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Application of ultrasound biofeedback to the learning of the Mendelsohn maneuver in non-dysphagic adults: a pilot study.

Abstract

Purposes: This study aimed to investigate the application of ultrasound to the learning of swallowing maneuver.

Method: Forty non-dysphagic adults of both genders who were naïve to the Mendelsohn maneuver participated in the study. They were randomly assigned to receive ultrasound or surface electromyography (sEMG) as biofeedback when acquiring the Mendelsohn maneuver. Thirty-eight subjects (n = 19) completed the Learning phase. Accuracy of executing the Mendelsohn maneuver was measured immediately (Post-training percentage accuracy) and one week post-training (Retention percentage accuracy).

Results: Whereas comparable numbers of training blocks were completed by the two groups ($t(31.51) = 3.68$, $p = 0.330$), the Ultrasound group attained significantly higher percentage accuracies than the sEMG group at both Post-training ($t(28.88) = 4.04$, $p < 0.001$, $d = 1.309$) and Retention ($t(30.78) = 2.13$, $p = 0.042$, $d = 0.690$).

Conclusion: Ultrasound is a more effective biofeedback than sEMG in the acquisition of the Mendelsohn maneuver and may be adopted to the rehabilitative treatment for dysphagic individuals. Non-specificity of sEMG as biofeedback should be emphasized when it is employed in the training and learning of swallowing maneuvers. Findings from the present study suggest that ultrasound is preferable to sEMG as biofeedback in the learning of the Mendelsohn maneuver.

The following publication Kwong, E., Ng, KW.K., Leung, MT. et al. Application of Ultrasound Biofeedback to the Learning of the Mendelsohn Maneuver in Non-dysphagic Adults: A Pilot Study. Dysphagia 36, 650–658 (2021) is available at https://dx.doi.org/10.1007/s00455-020-10179-y.

Introduction

Dysphagia and the Mendelsohn Maneuver

Dysphagia is associated with morbidity and mortality due to risks of aspiration pneumonia and malnutrition [1, 2]. Management of dysphagia may be categorized into compensatory strategies or rehabilitative strategies [1, 3]. Compensatory strategies; for instance, diet modification; are used to provide short-term adjustments to reduce symptoms of dysphagia while rehabilitative strategies aim to improve impaired swallowing physiology [1, 3]. Among the most commonly documented rehabilitative techniques are tongue strengthening exercises, the Mendelsohn maneuver, the Shaker exercise, supraglottic and super-supraglottic swallow, and effortful swallow [3].

The Mendelsohn maneuver is a swallowing maneuver that has been used as both a compensatory strategy and a rehabilitation strategy for patients with pharyngeal dysphagia [1, 3-5]. It is designed to increase the duration and displacement of hyolaryngeal elevation by having the hyoid bone move anterior-superiorly towards the mandible. Such motion, when executed properly, would not only elevate the laryngeal structures but also relax and open the upper esophageal sphincter (UES), and thus create a safer swallow [1, 5-8]. McCullough and colleagues examined the changes in swallowing physiology with the use of the Mendelsohn maneuver [5]. Positive effects were found among eighteen post-stroke participants with reduced hyolaryngeal elevation or UES opening and pharyngeal residue after swallow. It was found that the use of the Mendelsohn maneuver improved the duration of hyoid bone maximum elevation, hyoid anterior excursion and UES opening. Inamoto and colleagues investigated the effect of the Mendelsohn maneuver on healthy participants by visualizing and analyzing the swallowing movement with the use of area detector computed tomography [9]. Apart from prolonged duration of hyolaryngeal elevation and UES opening, it was also found that after the bolus tail had passed through the UES, the tongue base and posterior lateral pharyngeal wall remained in contact. This might decrease the risk of aspiration by allowing the bolus to descend through the laryngopharyx into the esophagus more efficiently.

Application of motor learning and biofeedback to swallowing

Motor learning is a set of internal processes to acquire capability to produce skilled performance, leading to changes in capability to perform the movement and retainment of such changes [10, 11]. It is usually achieved through practice or experience [10]. Application of motor learning principles to swallowing rehabilitation, especially on learning a novel and difficult-to-monitor movement like swallowing maneuvers, is gaining increasing attention.

Feedback that affects motor learning can be classified into intrinsic and extrinsic ones. Intrinsic feedback is sensory feedback gained from an individual's own movement [11], while extrinsic feedback provides information about the movement from the environment [10, 12, 13]. Extrinsic feedback may be used to enhance motor learning through supplementing intrinsic feedback [10, 11]. It provides information about the corresponding movement in the forms of knowledge of results (KR) and knowledge of performance (KP). KR provides information on the outcome of movement, while KP involves information on the movement pattern [10, 13]. KP can be provided through adopting different types of biofeedback and it plays an important role in motor skills learning, when internal representation of the movement goal is not reliable, intrinsic feedback is limited, and at the early stage of acquisition [14].

Intrinsic feedback provides sensory information relating to movement and assists precise execution of motor tasks [15]. Proprioception, which is a kind of intrinsic feedback, is especially important for non-visible movements like swallowing [16]. This is of clinical significance as it is not uncommon to see dysphagic individuals who exhibit reduced or impaired sensation in the oral and pharyngeal areas, and thus receive reduced intrinsic feedback [2]. To facilitate the acquisition of swallowing maneuvers in a group of individuals with limited intrinsic feedback, the provision of extrinsic feedback could provide augmented essential information regarding the movement physiology, and in turn, promote motor learning. Biofeedback is a kind of extrinsic feedback that provide information regarding internal physiological events (e.g. heart rate, blood pressure, muscle activity) [10, 17]. Specifically, visual biofeedback, which can be kinematic or nonkinematic in nature, presents the target movement pattern.

Surface electromyography (sEMG). Surface electromyography (sEMG) is a commonly used non-kinematic biofeedback to facilitate the acquisition of swallowing maneuvers in clinical settings [2, 5]. It records muscle activity obtained from electrodes applied on the skin and provides general information about the timing and relative amplitude of selected muscle activity, which is increased when the duration and/or the force of muscle contraction changes [2, 18, 19]. It is considered as a useful tool for detecting the activation of submental muscle groups during swallows when training swallowing maneuvers [1, 15, 18]. In McCullough and colleagues' study, real-time sEMG visual biofeedback was used to train post-stroke patients with dysphagia to perform Mendelsohn maneuver [5]. The use of sEMG biofeedback adjunct to swallowing therapy was found to be facilitative to both stroke and head/neck cancer patients [20].

The effect of sEMG as visual biofeedback was compared with video fluoroscopic swallow study (VFSS) for the training on volitional laryngeal vestibule closure maneuver by Azola and colleagues [15]. Results suggested that the performance accuracy was higher when participants received VFSS as kinematic biofeedback during training, when compared to those who received sEMG as non-kinematic biofeedback. Furthermore, sEMG only measures and displays the relative composite activity of underlying muscles in analog form. It is not capable of identifying specific muscle activity, especially for the region with overlapping muscles like the neck [18, 19]. However, VFSS exposes patients to radiation, requires specialized equipment, and is a diagnostic procedure not intended to be used repeatedly in therapy sessions [21-23].

Ultrasonography. Ultrasonography is a radiation-free and non-invasive imaging technique which may be used as a therapeutic tool to provide visual-motor biofeedback in real time of the specific anatomical structures seen during a swallow [24-28]. Shawker et al. [28] applied ultrasound to observe the motor sequence of tongue movement, and also hyoid bone movement during swallowing. In another study, Shawker and colleagues analyzed the lingual and hyolaryngeal activities during swallowing of a 5-cc water bolus using ultrasound [29]. Sonies, Wang and Sapper developed a method based on the ultrasound duplex-doppler imaging technique to analyze normal and abnormal hyoid bone movement during swallowing [30]. Miller and Watkin [31] conducted a preliminary study on using ultrasound to quantify the displacement and duration of lateral pharyngeal wall movement during selected maneuvers (i.e. supraglottic, super-supraglottic, and the Mendelsohn maneuvers). Results suggested that ultrasound could be a promising tool to evaluate the efficacy of different swallowing maneuvers, as well as to provide real-time biofeedback in treatment. In a study conducted by Hsiao and his colleagues [21], ultrasound was shown to reliably measure hyoid bone displacement, which is a significant contributor to laryngeal elevation. This further suggested the potential of submental ultrasound as kinematic biofeedback to supplement training of novel swallowing maneuvers.

Purpose of the study

The present study set out to investigate the application of ultrasound to the learning of a swallowing maneuver. It was hypothesized that ultrasound is a more effective biofeedback tool than sEMG for the acquisition of the Mendelsohn maneuver. Effectiveness was evaluated in terms of the participants' performance in the learning phase and that in the retention phase. Level of acquisition was measured specifically with the accuracy attained by participants in performing the Mendelsohn maneuver at retention.

Method

Participants

The present study was approved by the Human Subjects Ethics Sub-committee, the Hong Kong Polytechnic University (Ref. HSEARS20190517006). Forty participants (20 males and 20 females) with no history of swallowing, speech, and voice problems; surgery to the head and neck; and neurological diseases participated in the study. All participants were university graduates (n = 38) or undergraduate students (n = 2), and were naïve to Mendelsohn maneuver. They were randomly assigned to the sEMG group (n = 20, mean age = 26.0years), and the Ultrasound group (n = 20, mean age = 24.6years) with balanced gender ratios. Two subjects (one male and one female) failed to reach the practice termination criteria after 12 training blocks in the Learning phase and thus did not proceed to Post-training accuracy assessment. Complete sets of data were obtained from 38 subjects (ten males and nine females in the sEMG group, nine males and ten females in the Ultrasound group) for subsequent data extraction and analyses.

Equipment and materials

For both groups, an Aixplorer® Multiwave™ Ultrasound System with a XC6-1 convex transducer was used in the study. Gel pads (Acton® BOL-I-X bolus with film by Action®) with the dimensions of 10cm x 10cm x 1cm were used to facilitate fitting of the convex transducer to the neck contour. An addition gel pad (dimension: 10cm x 2cm x 1cm) was also used at the experimenter's discretion to ensure adequate submandibular transducer placement. The Guardian Way single channel Aspire2 Device, with a frequency ranging from 5Hz to 100Hz, connected to a tablet (iPad Pro by Apple Inc.) was used for providing sEMG biofeedback. Bipolar round electrodes with diameter of 1" (WT1 by V2U Healthcare) were used for sEMG signal measurement and round electrodes with diameter of 1.25" (CF125 by ValuTrode®) were used as the reference electrodes.

Procedures

Phase 1: Introduction phase. The flow of the Introduction phase is illustrated in Figure 1. The goal of this phase was to introduce the Mendelsohn maneuver and to familiarize the participants with their assigned biofeedback technique (i.e. ultrasound or sEMG). In order to standardize the introduction process and minimize the variability due to experimenter input, two videos were prepared and played to subjects in the two groups. Both videos began with an introduction to the physiology of normal swallowing and the Mendelsohn maneuver. To facilitate understanding, subjects were instructed to palpate the middle of their neck at the level of the notch in the thyroid cartilage to obtain a feeling of the swallowing motion during a dry swallow.

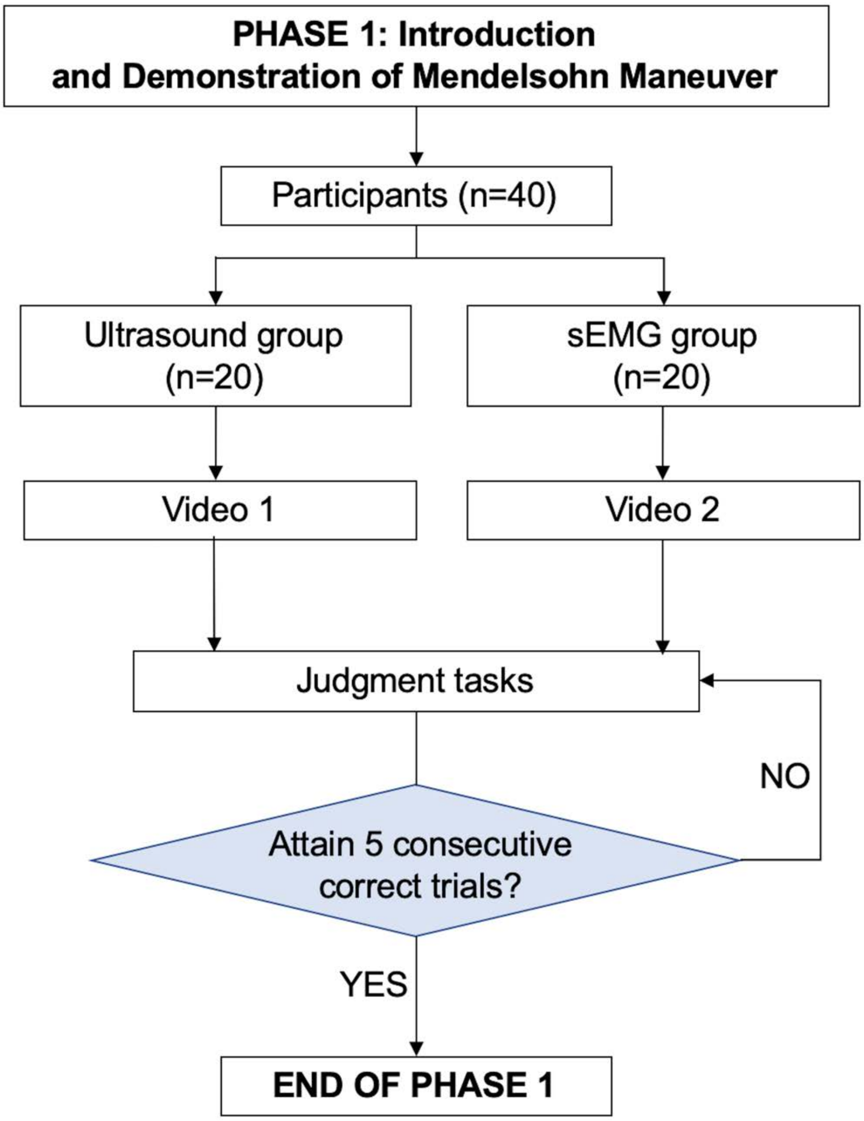

Fig.1 Flow of the Introduction phase (Phase 1)

In the video prepared for the Ultrasound group, instructions and placement of ultrasound transducer during training trials were shown. Subjects were taught that the images were from a mid-sagittal view of the oral and pharyngeal cavity. The two dark shadows in the images corresponded to the hyoid bone and thyroid cartilage (see Figure 2). Since the orientations of the transducer and ultrasound images were standardized in the introduction video and throughout the data collection process, the leftward movement of the two shadows would represent the anterior-superior movement of the hyoid bone and thyroid cartilage. Subjects were instructed that when the Mendelsohn maneuver is performed correctly, the dark shadows should move to the left and be held in position for at least two seconds. In the video prepared for the sEMG group, instructions and placement of sEMG electrodes were shown. Subjects were taught to interpret the sEMG signal, including the meaning of duration and amplitude changes on the X- and Y-axes. They were told that an increased amplitude infers more muscle activity and they were instructed to sustain the increased amplitude for at least two seconds so as to correctly perform the Mendelsohn maneuver. The two-second criterion was adopted as suggested by Azola et al [22].

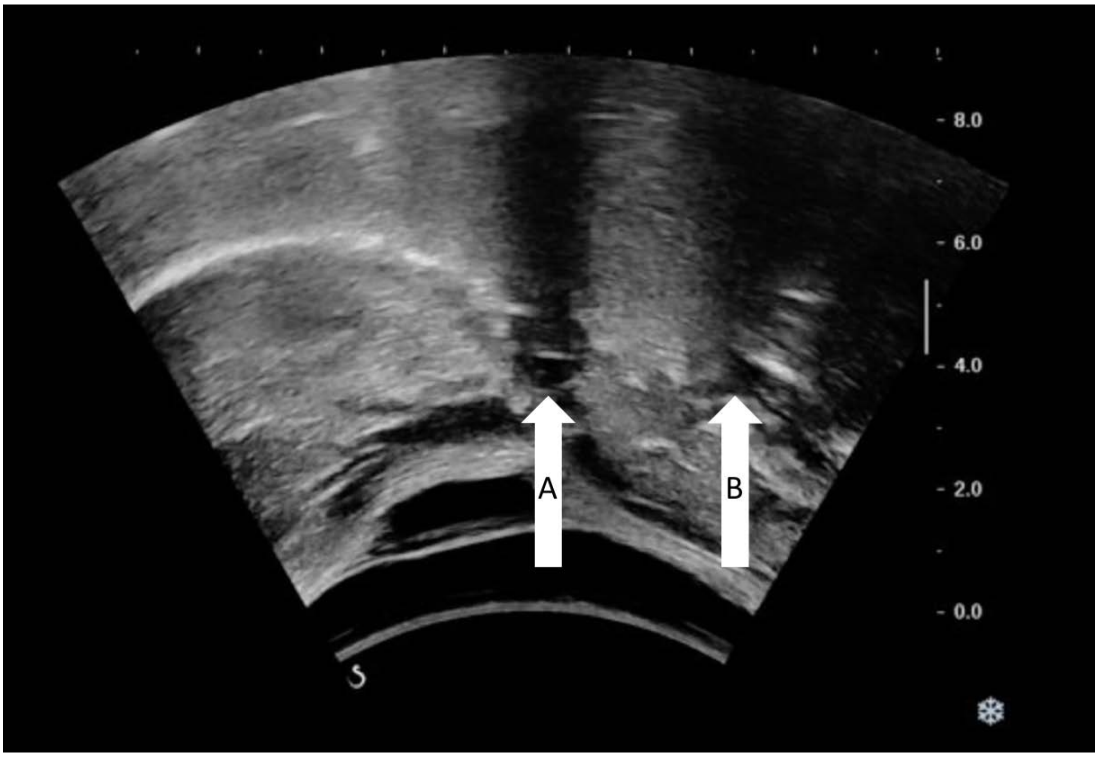

Fig. 2 Sample ultrasound image shown to the subjects. Arrows A and B indicate the acoustic shadows of hyoid bone and thyroid cartilage respectively

After viewing the videos, subjects underwent judgement tasks on sample clips of ultrasound images or sEMG signals, according to their group assignments, regarding the Mendelsohn maneuver performances. They were asked to judge whether the Mendelsohn maneuvers are performed accurately in the clips. This was to ensure that the subjects were familiarized with their biofeedback format before entering the Learning phase. The Introduction phase would be terminated only if a subject could accurately judge, for five consecutive trials, the performances of the Mendelsohn maneuvers shown in the sample clips.

Phase 2: Learning phase. Figure 3 illustrates the flow of the Learning phase, which took place immediately after Phase 1. Subjects in the Ultrasound group sat in an upright position on a chair. A gel pad was placed submentally (under the chin) to obtain contact with the transducer and to insure proper placement. The subjects were first asked to perform dry swallow to ensure clear visualization. An additional strip of gel pad might be used at the experimenter's discretion to ensure the best visualization of the hyolaryngeal area (see Figures 4a and 4b for the placement of gel pads and transducer). Ultrasound images were shown to the subjects as visual kinematic biofeedback in real time. Subjects in the sEMG group also sat in an upright position on a chair. Biopolar sEMG electrodes were placed on the left and right sides of the participant's submental muscles. A reference electrode was placed on the participant's clavicle bone. The sEMG signals were shown, in real time, on a tablet as visual non-kinematic biofeedback. Accuracies of the Mendelsohn maneuver performance were judged by a final year Master of Speech Therapy student who was trained for dysphagia management and was familiar with sEMG signal and ultrasound image interpretation. A trial would be regarded as "accurate" if the two dark triangular shadows that correspond to hyoid bone and thyroid cartilage moved forward and upward toward the left on the ultrasound image for at least two seconds and the sEMG signal increased in amplitude for at least two seconds for the Ultrasound and sEMG groups respectively.

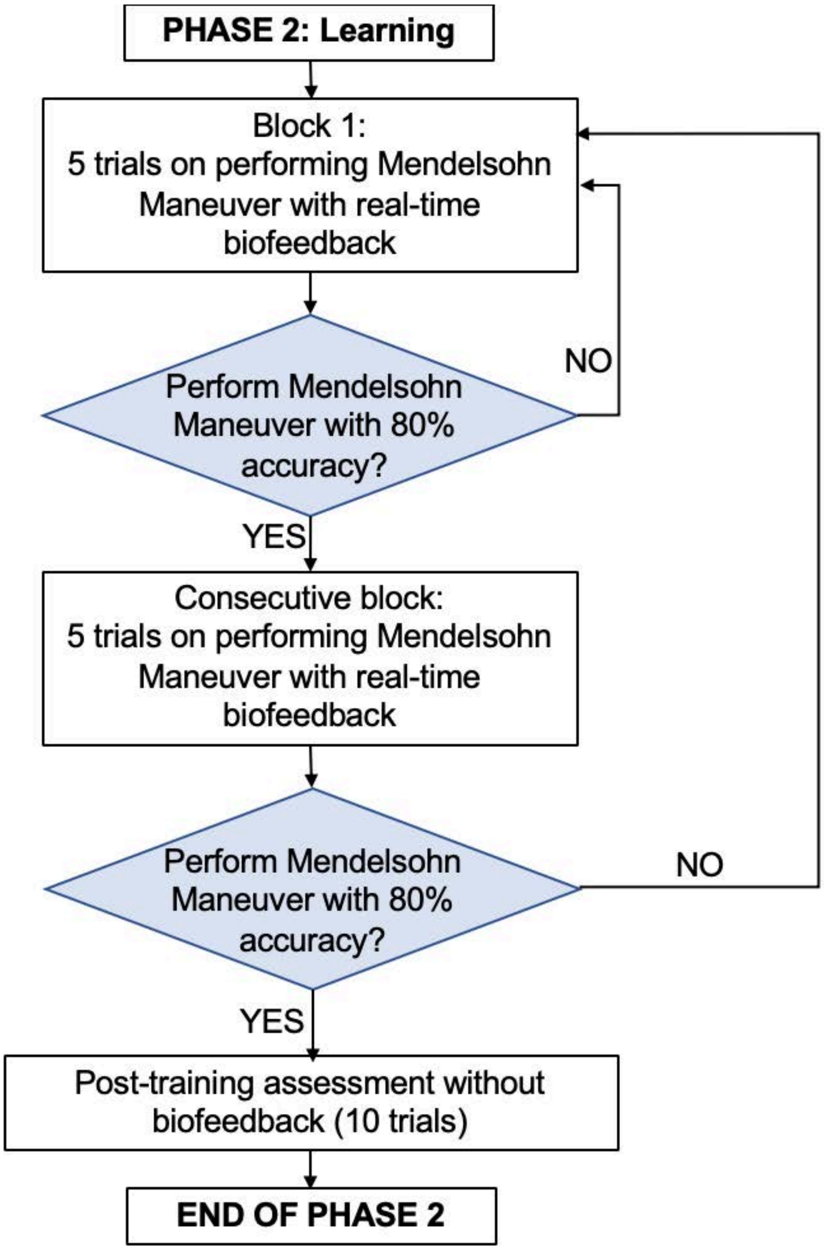

Fig.3 Flow of the Learning phase (Phase 2)

Fig. 4a Placement of gel pads and transducer from the anterior view

Fig. 4b Placement of gel pads and transducer from the lateral view

Regardless of group assignment, training trials were arranged in blocks of five trials. Accurate performance of the Mendelsohn maneuvers in four out of five trials (i.e. 80% accuracy) was regarded as one successful training block. If two consecutive successful blocks were achieved, subjects were considered to have fulfilled the practice termination criteria and would proceed to Post-training assessment, in which subjects were required to perform ten trials of the Mendelsohn maneuvers without biofeedback. Their performances were recorded using ultrasound imaging with the same experimental set up as the Ultrasound group's for later data extraction.

Phase 3: Retention. All subjects who had completed the Introduction and Learning phases returned to the experimental site after one week for a Retention assessment. The one-week period was selected such that the two visits could fit into schedules of most subjects and in turn minimize subject attrition. Further, the two visits were not too separated from each other such that retention might be maximized. Subjects were required to perform the Mendelsohn maneuvers for ten trials with no feedback provided, that is, no ultrasound images (for the Ultrasound group) and sEMG signals (for the sEMG group) were shown to the subjects. All trials were recorded using ultrasound imaging with the same experimental set up as the Ultrasound group's for later data extraction.

Data extraction

Eight out of the ten ultrasound images recorded for each subject in each assessment with the best quality were selected by the second author (K.N., a final year Master of Speech Therapy student had the same background as the Phase 2 experimenter). The images were randomised and rated by three final year Master of Speech Therapy students, who were blind to the subjects' group assignment, for accuracies in preforming the Mendelsohn maneuver. Before the actual rating sessions, the three raters met in a consensus meeting to agree on 1) the criteria of successful trials (i.e. the two dark shadows that represent the hyoid bone and thyroid cartilage had moved to the left and were held in position for at least two seconds), and 2) their judgement on accuracy based on the above criteria on 15 randomly selected ultrasound images. In the actual rating session, the raters were allowed to view the images for as many times as necessary. Percentage accuracies for each subject in each assessment were obtained by dividing the number of successful trials by eight. The percentage accuracy given by the three raters were averaged for later data analyses. Fifteen percent of the videos were randomly selected and rated for a second time by each rater to obtain intra-rater reliability.

Statistical analyses

All statistical analyses were carried out using the IBM SPSS Statistics 25 software. Inter-rater reliability was estimated using Intra-class Correlations Coefficient (ICC) based on a mean-rating (k = 3), absolute agreement, 2-way mixed-effects model, whereas intra-rater reliabilities were estimated using ICC based on a single measure, absolute agreement, 2-way mixed-effects model. Number of training blocks undertaken, percentage accuracy at Post-training and percentage accuracy at Retention were compared across the two groups using independent *t*-tests. Alpha levels were set at 0.05 for all statistical tests.

Results

Intra-class Correlations Coefficient (ICC) results showed good inter-rater reliability (ICC = 0.828, $p < 0.001$) and poor intra-rater reliabilities (ICC = 0.387, 0.417, 0.405; $p < 0.001$). Results from the Levene's tests showed that the assumptions of equal variance were violated ($p \leq 0.001$). Degrees of freedom (*df*) and levels of significance were adjusted for the independent *t*-tests. Table 1 summarizes the means (*M*s), standard deviations (*SD*s) and results of the independent *t*-tests. The number of training blocks undertaken by the sEMG group (M = 4.47, SD = 2.89) was slightly greater than that undertaken by the Ultrasound group (M = 3.68, SD = 1.95). The difference, however, did not reach statistical significance ($t(31.51) = 0.987$, $p = 0.330$). The Post-training percentage accuracy of the Ultrasound group was significantly higher than that of the sEMG group ($t(28.88) = 4.04$, $p < 0.001$), with an extremely large effect size (Cohen's d = 1.309).

Table 1

Descriptive data on Number of training blocks, Post-training and Retention percentage accuracies of the sEMG and Ultrasound biofeedback groups and comparisons between the two groups

	sEMG group (n = 19)		Ultrasound group (n = 19)				
Measures	*Mean*	*SD*	*Mean*	*SD*	*t*	*p*	*Cohen's d*
Number of training blocks	4.47	2.89	3.68	1.95	0.987	0.331	0.320
Post-training percentage accuracy	43.42	37.71	83.77	21.87	4.035	<0.001*	1.309
Retention percentage accuracy	52.63	37.40	74.34	24.15	2.126	0.042*	0.690

Note. *SD* = standard deviation. * significant at 0.05 level.

The magnitude of difference between the two groups reduced in the Retention percentage accuracy measure. From immediately after training to one week after training, it is noted that the sEMG group showed increase (Post-training: M = 43.42, SD = 37.71; Retention: M = 52.63, SD = 37.40) whereas the Ultrasound group showed decrease (Post-training: M = 83.77, SD = 21.87; Retention: M = 74.34, SD = 24.15) (see Table 1) in mean percentage accuracy. The

Ultrasound group, nevertheless, still showed significantly higher mean percentage accuracy than the sEMG group at Retention ($t(30.78) = 2.13$, $p = 0.042$) with a medium effect size (Cohen's $d = 0.690$). Figure 5 illustrates the comparisons on percentage accuracies between the two groups.

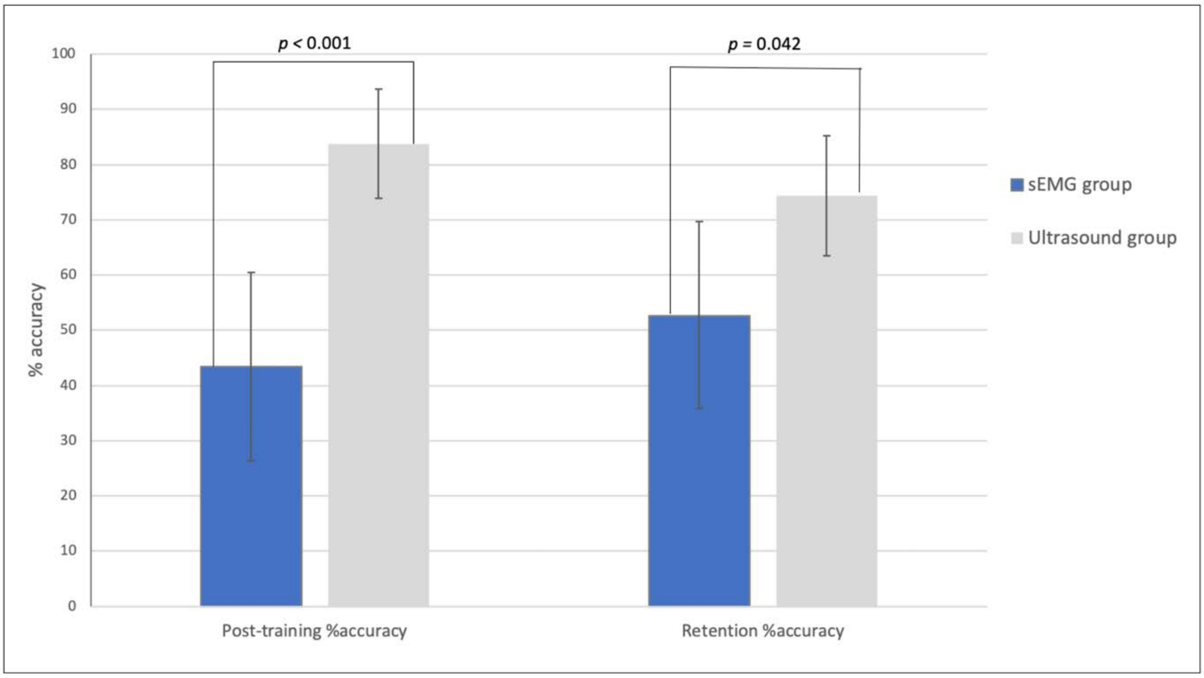

Fig. 5 Mean percentage accuracies attained by the sEMG and Ultrasound groups immediately after training (Post-training) and one week after training (Retention). Error bars represent 95% confidence interval

Discussion

The present study aimed to investigate the application of ultrasound as biofeedback to the motor learning of the Mendelsohn maneuver in a group of non-dysphagic adults. Ultrasound was compared to sEMG, a frequently adopted biofeedback in dysphagia management, in terms of effectiveness in swallowing maneuver acquisition.

The level of acquisition was measured with the performance of carrying out the Mendelsohn maneuver at Retention, which took place one week after the Learning phase. The difference in Retention percentage accuracy between the two groups suggests that ultrasound is a more effective biofeedback than sEMG in the learning of the novel swallowing maneuver. Such difference is not attributed to the difference in amount of practice time, as the numbers of training blocks undertaken were comparable in the two groups; and the age and educational background of subjects, as these factors were also considered comparable in the two groups. The medium effect size suggests that the across group difference is related to the type of biofeedback to a moderate extent.

Another finding that indicates ultrasound being superior to sEMG lies in the performance in carrying out the Mendelsohn maneuver in the Learning phase. Given comparable amount of practice time, the Ultrasound group demonstrated better performance than the sEMG group at Post-training. The extremely large effect size further suggests that the difference in performance had a strong relationship with the kind of biofeedback provided. A performance curve illustrating the change in performance throughout the Learning phase may provide additional insights regarding the effect of ultrasound on the learning process [10].

It is observed that the across-group differences in percentage accuracy diminished slightly from Post-training to Retention. The two groups differed significantly in Post-training percentage accuracy with an extremely large effect size. However, some differences in performance shown in the Learning phase might not be "permanent" and did not persist into Retention [10]. Despite this, significantly higher percentage accuracy was found in the Ultrasound group at Retention, and thus ultrasound is still considered superior to sEMG in the learning of the Mendelsohn maneuver.

A closer look at the performances of individual subjects further suggests that adopting ultrasound as biofeedback is more promising than sEMG. Relatively large *SDs* were observed in the sEMG group in both the Post-training and Retention percentage accuracies. This may be attributed to a more diverse performance in carrying out the Mendelsohn maneuver in individual subjects of the sEMG group. Despite that all subjects had fulfilled the practice termination criteria and were considered to have undergone sufficient practices, there were at least four subjects in the sEMG group who attained 0% Post-training accuracy and two of them also attained 0% accuracy at Retention. Such phenomenon, nevertheless, was not found in the Ultrasound group.

Findings from the present study agree with some earlier studies that suggested the non-specificity of sEMG in measuring hyo-laryngeal movement (e.g.[15, 22]). The non-specificity of biofeedback may result in learners' inaccurate or suboptimal attentional foci on the movement, and thus negatively impact the acquisition of the movement [10]. As a visual kinematic biofeedback, ultrasound also provides more KP information to subjects than a non-kinematic biofeedback like sEMG [15]. Such information is particularly facilitative in the acquisition of complex non-visible movements like the Mendelsohn maneuver [13].

Clinical implications

Findings from the present study suggest that ultrasound is an effective biofeedback technique to learn the Mendelsohn maneuver and other swallowing maneuvers. It is considered more effective than non-kinematic biofeedback like sEMG; and physically and radioactively non-invasive as compared to other visual kinematic biofeedback like video-fluoroscopy. This allows ultrasound to be used repeatedly in therapy sessions. Further, ultrasound allows visualization of anatomical images in real-time and those images can also be recorded for later viewing. A controlled trial on dysphagic individuals is warranted to confirm its therapeutic application to the target population. Furthermore, the non-specificity of sEMG may lead to inaccurate attentional foci and thus, hinder the acquisition of swallowing maneuvers. Clinicians adopting sEMG as biofeedback should be well-aware of such possibility.

Despite that sEMG is adopted extensively in clinical settings, it may potentially confound the clinicians' judgement on patients' performance. In the experiment, Learning phase would be terminated only if the subject had fulfilled the termination criteria. The judgement was made by the experimenter, based on the subjects' performances shown in the sEMG or ultrasound biofeedback. Despite that all the subjects included in data analyses were judged to have fulfilled practice termination criteria, the actual performances (as measured with Post-training percentage accuracy) were significantly different between the two groups. As mentioned, there were four subjects who attained 0% accuracy at Post-training and two of them continued to attain 0% at Retention. Experimenters or clinicians might be misled by the sEMG biofeedback to believe that sufficient practices were allowed for the acquisition of the Mendelsohn maneuver, and the actual performance and level of learning might be overestimated. Inaccurate clinician's judgement may result in the provision of inaccurate KR information. This would undoubtedly affect the training and learning of swallowing maneuvers [13].

Limitations of the present study

Performance in the Learning phase was only measured after practice had been terminated. It is recommended that performance throughout the learning process may be recorded such that the rate and/or pattern of acquisition may be compared across the sEMG and Ultrasound groups. This may be achieved by collecting accuracy data simultaneously using ultrasound for every single trial. Correlation between the judgement by clinicians and the actual performance for each trial may also be investigated to look for any superiority in supplementing clinicians' judgement between the two biofeedback modalities. Further, intra-rater reliabilities were poor for all raters. More training on interpretation and judgement on ultrasound images is warranted.

Conclusion

Ultrasound is a more effective biofeedback tool than sEMG in the acquisition of the Mendelsohn maneuver. Clinically, ultrasound may be applicable to the rehabilitative treatment for dysphagic individuals. Findings from the present study indicate the non-specificity of sEMG in providing biofeedback. Its limitations should be observed when adopted in the training and learning of swallowing maneuvers.

Conflict of interest

The authors declare that they have no conflict of interest.

Reference

1. Groher ME, Crary ME (2016) Dysphagia : clinical management in adults and children.2nd edn. Elsevier, St. Louis, Missouri

2. Benfield JK, Everton LF, Bath PM, England TJ (2019) Does therapy with biofeedback improve swallowing in adults with dysphagia? A systematic review and meta-analysis. Arch Phys Med Rehab 100 (3):551-561.

3. González-Fernández M, Ottenstein L, Atanelov L, Christian AB (2013) Dysphagia After Stroke: an overview. Curr. Phys. Med. Rehabil. Rep. 1 (3):187-196.

4. Logemann JA, Kahrilas PJ (1990) Relearning to swallow after stroke— application of maneuvers and indirect biofeedback: a case study. Neurology 40 (7):1136-1136.

5. McCullough GH, Kamarunas E, Mann GC, Schmidley JW, Robbins JA, Crary MA (2012) Effects of mendelsohn maneuver on measures of swallowing duration post stroke. Top Stroke Rehabil 19 (3):234-243.

6. Logemann JA (1998) The evaluation and treatment of swallowing disorders. Curr Opin Otolaryngo 6 (6):395-400.

7. Cichero JA, Murdoch BE (2006) Dysphagia: Foundation, theory and practice. John Wiley & Sons, New Jersey

8. Wheeler-Hegland KM, Rosenbek JC, Sapienza CM (2008) Submental sEMG and hyoid movement during mendelsohn maneuver, effortful swallow, and expiratory muscle strength training. J Speech Lang Hear R 51 (5):1072-1087.

9. Inamoto Y, Saitoh E, Ito Y, Kagaya H, Aoyagi Y, Shibata S, Ota K, Fujii N, Palmer JB (2018) The mendelsohn maneuver and its effects on swallowing: kinematic analysis in three dimensions using dynamic area detector CT. Dysphagia 33 (4):419-430.

10. Schmidt RA, Lee TD, Winstein C, Wulf G, Zelaznik HN (2018) Motor control and learning: a behavioral emphasis. Sixth edition. Human Kinetics, Illinois

11. Humbert IA, German RZ (2013) New directions for understanding neural control in swallowing: the potential and promise of motor learning. Dysphagia 28 (1):1-10.

12. Zwicker JG, Harris SR (2009) A reflection on motor learning theory in pediatric occupational therapy practice. Can. J. Occup. Ther. 76 (1):29-37.

13. Macrae P, Anderson C, Taylor-Kamara I, Humbert I (2014) The effects of feedback on volitional manipulation of airway protection during swallowing. J. Mot. Behav. 46 (2):133-139.

14. Maas E, Robin DA, Hula SNA, Freedman SE, Wulf G, Ballard KJ, Schmidt RA (2008) Principles of motor learning in treatment of motor speech disorders. Am J Speech Lang Pathol 17 (3):277-298.

15. Azola AM, Sunday KL, Humbert IA (2017) Kinematic visual biofeedback improves accuracy of learning a swallowing maneuver and accuracy of clinician cues during training. Dysphagia 32 (1):115-122.

16. Johnson A, Proctor R (2017) Skill acquisition and training: achieving expertise in simple and complex tasks, 1st edn. Routledge, New York

17. Tate JJ, Milner CE (2010) Real-time kinematic, temporospatial, and kinetic biofeedback during gait retraining in patients: a systematic review. Phys Ther 90 (8):1123-1134.

18. Crary MA, Groher ME (2000) Basic concepts of surface electromyographic biofeedback in the treatment of dysphagia: a tutorial. Am J Speech Lang Pathol 9 (2):116-125.

19. Ding R, Larson CR, Logemann JA, Rademaker AW (2002) Surface electromyographic and electroglottographic studies in normal subjects under two swallow conditions: normal and during the mendelsohn manuever. Dysphagia 17 (1):1-12.

20. Crary MA, Carnaby GD, Groher ME, Helseth E (2004) Functional benefits of dysphagia therapy using adjunctive semg biofeedback. Dysphagia 19 (3):160-164.

21. Hsiao MY, Chang YC, Chen WS, Chang HY, Wang TG (2012) Application of ultrasonography in assessing oropharyngeal dysphagia in stroke patients. Ultrasound Med Biol 38 (9):1522-1528.

22. Azola AM, Greene LR, Taylor-Kamara I, Macrae P, Anderson C, Humbert IA (2015) The relationship between submental surface electromyography and hyo-laryngeal kinematic measures of mendelsohn maneuver duration. J Speech Lang Hear R 58 (6):1627-1636.

23. Vose AK, Marcus A, Humbert I (2019) Kinematic visual biofeedback improves accuracy of swallowing maneuver training and accuracy of clinician cues during training in stroke patients with dysphagia. PM R . 11 (11):1159-1169.

24. Hsiao MY, Wahyuni LK, Wang TG (2013) Ultrasonography in assessing oropharyngeal Dysphagia. J Ultrasound Med 21 (4):181-188.

25. Miller J, Sonies, BC (2008) Dynamic imaging of the tongue, larynx and pharynx during swallowing. In: Gunabushanam (ed) Head and neck ultrasonography. Plural Pub. Orloff, LA

26. Sonies BC, Chi-Fishman G, Miller JL (2002) Ultrasound imaging and swallowing. In: Jones B (ed) Normal and abnormal swallowing: imaging in diagnosis and therapy, 2nd edn. Springer-Verlag, New York.

27. Shawker TH, Sonies BC (1985) Ultrasound biofeedback for speech training. Invest Radiol 20: 90-3.

28. Shawker TH, Sonies B, Stone M, Baum BJ (1983) Real-time ultrasound visualization of tongue movement during swallowing. J Clin Ultrasound 11 (9):485-490.

29.Shawker TH, Sonies BC, Hall TE, Baum BF (1984) Ultrasound analysis of tongue, hyoid and larynx activity during swallow. Invest Radiol 19 (2): 82-6.

30. Sonies B, Wang C, Sapper DJ (1996) Evaluation of normal and abnormal hyoid bone movement during swallowing by use of ultrasound duplex-doppler imaging. Ultrasound Med. and Biol. 22 (9): 1169-1175.

31. Miller JL, Watkin KL (1997) Lateral pharyngeal wall motion during swallowing using real time ultrasound. Dysphagia 12 (3):125-132.