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ORIGINAL ARTICLE

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

Ching-Hsuan Peng[1,2] · **Barbara R. Pauloski**[1]

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Abstract

The Mendelsohn Maneuver (MM) is a therapeutic strategy that targets reduced laryngeal elevation. Both clinicians and clients identify the MM as one of the more difficult interventions to teach and learn. The purpose of this study was to examine the effect of applying real-time ultrasound as visual feedback in teaching the MM to healthy adults. Twenty-four healthy adults were randomized to two-parallel groups. The standard care group (control group) received verbal instruction, verbal reinforcement, and tactile cueing while practicing the maneuver. The experimental group received the same instruction with additional real-time ultrasound as visual biofeedback. Participants completed a single session which consisted of baseline assessment, training, and post-training assessment. Outcomes were submental surface electromyography (sEMG) signal duration, maximum amplitude, and area under the curve. Statistical analysis revealed that training with feedback significantly increased submental sEMG activity during the MM; however, the addition of ultrasound as biofeedback did not significantly increase muscle activation when performing the MM over verbal instruction with verbal/tactile feedback alone. Both groups demonstrated significantly greater muscle activity measured by sEMG when applying the MM. Although the current study did not indicate that adding ultrasound biofeedback was superior to traditional training alone in teaching healthy adults to perform the MM, it does support the clinical use of biofeedback tools for learning swallowing maneuvers. Ultrasound may be a biofeedback option for people with language deficits or differences to learn a swallowing maneuver. Further studies are required to determine the clinical application of ultrasound as biofeedback on people with dysphagia.

Keywords Dysphagia · Deglutition · Deglutition disorders · Ultrasound · Mendelsohn Maneuver · Biofeedback · Healthy adults · Swallowing exercise

Introduction

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.

Anterior and superior movement of the hyolaryngeal complex is one of the critical swallowing mechanisms to support swallowing efficiency and safety. Contraction of the suprahyoid muscles that is the mylohyoid, geniohyoid, anterior and posterior bellies of the digastric, and stylohyoid, exerts 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. It is well established in the literature that these muscles produce the force to elevate the

✉ Ching-Hsuan Peng
peng327@purdue.edu

1 Department of Communication Sciences and Disorders, College of Health Sciences, University of Wisconsin Milwaukee, 2400 E. Hartford Avenue, Suite 840, Milwaukee, WI 53211, USA

2 Present Address: Department of Speech, Language, and Hearing Sciences, Purdue University, 715 Clinic Drive, West Lafayette, IN 47907, USA

hyolaryngeal complex in anterior and superior dimensions of displacement [1]. Foundational research by Jacob et al. [2] found that the UES relaxed but did not open until substantial anterior and superior laryngeal elevation occurred. The change of the displacement in laryngeal elevation correlated inversely with UES pressure. These results indicate that hyolaryngeal excursion contributes to UES opening.

Any abnormal structural or functional deficit of the swallowing-related muscles and nerves will result in swallowing problems, also known as dysphagia. Reduced contraction of the suprahyoid muscles may result in reduced upper esophageal sphincter (UES) opening with accompanying pyriform sinus residue which may be penetrated or aspirated after the swallow [3–6]. The Mendelsohn Maneuver is one of the therapeutic strategies that is commonly used in clinical practice, aiming to target impaired or reduced hyolaryngeal elevation. 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, resulting in increased hyolaryngeal elevation, and reduced UES pressure [7–10]. An immediate effect of increased peak pharyngeal pressure, faster onset of upper UES opening, and increased submental surface electromyography (sEMG) amplitude has also been found when applying the maneuver [11]. The efficacy of the Mendelsohn Maneuver has been tested and analyzed across healthy adults and various patient populations [12–14].

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 [15]. 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 [16]. 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 [17]. Accelerometry [18], tongue manometry [19–22], and surface electromyography (sEMG) [23–26] are the three main types of biofeedback employed in swallowing rehabilitation [19].

Ultrasound (sonography) has been widely used as a noninvasive and harmless diagnostic imaging technique to capture real-time images of soft tissues such as muscles, circulatory systems, and organs [27–29]. Lingual movement, submental muscle, and pharyngeal and laryngeal functions are among the most common areas where ultrasound imaging is used for assessing swallowing function [30–34]. Ultrasound has been found to be a reliable and feasible tool to measure laryngeal elevation [31, 35–37] and the diameter of the UES opening during swallowing [38]. Some studies also used ultrasound to assess the submental muscle morphometric change to test treatment effects [39, 40]. There are only limited numbers of studies that investigate the efficacy of applying ultrasonography as biofeedback in swallowing rehabilitation. Blyth, McCabe, Madill, and Ballard [41] reported significantly reduced bolus transit duration and improved Functional Oral Intake Scale scores after training oral tongue movements with biofeedback with ultrasound on two patients with partial glossectomy. A recent study investigated the accuracy of performing the Mendelsohn Maneuver after learning and practicing with either sEMG or ultrasound [42]. The authors randomly assigned participants into the sEMG group and the ultrasound group. The study found that the ultrasound group had a better level of acquisition of the Mendelsohn Maneuver compared to sEMG group after two-week training period.

The purpose of the present study was to determine 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 aimed 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 may indicate whether ultrasound is an effective and applicable biofeedback tool to assist clinicians in teaching the Mendelsohn Maneuver.

Methods

This study was undertaken with the understanding and written consent of each subject and according to the ethical principles of the World Medical Association Declaration of Helsinki (version 2002) and approved by the Institutional Review Board of the University of Wisconsin Milwaukee. It was 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 as visual kinematic biofeedback. Both groups were measured at two time points: baseline and after training while completing saliva swallows and 5 ml water swallows. The outcomes were measured with 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.

Participants

Twenty-four (24) healthy adults were randomized into the study. Participants had no history of swallowing, neurological, or gastrointestinal disorders or surgery to the head and neck region with the exception of rhinoplasty, tonsil or adenoid removal, or dental extractions. None of the participants had current self-reported swallowing problems. All participants scored below 3 on the Eating Assessment Tool (EAT-10) [43].

Procedure

Each participant completed a single 45- to 60-min session which consisted of three phases: baseline assessment phase, training phase, and post-training assessment phase. Surface EMG was used to record muscle activity during the assessment phases. Details on sEMG electrode placement and outcome are detailed in the "Outcome" section below.

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 (water, IDDSI Level 0, https://iddsi.org/Framework) swallows via a straw. For saliva swallows, the participant was instructed to swallow once the examiner observed the sEMG signal to be stable at resting baseline. For the water swallows, participants were instructed to sip in the water and hold it in the mouth until instructed to swallow. Once the examiner observed the sEMG signal return to resting baseline after sipping the water, the participants were directed to swallow. Participants repeated the swallow condition 5 times, performing one swallow every 30 s. Participants had three minutes of rest between bolus conditions. This protocol was consistent with the one used by Steele et al. [44]. In order to minimize the potential for an order effect of bolus condition (saliva swallows and 5 ml thin liquid swallows), the sequence of the tasks was counterbalanced and randomized.

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 (Appendix B) and tactile feedback via laryngeal palpation. Participants were asked to feel the upward movement of the laryngeal prominence while swallowing normally. 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 (Fig. 1). Ultrasound gel (Parker Laboratories, New Jersey) was used to eliminate air and form a bond between skin and transducer to facilitate image quality.

The mandible bone ("A," Fig. 2) and hyoid bone ("B," Fig. 2) were visualized as two distinct hyperechoic plaques with an acoustic shadow and were used to assist in orienting the participant to the ultrasound image. Note that although Fig. 2 is a still image, the participant was observing real-time structural movement. The experimental group was trained to identify the location of the mandible and hyoid bone as well as perceive hyolaryngeal excursion movement using recorded examples of a saliva swallow and a saliva swallow with Mendelsohn Maneuver during ultrasound. This training was supported with ultrasound still images of the submental area. Then, subjects were instructed to observe and explore the hyolaryngeal displacement difference between their normal saliva swallow and their saliva swallow with the Mendelsohn Maneuver on the real-time ultrasound image. The script for training with ultrasound biofeedback is included in Appendix C.

Both groups were instructed to practice the Mendelsohn Maneuver for 2 sets of 10 repetitions of saliva swallows. Participants were provided verbal cues of whether the

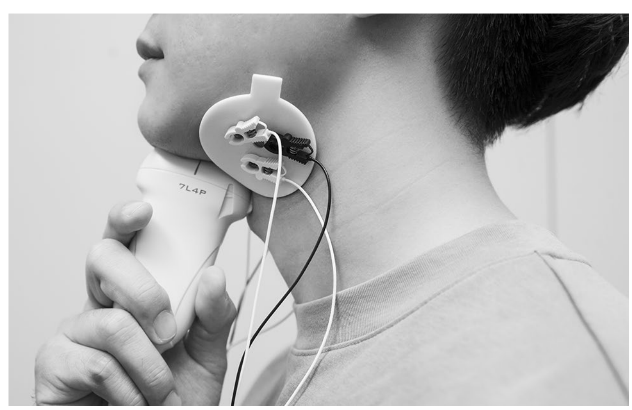

Fig. 1 The positioning of the transducer submentally in the midsagittal plane between the mandibular symphysis and the hyoid bone

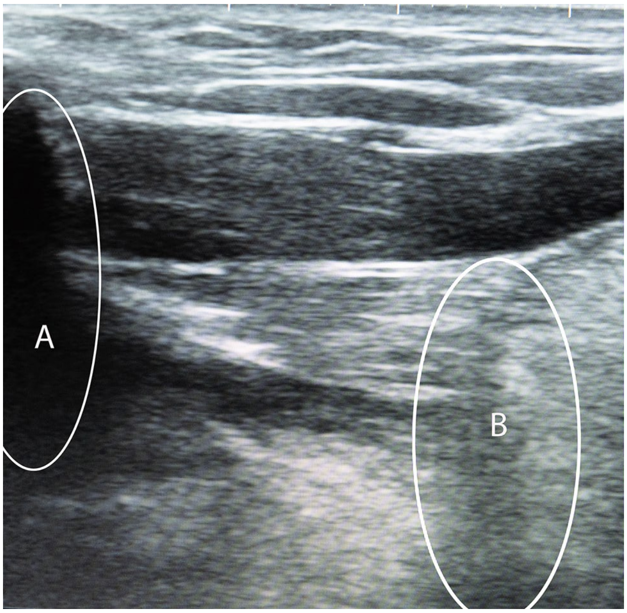

Fig. 2 Still image of real-time ultrasound used as biofeedback for the experimental group. The mandible bone (**A**) and hyoid bone (**B**) are visualized as two distinct hyperechoic plaques with an acoustic shadow and used to assist in orienting the participant to the ultrasound image

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-min rest between practice sets. The rest interval was based on the recommendation for muscle resistance training [45, 46].

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 s. Counterbalancing of the four conditions and randomization to a counterbalanced sequence were used to reduce a potential order effect in the post-training assessment.

Outcome Measures

Surface EMG was used to quantify submental muscle activity during the baseline and the post-training assessments. Surface EMG duration, maximum amplitude of sEMG, and area under curve (AUC) of the sEMG signal were measured to compare the outcome. Surface EMG data were 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, Greene, Taylor-Kamara, Macrae, Anderson, and Humbert [47] 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. Surface EMG 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 (Fig. 3). The lower recording electrodes were attached above the thyroid cartilage. The sEMG data obtained from five swallow trials in each swallow task were averaged for statistical analyses. Preliminary testing indicated that values between the left and right channels did not differ significantly, so the researchers averaged both channels for the final outcome measures used for statistical analysis.

Fig. 3 Placement of the sEMG recording electrodes bilaterally over the submental suprahyoid muscles

Statistical Analysis

Statistical analysis was completed using SPSS statistical software (SPSS Statistics version 28.0, IBM, Chicago, IL). The equality of age between the two randomized groups was assessed using independent *t* test. Fisher's Exact test was used to determine equality of gender distribution between groups. 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. A three-way mixed model repeated measure analysis of variance (ANOVA) was planned to determine whether training method (verbal/tactile only versus ultrasound) resulted in differences in sEMG activity when using the Mendelsohn Maneuver.

As a measurement of inter- and intrajudge reliability, 10% percent of the sEMG data were chosen at random and remeasured by the first author and the second author. Intra-class correlations coefficients (ICC) based on absolute agreement using a 2 way-mixed-effects model 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.

Results

Intra-class correlations' coefficients (ICC) with 95% confidence 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.

Baseline Equivalence of Randomized Groups

Twenty-four participants participated in the study. Genders, age, and means and standard deviations for the dependent variables by group and bolus type at baseline are presented in Table 1. The experimental group consisted of 5 males and 7 females, aged 28.08 ± 8.62 years (range = 20–54 years). The control group consisted of 2 males and 10 females, aged 28 ± 10.07 (range = 23–59 years).

There was no significant difference between the groups on age ($p = 0.983$) or gender ($p = 0.371$). Therefore, the control and experimental group were equivalent on subject demographics.

For peak sEMG activity and sEMG AUC, 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. There was a significant interaction between evaluation time and group ($p = 0.022$) in the ANOVA for duration of sEMG; therefore, in order to assess group equivalence, the paired comparisons between groups were interpreted 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 2). These results indicated that the randomized groups were equivalent on all subject demographics and on the dependent variables at baseline.

Table 2 Pairwise Comparisons of sEMG duration between groups by evaluation point

Evaluation			Mean difference (EG–CG)	Std. error	Sig
Baseline	EG	CG	0.014	0.058	0.812
Post-training	EG	CG	0.096	0.066	0.159

EG: experimental group, CG: control group

Table 1 Subject demographics and mean ± standard deviation of baseline sEMG outcome measures by training group and bolus type

	Experimental group N = 12	Control group N = 12
Gender	5 males, 7 females	2 males, 10 females
Age	28.08 ± 8.618	28 ± 10.072
Bolus type	Experimental group	Control group
Duration (s)		
SS	1.26 ± 0.19	1.25 ± 0 .66
5 ml	1.26 ± 0.18	1.24 ± 0.17
sEMG (μV		
SS	31.96 ± 13.51	34.71 ± 13.80
5 ml	35.10 ± 9.62	34.74 ± 17.81
AUC (μV s)		
SS	19.76 ± 6.99	21.19 ± 8.07
5 ml	21.26 ± 5.50	19.88 ± 9.33

SS: saliva swallow, 5 ml: 5 ml water swallow, sEMG: maximum sEMG amplitude, AUC: area under the curve

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 3 and further illustrated in Fig. 4. None of the outcome measures demonstrated a significant main effect or interaction involving training group, indicating that those who received biofeedback with ultrasound did not differ significantly when compared to those who received verbal/tactile feedback only for any measure of surface electromyography.

The results for the ANOVA of duration of sEMG showed no interactions among the independent variables. As indicated in Fig. 4, there was no main effect of training group ($p = 0.931$). In addition, no main effect of bolus type was found ($p = 0.085$). There was a significant main effect for condition ($p < 0.001$) (Fig. 5). Inspection of the means reveals that swallows performed with the Mendelsohn Maneuver had significantly longer sEMG duration than those performed without the maneuver.

The results for the ANOVA for peak sEMG activity showed no main effect of training group ($p = 0.732$) (Fig. 4), 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 condition ($p = 0.005$) (Fig. 6a) and bolus type ($p = 0.017$) (Fig. 6b). 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.

The results for the ANOVA for sEMG AUC showed no interaction of other independent variables with training group and no main effect of training group ($p = 0.575$) (Fig. 4), 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 condition and bolus type ($p = 0.012$) (Fig. 7). These results indicate that the effect of the Mendelsohn Maneuver on sEMG AUC differed as a function of bolus type. 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.

Discussion

This randomized controlled study evaluated the effect of ultrasound as an additional tool for instructing the Mendelsohn Maneuver. The outcomes were measured by sEMG duration, maximum amplitude of sEMG signal, and area under the curve. The results of the current study indicate 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 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. These results reveal that ultrasound feedback and traditional cueing were both effective for teaching the Mendelsohn Maneuver. Some participants in the experimental group reported the ultrasound image was helpful to visualize hyolaryngeal elevation during practice; however, another

Table 3 Post-training performances in different swallow tasks

Bolus type	Experimental group $N = 12$		Control group $N = 12$	
	Non-MM (baseline)	MM	Non-MM (baseline)	MM
Duration (s)				
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 (μV)				
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 (μV s)				
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

Non-MM: no maneuver swallow at baseline, MM: Mendelsohn Maneuver, SS: saliva swallow, 5 ml: 5 ml swallow, sEMG: maximum sEMG amplitude, AUC: area under the curve

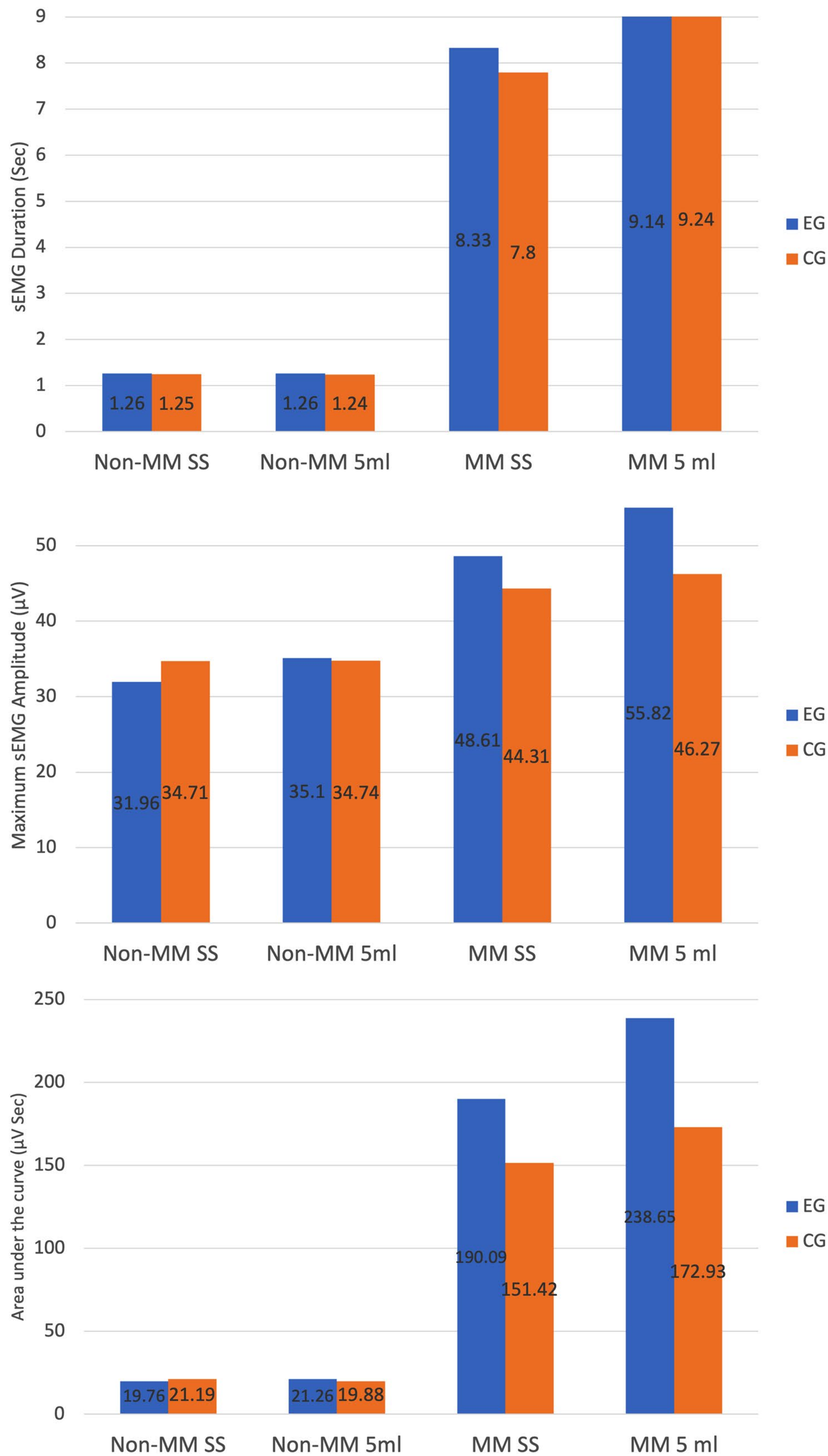

Fig. 4 Duration of sEMG, maximum sEMG amplitude, and sEMG area under the curve (AUC) by training group (control [CG], experimental [EG]), bolus type (saliva, 5 ml water), and condition (no maneuver, maneuver). There were no significant differences by training group, that is control group (CG) versus experimental group (EG) for any of the outcome measures

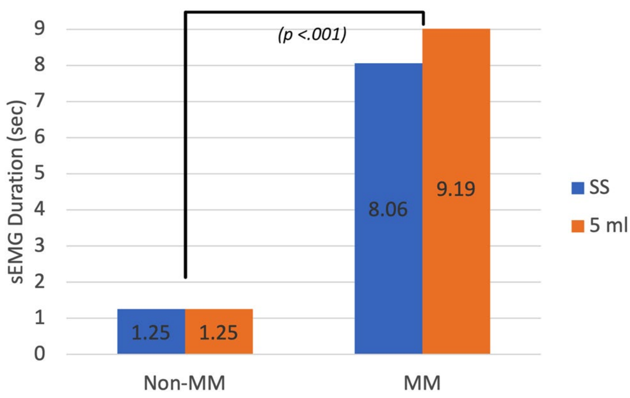

Fig. 5 Significant main effect between conditions for sEMG duration ($p < 0.001$) (*Non-MM* Swallow with no maneuver, *MM* Swallow with Mendelsohn Maneuver, *SS* saliva swallow, *5 ml* swallow with 5 ml water)

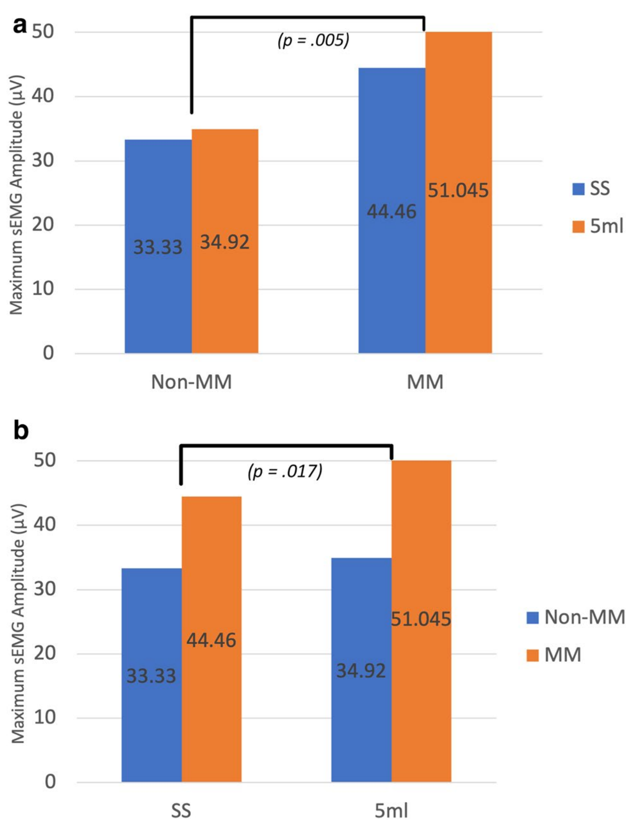

Fig. 6 **a** Significant main effect between conditions for maximum sEMG amplitude ($p = 0.005$). **b** Significant main effect between bolus types for maximum sEMG amplitude ($p = 0.017$)

participant 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

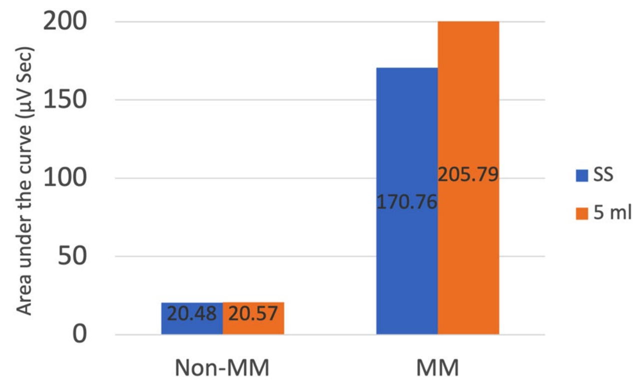

Fig. 7 Significant interaction between condition and bolus type for AUC sEMG ($p = 0.012$)

5 ml water was considerably greater than the volume of an average saliva swallow, which is about 0.5 ml [48]. 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 non-maneuver saliva swallows after training, whereas the control group demonstrated decreased duration with both bolus types on non-maneuver swallows after training. 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 et al. [49] 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 this study showed maximum amplitude of sEMG and sEMG duration were significantly greater with the Mendelsohn Maneuver than with normal swallows.

These findings are in agreement with previous studies [11, 50]. 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 et al. [51] and a 250% increase in maximum submental sEMG signal using the Mendelsohn Maneuver with 5 ml viscous jelly by Doeltgen et al. [11]. They 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 in the previous studies [11, 51]; 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 [52] and significantly increase the extent of hyolaryngeal elevation [53, 54]. Other studies have investigated the effect of the Mendelsohn Maneuver while swallowing liquids [8, 9], however, few studies compared the effect of modifying the bolus volume during the Mendelsohn Maneuver [7]. This study suggested that 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 the previous study [7].

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 [55], 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 [55–57]. Theoretically, interpreting and integrating additional information from biofeedback may potentially increase demands on the systems in these population [58]. A recent systematic review reported a positive effectiveness of rehabilitation using biofeedback in dynamic balance and gait on people with neurological diseases including stroke, Parkinson's disease, and mild cognitive impairment [59]. Limited research has been conducted to investigate the effect of biofeedback on patients with dysphagia. A recent study conducted by Archer, Smith and Newham [26] examined the sEMG performance of effortful swallow with sEMG biofeedback on patients with stroke-related dysphagia and healthy adults. The authors suggested that both healthy adults and patients benefitted similarly from biofeedback with surface electromyography. Although the type of feedback was different, it is possible that the use of ultrasound as biofeedback may produce similar clinical benefits with the neurogenic or older population versus healthy adults. Ultrasound as biofeedback is relatively new in the field of rehabilitation with limited study investigated the efficacy on patient population [60]. Although the current study reported a positive outcome of ultrasound biofeedback applied to instruction of the Mendelsohn Maneuver for healthy adults, the use 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 [61], 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. Gueye et al. [62] conducted a randomized controlled study using 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. Another study [26] 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.

Transducer placement is an important aspect of using ultrasound. It was observed that occasionally some participants in the experimental group did not always hold the transducer firmly against the skin during the course of the swallow. The current study used a linear transducer without any customized adjustments as some studies describe [30, 35, 63]. These reported adjustments were aimed to make sure that the evaluation had a consistent anchor point, but such 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 has also been reported [64]. 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 optimal target image 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 [49]. 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 support the clinical use of kinematic biofeedback tools such as ultrasound or videofluoroscopy [65] 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 Mendelsohn Maneuver improves UES opening during swallowing by voluntary prolongation of laryngeal excursion [7, 66]. 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 to 5 s [11, 12, 50, 67]. 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 s. 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 Maneuver 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 for 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 measured from simultaneous videofluoroscopy. 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.

Finally, the outcome of the current study suggests that the application of ultrasound biofeedback is effective, safe, and feasible for learning new swallowing maneuver by healthy adults. Additional research concerning the use of ultrasound biofeedback for different populations with dysphagia resulting from reduced hyolaryngeal elevation and reduced UES opening is needed to determine its applicability with patient populations. Future research will focus adaptation of this study's protocol to participants post-stroke or other neurological disease impacting hyolaryngeal elevation.

Summary

This study examined the effect of ultrasound as an additional tool for instructing the Mendelsohn Maneuver. The results demonstrated the use of biofeedback with ultrasound was effective to support the acquisition of the Mendelsohn Maneuver in a healthy population. However, the addition of ultrasound feedback did not significantly increase the duration or muscle activation of the submental suprahyoid muscles when performing the Mendelsohn maneuver over verbal/tactile feedback alone. Additional research is needed to determine the impact of ultrasound biofeedback on the instruction of the Mendelsohn Maneuver with patient populations.

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Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose. The authors have no conflicts of interest to declare that are relevant to the content of this article. All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript. The authors have no financial or proprietary interests in any material discussed in this article.

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Ching-Hsuan Peng MS

Barbara R. Pauloski PhD