallow, 5 ml = 5 ml swallow, sEMG = maximum sEMG amplitude, AUC= area under the curve)

	Bolus type	**Experimental group**	**Control group**
Duration (sec)	SS	1.26 ± 0.19	1.25 ± 0 .66
	5 ml	1.26 ± 0.18	1.24 ± 0.17
sEMG (uV)	SS	31.96 ± 13.51	34.71 ± 13.80
	5 ml	35.10 ± 9.62	34.74 ± 17.81
AUC (uV Sec)	SS	19.76 ± 6.99	21.19 ± 8.07
	5 ml	21.26 ± 5.50	19.88 ± 9.33

Primary Analysis of Outcome Measurements

Means and standard deviations for the dependent variables by training group (control, experimental), bolus type (saliva, 5 ml water), and condition (no maneuver, maneuver) are presented in Table 6.

In order to determine the effect of training group on performance of the Mendelsohn maneuver, a three-way repeated measures ANOVA using condition (no maneuver swallow at baseline, Mendelsohn maneuver) and bolus type (saliva, 5 ml water) as within-subjects independent measures and training group as the between-subjects independent measure was performed for each dependent variable. The results for the ANOVA for duration of sEMG are summarized in Table 7. There were no interactions among the independent variables.

There was no main effect of training group, indicating that those who received biofeedback with ultrasound did not differ significantly in sEMG duration when compared to those who received verbal/tactile feedback only. There was a significant main effect for condition. Inspection of the means reveals that swallows performed with the Mendelsohn maneuver had significantly longer sEMG duration than those performed without the maneuver.

Table 6. Post-training performances in different swallow tasks. (Non-MM = No maneuver swallow at baseline, MM = Mendelsohn maneuver, SS = saliva swallow, 5ml = 5 ml swallow, sEMG = maximum sEMG amplitude, AUC= area under the curve)

Bolus type		**Experimental group**		**Control group**	
		Non-MM (baseline)	**MM**	**Non-MM (baseline)**	**MM**
Duration (sec)	SS	1.26 ± 0.19	8.33 ± 4.06	1.25 ± 0 .66	7.80 ± 5.77
	5 ml	1.26 ± 0.18	9.14 ± 3.84	1.24 ± 0.17	9.24 ± 7.18
sEMG (uV)	SS	31.96 ± 13.51	48.61 ± 23.7	34.71 ± 13.80	44.31 ± 32.39
	5 ml	35.10 ± 9.62	55.82 ± 33.36	34.74 ± 17.81	46.27 ± 31.47
AUC (uV Sec)	SS	19.76 ± 6.99	190.09 ± 223.44	21.19 ± 8.07	151.42 ± 166.37
	5 ml	21.26 ± 5.50	238.65 ± 295.59	19.88 ± 9.33	172.93 ± 191.42

Table 7. Results of ANOVA for sEMG duration comparing the pre-training no maneuver swallow to the post-training Mendelsohn maneuver (* indicates p < 0.05)

Within-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Bolus	8.291	1	8.291	3.255	.085	.129
Bolus X Group	.776	1	.776	.305	.586	.014
Condition	1314.391	1	1314.391	49.805	<.001*	.694
Condition X Group	.147	1	.147	.006	.941	.000
Bolus X Condition	8.370	1	8.37	3.234	.086	.128
Bolus X Condition X Group	.829	1	.829	.320	.577	.014
Between-Subjects Effect	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	0.204	1	.204	.008	.931	.000

The results for the ANOVA for peak sEMG activity are summarized in Table 8. There were no interactions among the independent variables. There was no main effect of training group, indicating that those who received biofeedback with ultrasound did not differ significantly in peak sEMG activity when compared to those who received verbal/tactile feedback only. There was a significant main effect for bolus condition and bolus type. Inspection of the means reveals that swallows performed with the Mendelsohn maneuver had significantly greater peak sEMG than those performed without the maneuver. In addition, swallows of 5 ml water had significantly greater sEMG than did swallows of saliva.

Table 8. Results of ANOVA for the maximum amplitude of sEMG comparing the pre-training no maneuver swallow to the post-training Mendelsohn maneuver. (* indicates p < 0.05)

Within-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Bolus	228.412	1	228.412	6.618	.017*	.231
Bolus X Group	104.663	1	104.663	3.033	.096	.121
Condition	5136.150	1	5136.150	9.793	.005*	.308
Condition X Group	395.954	1	359.954	.755	.394	.033
Bolus X Condition	54.048	1	54.048	1.104	.305	.048
Bolus X Condition X Group	6.789	1	6.789	.139	.713	.006
Between-Subjects Effect	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	197.286	1	197.286	.120	.732	.005

The results for the ANOVA for sEMG AUC are summarized in Table 9. There was no interaction of other independent variables with training group and no main effect of training group, indicating that those who received biofeedback with ultrasound did not differ significantly in sEMG AUC when compared to those who received verbal/tactile feedback only. There was a significant interaction between bolus type and condition, as well as significant main effects for both bolus type and condition. These results indicate that the effect of the Mendelsohn maneuver on sEMG AUC differed as a function of bolus type.

Figure 6 illustrates the interaction. Use of the Mendelsohn maneuver significantly increased sEMG AUC for both saliva and 5 ml water swallows, however the effect was much greater for the water swallow.

Table 9. Results of ANOVA for the area under the curve of sEMG comparing the pre-training no maneuver swallow to the post-training Mendelsohn maneuver (* indicates p < 0.05)

Within-Subjects Effects	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Bolus	7401.200	1	7401.200	7.340	.013*	.250
Bolus X Group	1337.964	1	1337.964	1.327	.262	.057
Condition	675374.855	1	675374.855	13.953	.001*	.388
Condition X Group	16363.811	1	16363.811	.338	.567	.015
Bolus X Condition	7325.103	1	7325.103	7.501	.012*	.254
Bolus X Condition X Group	881.220	1	881.220	.902	.352	.039
Between-Subjects Effect	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Group	16331.560	1	16331.560	.323	.575	.014

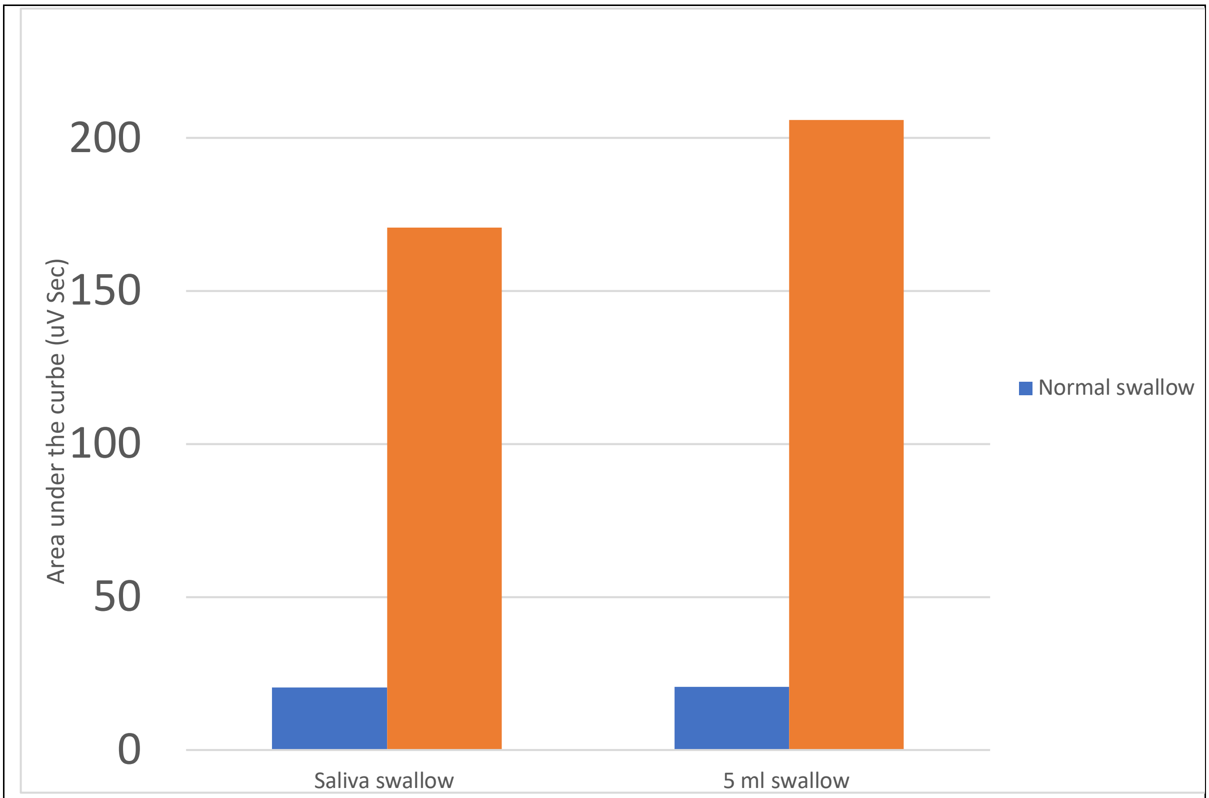


Figure 6. Interaction effect between bolus type and condition on sEMG AUC

Secondary Analysis of sEMG Duration

As reported previously, a three-way repeated measures ANOVA using evaluation point and bolus type as within-subjects independent measures and training group as the between-subjects independent measure was used during the assessment of group equivalence at baseline. Analysis of sEMG duration showed that there was a significant evaluation-by-group interaction effect (Table 3, $p = 0.22$), which indicated that the effect of evaluation points was different for the two groups. Participants in the control group demonstrated a decrease in swallow duration for both saliva swallows and 5 ml swallows after training. By contrast, the experimental group demonstrated increased duration after training for the saliva swallows but a decrease in duration for the 5 ml swallows. The main effect of bolus type showed that the duration of the 5 ml swallow was significantly less than saliva swallow regardless of group or evaluation point (*p* = .013). Table 10 summarizes the descriptive statistics for sEMG duration.

Table 10. Means and standard deviations for the experimental and control groups on sEMG duration for the no maneuver swallows at baseline and after training. (SS = saliva swallow)

Bolus type		**Experimental group**		**Control group**	
		Non-MM (baseline)	**Non-MM (post-training)**	**Non-MM (baseline)**	**Non-MM (post-training)**
Duration (sec)	SS	1.26 ± 0.19	1.30 ± 0.26	1.25 ± 0 .66	1.21 ± 0.15
	5 ml	1.26 ± 0.18	1.20 ± 0.18	1.24 ± 0.17	1.09 ± 0.10

Discussion

Interpretation of Results

This randomized controlled study evaluated the effect of ultrasound as an additional tool for learning the Mendelsohn maneuver. The outcomes were measured by the sEMG duration, maximum amplitude of sEMG signal, and the area under the curve. The study proposed two research questions to examine the effect. First, does training with feedback increase the effectiveness of the Mendelsohn maneuver as assessed by sEMG? Second, does feedback with ultrasound increase the effectiveness of the Mendelsohn maneuver as assessed by sEMG more than verbal/tactile feedback. The results of the current study indicated that training with feedback does increase submental sEMG activity during the Mendelsohn maneuver, however the addition of ultrasound as biofeedback to verbal instruction with verbal/tactile feedback did not significantly increase the duration and muscle activation when performing the Mendelsohn maneuver over verbal instruction with verbal/tactile feedback alone. This implies that the traditional teaching methods using the combination of different cueing such as modeling, verbal instruction, tactile feedback, visual cues, and verbal cues were sufficient for a healthy adult to learn and perform the Mendelsohn maneuver with accurate strength and form. Both training groups demonstrated significantly greater duration and muscle activity measured by sEMG when applying the Mendelsohn maneuver. This revealed that ultrasound feedback and traditional cueing were both effective for teaching the Mendelsohn maneuver. Some participants reported the ultrasound image was helpful to visualize the hyolaryngeal elevation during practice; however, another participant in the experimental group reported that the image was redundant since the verbal instructions were straightforward.

The present study also found significantly greater suprahyoid muscle activation when swallowing a larger bolus size with or without the maneuver. The volume of 5 ml water was considerably greater than the volume of an average saliva swallow, which is about 0.5 ml (Rudney, Ji, & Larson, 1995). There was significantly greater submental muscle activation which was driven by the larger bolus volume of the water trials, especially during the Mendelsohn maneuver.

Participants were instructed to "swallow as you typically do" on every trial during the baseline measurements and post-training measurement with non-Mendelsohn swallows. Compared to the results of baseline training, participants in the experimental group exhibited increased duration with saliva swallows after training, whereas the control group demonstrated decreased duration with both bolus types. It is unclear why the duration of post-training sEMG with normal saliva swallows in the experimental group was longer. The increase may have resulted from the carryover effect of training with biofeedback as participants were asked to watch the ultrasound image and practice the Mendelsohn maneuver with only saliva swallows during training phase.

Relationship of Results to Previous Research

The results of the current study support the observation by Macrae, Anderson, Taylor-Kamara, and Humbert (2014) that augmented feedback is essential in swallowing maneuver training. Verbal feedback and tactile feedback based on the knowledge of performance and knowledge of results were provided to both control group and experimental group by the researcher in the present study. The control group had similar levels of submental muscle activity outcomes when performing the Mendelsohn maneuver compared to the subjects who received the additional ultrasound feedback. The verbal and tactile feedback for the control group was sufficient for a healthy adult to make performance gains.

The results of the present study indicate that feedback with ultrasound was effective at training non-dysphagic healthy adults to produce the Mendelsohn maneuver, although it does not further facilitate the performance of the Mendelsohn maneuver over training with verbal instruction with verbal/tactile feedback. The success of ultrasound as a biofeedback method is consistent with the work of Kwong et al. (2020), who also suggested that application of ultrasound is an effective technique to learn the Mendelsohn maneuver. By contrast however, Kwong et al. (2020) found that feedback with ultrasound was significantly better than their comparator, feedback using sEMG. In addition, their primary outcome measure, the subjective accuracy rate of Mendelsohn maneuver assessed with ultrasound, was the same metric used for training the subjects. Kwong et al. (2020)'s conclusion was drawn by the subjective judgment on accuracy rate with reportedly “poor” intra-rater reliabilities for all the raters in the study. The current study relied on objective data that were not used for the training of the participants. These measures also had excellent intrajudge and interjudge reliability. The quality of the reliability in the Kwong et al. (2020) study as well as differences in study design limit direct comparison to the current study.

The results of this study showed maximum amplitude of sEMG and the duration were significantly higher with the Mendelsohn maneuver than with normal swallows. These findings are in agreement with previous studies (Ding, Larson, Logemann, & Rademaker, 2002; Doeltgen et al., 2017). Due to research methodology differences (i.e., electrode size and configuration, equipment, signal filtering and rectification), comparison of absolute magnitude to that reported in other studies is difficult. The relative change of submental sEMG activity between the Mendelsohn maneuver and normal swallow was compared to the findings from previous research. There was a 204% increase in maximum submental sEMG signal reported by Wheeler-Hegland, Rosenbek, and Sapienza (2008) and a 250% increase in maximum submental sEMG signal using the Mendelsohn maneuver with 5 ml viscous jelly by Doeltgen et al. (2017). Doeltgen et al. (2017) also reported a 750% increase with 5 ml viscous jelly in sEMG AUC. In contrast, the findings of the present study showed a 152% increase with saliva swallows and 159% increase with 5 ml thin liquids in maximum submental sEMG, but a 1194% increase with 5 ml thin liquids in sEMG AUC when using the Mendelsohn maneuver. The duration of the Mendelsohn maneuver was not reported by Wheeler-Hegland et al., (2008) or Doeltgen et al., (2017); therefore the results for sEMG duration from the current study could not be compared. The lower peak sEMG change observed in the current study was suspected to be secondary to the average longer prolongation of the Mendelsohn maneuver. The subjects could not maintain the high submental contraction while holding the maneuver for a relatively long time.

In this study, swallowing with a larger bolus volume (5 ml water versus saliva) resulted in significantly higher maximum amplitude of submental muscle contraction and higher sEMG amplitude across the duration of the swallow. This increase is consistent with reports that larger bolus sizes demonstrate greater submental muscle activity (Zhu et al., 2017) and significantly increase the extent of hyolaryngeal elevation (Logemann et al., 2000; Nagy, Molfenter, Péladeau-Pigeon, Stokely, & Steele, 2014). Other studies have investigated the effect of the Mendelsohn maneuver while swallowing liquids (Hoffman et al., 2012; Inamoto et al., 2018) , however few studies compared the effect of modifying the bolus volume during the Mendelsohn maneuver (Kahrilas et al., 1991). These authors analyzed the movement of the hyoid and larynx, the UES opening, and pharyngeal pressure obtained with synchronized videofluoroscopy and manometry. Their study suggested that the increased bolus volume prolonged the duration of both anterior and superior hyolaryngeal movements and the duration and extent of UES opening during the Mendelson maneuver. The augmented effect of bolus volume during the Mendelsohn maneuver in the current study is consistent with that observed by Kahrilas et al. (1991).

Limitations of the Study

Several limitations should be considered when interpreting the findings. The participants enrolled in the current study were younger healthy adults without any neurological disease. Patients with neurological disorders caused by stroke, degenerative diseases, or traumatic brain injury are often time suffering from swallowing disorders as well as cognitive deficits. These medical comorbidities may severely impact clients' visual-spatial processing skills, working memory, and executive function (Pinkston, Alekseeva, & González Toledo, 2009). A recent study conducted by Archer et al. (2021) examined the sEMG performance of effortful swallow with sEMG biofeedback on patients with stokerelated dysphagia and healthy adults. The authors suggested that both healthy adults and patients benefitted similarly from biofeedback. All participants practiced and mastered the effortful swallow provided with verbal instructions prior to the measurement of sEMG. The measurements were collected when participants were undergoing each condition: effortful swallow with biofeedback as well as without any feedback. In contrast to the current study, biofeedback was used only during the training phase. Neither control group nor experimental group received any feedback during the baseline measurement or post training measurement. Although the study design was different, it is highly possible that the use of biofeedback may produce similar clinical benefits on the neurogenic or older population versus healthy adults. The application of ultrasound in populations with dysphagia requires more study to support this hypothesis.

In the current study, the average age of the participants was lower than aging adults who are vulnerable to have increased risk for developing dysphagia (Sura et al., 2012), which could affect the generalizability of the results. However, older adults do not seem to respond differently to kinematic biofeedback when compared to younger adults. A randomized controlled study conducted by Gueye, Dedkova, Rogalewicz, Grunerova-Lippertova, and Angerova (2021) used robot-assisted therapies and virtual reality as biofeedback to treat stroke-related upper limb function deficits for patients with early stroke. Their findings indicated that age did not significantly impact the biofeedback effect. Archer et al. (2021) also reported no significant age effect when performing effortful swallow with sEMG biofeedback. These findings indicate that the clinical utility of biofeedback may be useful among geriatrics populations with dysphagia.

The transducer may not always be firmly attached to the skin during the course of the swallow. The current study used a linear transducer without any customized adjustments as some studies described (Chen et al., 2017; Hsiao et al., 2013; Peng, Jost-Brinkmann, Miethke, & Lin, 2000). The adjustments were aimed to make sure that the evaluation had a consistent anchor point, but those customizations may not always be accessible in typical clinical settings. The difficulty of maintaining good skin-to-transducer contact especially in subjects with a prominent thyroid cartilage was also reported in a study conducted by Hsiao, Chang, Chen, Chang, and Wang (2012). Depending upon the subjects' anatomy and the structure of the submental area, some participants may be asked to increase the length of blackout time on the screen while some may be asked to maintain the image of a shortened muscle on the screen. Therefore, the target picture may be slightly different among subjects.

Clinicians should be aware of the limitations when utilizing ultrasound as biofeedback in their swallowing treatment.

Implications of the Study

Extrinsic biofeedback has proven to be a valuable tool for clinicians to increase patients' proprioception and achieve the targeted accurate form and strength of the movement (Macrae et al., 2014). Although the current study does not indicate that adding ultrasound feedback to traditional training methods is superior to traditional training alone in teaching healthy adults to perform the Mendelsohn maneuver, it does supports the clinical use of kinematic biofeedback tools such as ultrasound or videofluoroscopy (Azola, Sunday, & Humbert, 2017) for learning swallowing maneuvers even with some limitations. The visual feedback obtained from ultrasound may also provide the additional kinematic information of real-time movement for the clinician to give accurate and proper verbal feedback. More research should be conducted to confirm the therapeutic implementation of ultrasound.

The training phase for the experimental group in the study took less than 30 minutes. This displayed that applying ultrasound into the clinical setting is feasible for learning a complex rehabilitative technique.

It is important to note that training and evaluations were administered in-person with subjects in the Swallow Physiology Laboratory at the University of Wisconsin-Milwaukee during the COVID-19 pandemic. The subjects were required to wear surgical masks during the entire course of the session and take sips via straw while masks remained on. Personnel maintained social distancing with subjects most of the time except when attaching the sEMG electrodes on subjects' neck. It is clinically important that the swallowing exercise could be learned effectively even when personal protective equipment were used.

The Mendelsohn maneuverer was designed to improve UES opening during swallowing by voluntary prolongation of laryngeal excursion (Kahrilas et al., 1991; Logemann & Kahrilas, 1990). Kahrilas and colleagues did not identify an optimal duration for holding the Mendelsohn maneuver. Successive studies have asked subjects to hold the maneuver for various durations from 1.5 seconds to 5 seconds (Ding et al., 2002; Doeltgen et al., 2017; Kim et al., 2017; McCullough et al., 2012). The current study did not restrict the duration of subjects' prolongation of the Mendelsohn maneuver as the instruction was to "Hold Adam's apple up, and don't let it drop for as long as you can". The findings of the current study indicated that a successful Mendelsohn maneuver with increased peak sEMG and AUC of sEMG could be as long as approximately 8 seconds. To date, there is no consensus on optimal dynamics for the Mendelsohn maneuver in terms of the duration.

The findings of this study indicated that practicing the Mendelsohn Maneuverer with saliva swallows and 5 ml water were both effective. Therefore, patients with restricted oral diet can also gain rehabilitative benefits from practicing the Mendelsohn maneuver with saliva only. Practicing the maneuver with a certain amount of water may increase therapeutic gain with even greater submental muscle activation if the therapy is properly supervised and the necessary oral hygiene is taking place.

Implications for Future Research

Further studies are required to determine the clinical application of ultrasound as biofeedback on people with dysphagia. This study noted a possible carryover effect on normal saliva swallows after training with biofeedback. Future research investigating retainment of the physiological change may determine whether the use of biofeedback in training may facilitate the long-term effect of the maneuver. Different approaches of attaching the transducer to the skin also should be investigated in order to aid the patient to learn the maneuver or exercise with an ultrasound image customized to their special anatomy.

Future research investigating the biomechanical and electromyographic interaction on different durations of the Mendelsohn maneuver with different volumes and different consistencies of bolus are also warranted. Further investigation is also necessary to determine the changes of sEMG activity with the Mendelsohn maneuver regarding its correlation to an actual increase of hyolaryngeal dynamics or duration and extent of upper esophageal sphincter opening. These studies would provide insight to the optimal therapeutic dosage effect when performing the maneuver.

Both groups in the current study received the same number of practice swallows to control for internal validity. However, the introduction of the ultrasound equipment and the education regarding the target image resulted in longer session times for the group with ultrasound. Varying the number of the practice swallows to study the efficiency of learning a swallowing maneuver with the application of biofeedback tools would be of interest.

Summary and Conclusion

This study examined the effect of ultrasound as an additional tool for learning the Mendelsohn maneuver. The results demonstrated the use of feedback was effective to support the acquisition of the Mendelsohn maneuver. However, the addition of ultrasound feedback did not significantly increase the duration and muscle activation when performing the Mendelsohn maneuver over verbal/tactile feedback alone. The outcome of the current study suggests that the application of ultrasound biofeedback is effective, safe, and feasible for learning a new swallowing maneuver by healthy adults. This implies that ultrasound can be one of the therapeutic feedback options for people with language deficits or language differences to learn a new swallowing maneuver. The results direct future studies to investigate the use of ultrasound biofeedback on different populations with dysphagia.

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Appendices

Appendix A: Mendelsohn Maneuver Handout

The Mendelsohn maneuver is an exercise used to increase and prolong voice box lifting to improve pharyngeal swallowing function. When we swallow, our voice box moves upwards and forward. It is a swallowing mechanism that helps us to clear the food in our pharynx.

1. Put your finger on your neck and feel your Adam's apple lift as you swallow your saliva. You should feel the upward movement of the throat.
2. Swallow again. When you feel the voice box lift up, squeeze the muscles in the throat to hold Adam's apple up, and don't let it drop for as long as you can.

Appendix B: Mendelsohn Maneuver Verbal Instruction Script for Control Group

The Mendelsohn maneuver is an exercise used to increase and prolong voice box lifting to improve pharyngeal swallowing function. When we swallow, our voice box moves upwards and forward. It is a swallowing mechanism that helps us to clear the food in our pharynx. Now put your finger on your neck and feel your Adam’s apple lift as you swallow your saliva. You should feel the upward movement of the throat. Now, swallow again. When you feel the voice box lift up, squeeze the muscles in the throat to hold Adam’s apple up, and don’t let it drop for as long as you can. You should feel your Adam’s apple up for a longer duration compared to your saliva swallow. This is the Mendelsohn maneuver. Learning a new skill requires practice to ensure that we master the technique. Repeat this technique for 2 sets of 10 repetitions. 3 mins of rest interval should be placed between sets for optimal practice outcome.

Appendix C: Mendelsohn Maneuver Verbal Instruction Script for Experimental Group

The Mendelsohn maneuver is an exercise used to increase and prolong voice box lifting to improve pharyngeal swallowing function. When we swallow, our voice box moves upwards and forward. It is a swallowing mechanism that helps us to clear the food in our pharynx. Now put your finger on your neck and feel your Adam's apple lift as you swallow your saliva. You should feel the upward movement of the throat. Now, swallow again. When you feel the voice box lift up, squeeze the muscles in the throat to hold Adam's apple up, and don't let it drop for as long as you can. You should feel your Adam's apple up for a longer duration compared to your saliva swallow. This is the Mendelsohn maneuver.

I would like to introduce an additional tool to help you visualize the elevation of voice box. Other than the typical verbal instruction, you will also receive feedback from the ultrasound. Ultrasound is used to capture the images of soft tissues. It could also help us to visualize the elevation of the voice box. Some ultrasound gel will be applied to your neck skin. And an ultrasound transducer will be placed between your chin and throat.

You will see the triangular shadow on the left in the image, which is your chin bone. You will also see a long grey shadow on the right in the image, which is your hyoid bone. When you swallow, the hyoid bone moves upwards and forward and pull your throat toward your chin bone. During the swallow, you will see a temporary blackout, just like the video has shown. When we swallow with the Mendelsohn maneuver, you will see the duration of the blackout prolonged, just like the video has shown.

Right now, do a saliva swallow and see how the image displays your saliva swallow. You should see a short duration of the blackout. Now, swallow with the Mendelsohn mauver and see if you can increase the length of blackout time. Learning a new skill requires practice to ensure that we master the technique. Repeat this technique for 2 sets of 10 repetitions. 3 mins of rest interval should be placed between sets for optimal practice outcome.