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Kinematic visual biofeedback improves accuracy of learning a swallowing maneuver and accuracy of clinician cues during training

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Abstract

Submental surface electromyography (ssEMG) visual biofeedback is widely used to train swallowing maneuvers. This study compares the effect of ssEMG and videofluoroscopy (VF) visual biofeedback on hyo-laryngeal accuracy when training a swallowing maneuver. Furthermore, it examines the clinician's ability to provide accurate verbal cues during swallowing maneuver training. Thirty healthy adults performed the volitional Laryngeal Vestibule Closure maneuver (vLVC), which involves swallowing and sustaining closure of the laryngeal vestibule for 2 seconds. The study included 2 stages: (1) First accurate demonstration of the vLVC maneuver, followed by (2) Training - 20 vLVC training swallows. Participants were randomized into 3 groups: A) ssEMG biofeedback only; B) VF biofeedback only; and C) Mixed biofeedback (VF for the first accurate demonstration and ssEMG for the training stage). Participants' performances were verbally critiqued or reinforced in real-time while both the clinician and participant were observing the assigned visual biofeedback. Videofluoroscopy and ssEMG were continuously recorded for all participants. Results show that accuracy of both vLVC performance and clinician cues was greater with VF biofeedback than with either ssEMG or Mixed biofeedback ($p < 0.001$). Using ssEMG for providing real-time biofeedback during training could lead to errors while learning and training a swallowing maneuver.

Introduction

Oropharyngeal dysphagia is a highly prevalent, yet under diagnosed condition, affecting the elderly population, patients with neurological or neurodegenerative disorders and those with head and neck diseases (1). Dysphagia management is designed to target the specific

pathophysiologic processes responsible for the impairment, including training swallowing novel maneuvers. One of the major challenges of dysphagia rehabilitation therapy is the inability to confirm whether the target movements of a swallowing maneuver have been achieved. This is a challenge because the intricate movements of pharyngeal and laryngeal structures are not visible without instrumentation. In therapy, patients are expected to exert volitional control over hyo-laryngeal structures that they are usually not familiar with and cannot directly visualize, and furthermore, are disordered due to their underlying medical diagnosis.

Humans are equipped with a complex sensory system used to provide intrinsic feedback (proprioception), which keeps track of the movement of muscles, joints, and general body position, allowing us to make accurate gross and fine movements (Gandevia et al 2002; Abbruzzese et al 2014). Intrinsic feedback is the primary source of movement-related sensory information needed to accurately execute motor tasks (Rose and Christina 2006). Extrinsic feedback is different than intrinsic feedback because its source is not from the sensory system (endogenous), rather it is a “second source of movement-related information that can be provided to the individual” according to Rose and Christina et al (2006). Extrinsic feedback can be used to supplement intrinsic feedback, especially when acquiring a new skill or re-learning previously acquired skills that are impaired due to injury (Rose and Christina 2006; Gandevia et al 2002; Abbruzzese et al 2014). The application of motor learning principles to dysphagia rehabilitation research has been proposed as a way to broaden our knowledge of swallowing physiology and in particular, aid in the development of successful rehabilitative strategies (2). Extrinsic feedback is fundamental in motor learning and rehabilitation, because it supplements losses in intrinsic feedback, while increasing motivation, generalization and retention (refs in comment 3). In clinical settings, extrinsic feedback can be further divided into two forms: clinician verbal cues and visual biofeedback. Clinician cues are typically verbal information that is provided to encourage, discourage, or describe the quality or outcome of the patient's movements when learning or re-learning a movement. Visual biofeedback is information that a patient can see that represents their movements and may be kinematic (i.e. mirror, videofluoroscopy) or non-kinematic (i.e. electromyography). In many circumstances, clinician cues and visual biofeedback can be combined to amplify the impact of extrinsic feedback, to augment intrinsic feedback and, ultimately, to increase learning. Interestingly, it has been shown that when intrinsic feedback is contradicted by erroneous extrinsic feedback, the erroneous extrinsic feedback will influence the participant's motor responses (13). This finding highlights the importance of accurate extrinsic feedback, (i.e. clinical verbal cues and visual biofeedback) when training novel swallowing movements.

Electromyography (EMG) is a form of visual biofeedback that is commonly used in musculoskeletal and neurological rehabilitation of gait and other complex motor functions, with promising results (3). Uncontrolled studies in the deglutition literature support the use of submental surface EMG (ssEMG) visual biofeedback to facilitate swallowing maneuver training (4,5). In swallowing rehabilitation, the use of ssEMG as visual biofeedback represents the activity of a muscle group that is involved in swallowing, but it does not directly reflect the motion of the structures (i.e. lingual or hyoid kinematics). Thus, ssEMG as visual biofeedback might not confirm that certain target therapeutic movements have been

attained. This was supported by Azola et al (2015), wherein ssEMG represented less than 40% of hyo-laryngeal movements (duration of hyoid elevation, and laryngeal vestibule closure duration) seen in videofluoroscopy (VF) during Mendelsohn maneuver training in healthy adults and in individuals with dysphagia due to stroke (6). This discrepancy in measurement specificity between ssEMG and videofluoroscopy outcomes likely exists because the submental muscle group is also active during other co-occurring swallowing functions, including lingual movement and stabilization against infrahyoid musculature (7,8).

There have been few controlled studies investigating the effects of extrinsic feedback when training a specific swallowing function (9,10). Macrae et al (2014) conducted a study investigating clinician verbal cues on training a swallowing maneuver called volitional laryngeal vestibule closure (vLVC). The vLVC maneuver involves achieving laryngeal vestibule closure first with a swallow and volitionally prolonging it for at least 2 seconds. This investigation demonstrated that clinician verbal cues (that were based on kinematic, videofluoroscopic movements) improved the accuracy of vLVC performance, compared to no feedback at all.

The effect of kinematic versus non-kinematic visual biofeedback on the accuracy of clinician verbal cues and the accuracy of swallowing maneuver performance is largely unknown. This is significant because if patients are not training the target movement, they may be learning maladaptive or incorrect swallowing movement instead of the intended therapeutic maneuver to ameliorate dysphagia. The goal of this study was to compare the effects of three different biofeedback conditions, including: (a) ssEMG; (b) VF; (c) Mixed biofeedback, which is a combination of ssEMG and VF (described further in the *methods* below). We examined the effects of these three forms of visual biofeedback on two different outcomes, including: (a) accurate performance of the volitional laryngeal vestibule closure (vLVC) maneuver among healthy adults, and; (b) accuracy of clinician cues when training the vLVC maneuver. Based on the constraints of ssEMG discussed above, we hypothesized that accuracy of vLVC performance and of the clinician cues would be most reduced with ssEMG compared to either VF or Mixed visual feedback.

Methods

Participants

We recruited 35 healthy adults (mean age =35, SD=14 years) from the community for this study. Participants denied any history of dysphagia, speech or voice problems, surgery to the head and neck, as well as neurological disease or damage. All procedures received the approval of our institutional review board and all participants signed written informed consent prior to participation.

Procedures

Study Design

The study design included 2 stages: 1) First accurate demonstration of the vLVC maneuver, and 2) Training - 20 consecutive vLVC training swallows to be completed in specified time

windows. If participants could not accurately first demonstrate the vLVC maneuver, they were excluded and did not participate in the training.

All participants received clinical verbal cues and one of three forms of visual biofeedback, to which they were randomly assigned. The three visual biofeedback protocols included: (1) ssEMG biofeedback (N= 10), VF biofeedback (N=12), and Mixed biofeedback (N=13). In the ssEMG biofeedback group, submental surface EMG was used for visual biofeedback during both the first accurate demonstration and the training. Likewise, in the VF biofeedback group, VIDEOFLUOROSCOPY was provided for both the first accurate demonstration and the training. In the Mixed biofeedback group, VIDEOFLUOROSCOPY was used for visual feedback during the first accurate demonstration attempts, and then ssEMG was provided for feedback during the training phase. Two subjects from the VF group and 3 subjects of the Mixed group were excluded because they could not first demonstrate accurate vLVC performance and did not continue to the training stage. Thus, each training group included 10 participants.

During the study, one investigator served as the clinician (2 years of experience). Prior to this study, the clinician had extensive experience in both videofluoroscopic swallowing studies in patients and in healthy adults including laryngeal vestibule closure. Furthermore, the clinician was experienced in the application and analysis of ssEMG during swallowing. The role of the clinician was to provide verbal cues about whether the participant was performing the vLVC maneuver for 2 seconds and within the target duration of time specified for each trial. The clinician verbal cues were based on the same visual biofeedback that the participant was assigned to. Both ssEMG and videofluoroscopy were recorded for all swallows and for all participants. The accuracy of the clinician feedback was verified with frame-by-frame analyses of the videofluoroscopy recordings (i.e. total duration of Laryngeal vestibule closure).

Visual biofeedback types—All participants were seated at a comfortable distance from the computer screen that displayed either the live ssEMG signal or the live videofluoroscopy images. These were only visual and no audio was included.

ssEMG biofeedback group: Submental surface EMG is the current standard for biofeedback during clinical care and in research (16). It is safe, widely available, and less expensive than videofluoroscopy. We used the same ssEMG recording procedures as Azola et al (2015). Bipolar ssEMG electrodes (Dual Bio Amp by AD Instruments) were placed on the left and right sides of the submental muscle group, approximately half way between the hyoid bone and the mentalis of the mandible. The ground electrode was positioned on the carpal of one wrist. Recordings throughout the study were at a sampling rate of 10,000 Hz. Raw ssEMG signals were used as visual biofeedback (Figure 1). Participants were oriented to the meaning of changes in the ssEMG signal on the Y-axis (thicker signal means more muscle activity) and to sustain thickness at four times the baseline (rest) signal, as in Azola et al (2015). Participants were also oriented to the time course along the X-axis to improve their interpretation of increasing ssEMG signal thickness for 2 seconds. The purpose and location of submental musculature as it relates to hyo-laryngeal involvement in swallowing and vLVC performance was also explained.

VF biofeedback group: Videofluoroscopy is the gold standard for imaging swallowing kinematics and identifying swallowing impairments. Videofluoroscopy is not used as a therapeutic technique due to radiation exposure, limited availability and greater cost than ssEMG. However, we tested videofluoroscopic visual feedback in the current study to examine an ideal training circumstance where laryngeal vestibule kinematics can be observed in real time. Videofluoroscopic data were continuously acquired at 30 frames per second in the sagittal plane. All participants received less than 5 minutes of radiation exposure during this study. Digital recordings were viewed in real time on a monitor and exported to an image processing computer system (LabChart 7 Pro) where they were archived and synched with ssEMG output for offline analysis. The field of view included the oral cavity, pharynx, laryngeal vestibule, subglottal air column, and upper esophagus, including the upper esophageal sphincter. A simultaneously recorded time code was used for data analysis. To familiarize the participant with their visual biofeedback format we used a lateral fluoroscopic still shot of the participants' neck and oriented them to the regional anatomy and the changes that would be observed in the x-ray when laryngeal vestibule closure occurs. Then, participants performed a saliva swallow and observed laryngeal vestibule closure in a real-time videofluoroscopic image. Finally, participants were directed to attempt the vLVC while watching real-time videofluoroscopy. Again, attention was drawn to the laryngeal vestibule and the changes in appearance as the vestibule closes (i.e. loss of radiolucency in the area when its closed). Successful laryngeal vestibule closure was defined as full approximation of the superior tip of the arytenoids to the petiole (base) of the epiglottis (Logemann, 1992).

Mixed biofeedback group: The Mixed biofeedback group had videofluoroscopic feedback during the first accurate demonstration of the vLVC maneuver, then they transitioned to ssEMG biofeedback during the training phase. The rationale for the Mixed group was to test a typical clinical situation where videofluoroscopy is used to diagnose and to test the immediate effects of swallowing maneuvers, followed by treatment where videofluoroscopy is not available and swallowing maneuvers are trained with ssEMG. Thus, the outcomes from examining the Mixed biofeedback group would allow us to determine whether using videofluoroscopy to first confirm that the vLVC was initially accurately demonstrated could improve performance accuracy in subsequent training of the vLVC maneuver with ssEMG biofeedback. Participants in the Mixed biofeedback group experienced the same orientation as the videofluoroscopic and ssEMG training groups described above.

First accurate demonstration of the vLVC maneuver

The goal of this stage was to determine whether participants could accurately perform the vLVC maneuver prior to training. This was important because our previous experience with training this maneuver indicates that about 20% of healthy participants cannot demonstrate the first accurate vLVC performance, despite several attempts. All participants were provided the same verbal instructions for performing the vLVC and prior to viewing any feedback. The instructions were to first palpate their thyroid notch and observe its movement during a saliva swallow. Then, they were instructed to swallow and hold the thyroid notch up as high and as long as possible. In addition, participants were told that they should not be able to breathe while performing the task. When trying to demonstrate the first accurate

vLVC, all participants swallowed saliva. A 1ml bolus of water was offered if they felt their mouth was too dry to initiate a swallow.

The participants in the ssEMG visual biofeedback group were instructed to observe the increased thickness of the ssEMG trace first during a natural swallow. Then, they were asked to attempt the vLVC swallow, which is often accompanied by prolonged hyo-laryngeal elevation and should also extend the duration of the increased amplitude of the ssEMG trace approximately four times the baseline (rest) signal. Their duration target was 2 seconds of increased ssEMG amplitude. Similar to Ding et al (2002), Crary et al (2004), and Azola et al (2015), a specific amplitude target threshold was not established. Instead, we aimed to simulate clinical use of ssEMG biofeedback without simultaneous complex analysis and interpretation of the EMG signal by the participant.

In the VF and Mixed trainings, a lateral fluoroscopic still shot of the participants' neck was used for instructional purposes. Participants were oriented to the laryngeal anatomy and the changes observed in the x-ray with laryngeal vestibule closure. A saliva swallow was first performed so that the clinician could point to laryngeal vestibule closure in real time videofluoroscopy. Then, participants were directed to attempt the vLVC while watching realtime videofluoroscopy. Attention was drawn to the laryngeal vestibule and the changes in appearance as the vestibule closes (i.e. loss of radiolucency in the area when its closed).

Each participant was allowed up to five attempts to perform the vLVC swallow correctly before they were excluded from the study. Participants who could accurately perform the vLVC swallow within 5 attempts were permitted to continue to the training phase of the study.

Training Phase

The training phase involved 20 saliva vLVC trials with concurrent visual biofeedback and clinician cues corresponding to their assigned feedback group. Participants were also required to complete the 2-second vLVC trials within a specified time window ranging between 3 and 7.5 seconds. The 20 trials were divided into a linear 10-trial set and a random 10-trial set. The time window in the linear 10-trial set was presented from longest to shortest in duration in .5 second increments (7.5, 7, 6.5, 6, 5.5, ... 3). The random 10-trial set had randomly arranged time windows (i.e. 4, 3.5, 7, 5.5, etc). The start and end of each time window was signaled via a surface electrical stimulation sensory cue that was administered to the infrahyoid region (Stimulus Isolator, ADInstruments) (Figure 1). A surface electrical stimulation cue was chosen because it is novel and could be easily identified and, unlike audio or visual cues, is less likely to be confused with other ongoing sounds or sights within our experimental environment. Also, it could be easily identified in the ssEMG data (artifact). Clinician verbal cues about whether kinematics of the vLVC were accurate, whether the vLVC lasted for 2 seconds, and whether performance was completed within the required time window were provided by the clinician (recorded on the data collection sheet) and were based on the assigned biofeedback protocol. Participants received 1ml water boluses between all trials to maintain enough oral moisture to initiate the vLVC swallows. The inter-trial intervals were approximately 30 seconds throughout training.

Data Analysis

The videofluoroscopic recordings were cropped into clips of single swallows. Individual swallow clips were assigned a four-digit code for blinded, frame-by-frame analysis by two of the authors. One author analyzed all of the swallows and a second investigator analyzed 20% of the total swallows for inter-rater reliability testing. We derived LVC duration in seconds, which is defined as the duration of contact between the arytenoids and epiglottis base during the swallow, including complete epiglottic inversion (14,15,16). Based on the frame-by-frame analysis of the videofluoroscopic data obtained for all participants during the training phase, we determined whether or not the task of 2 sec LVC was accurate (1 = accurate, 0 = not accurate). The synchronized videofluoroscopy and ssEMG data were used to determine if the task was completed within the required time interval (1 = within the time interval, 0 = not within the time interval). Using the clinician annotations and comparing them to our frame-by-frame videofluoroscopic analyses, we also determined when clinician cues were accurate (1 = vLVC kinematics accurate, 0 = vLVC kinematics not accurate).

Comparisons and Statistical Analyses

Statistical analyses were conducted with SPSS (Version 22). A linear mixed effects model (Gelman and Hill, 2007) was used to compare the duration (sec) of vLVC among the 3 training groups. Pairwise comparisons were used when fixed effects were significant (Sidak corrected). Outcomes from both analyses were significant at $p < 0.05$.

A Kruskal Wallis nonparametric test was used to handle the ordinal data (i.e. 1 = accurate; 0 = inaccurate). Outcomes from this analysis were significant at $p < 0.05$. We compared the following among the 3 biofeedback training groups: (1) vLVC duration in seconds; (2) vLVC performance accuracy (2 sec duration); (3) vLVC performance accuracy (2 sec duration) within the required time window; and, (4) accuracy of clinician cues. The Mann Whitney test was used to derive pairwise comparisons where main effects were significant. These analyses were Bonferroni corrected for multiple comparisons by dividing the 0.05 alpha level by the number of comparisons when samples were related (3 training groups). Thus, our significance level was 0.016 (0.05/3).

Inter-rater reliability (20% of the data) and intra-rater reliability (5% of the data) were analyzed using single-measure intraclass correlation coefficients (ICCs) with a consistency of agreement definition.

Results

All participants were able to complete the study without adverse events. Rater reliability showed excellent agreement with an ICC of 0.99 for intra rater and 0.98 for inter rater reliability ($p < 0.001$). Six hundred swallows were recorded during the training portion of the study. Fifty-six of the 600 swallows were missed swallow trials (timing asynchrony with videofluoroscopy onset and the swallow). A total of 178 swallows from the EMG group, 192 swallows from the VF biofeedback group, and 174 swallows from the Mixed biofeedback group were analyzed. On average, the first accurate demonstration of vLVC required 2 attempts (range: 1-4).

vLVC Duration (seconds)

Fixed effects were significant when comparing among the 3 training groups ($p < 0.001$; $F = 41.8$). Pairwise comparisons showed that the duration of laryngeal vestibule closure during vLVC performance was longer for the VF training group (3.162, $SE \pm 0.067$ sec) compared to both the ssEMG (2.41 $SE \pm 0.075$ sec; $p < 0.001$) and Mixed (2.35 $SE \pm 0.075$ sec; $p < 0.001$) biofeedback groups. No significant differences were found when ssEMG and Mixed biofeedback groups were compared ($p = 0.91$).

1. Accuracy

a. vLVC performance accuracy (2 sec duration): A significant difference among the 3 groups was found when comparing frequency of vLVC performance accuracy ($p < 0.001$). The VF biofeedback group was accurate 92% of the time, the ssEMG biofeedback group was accurate 67% of the time, and the Mixed biofeedback group was accurate 57% of the time. Pairwise comparisons showed a significant difference in performance accuracy between the VF biofeedback and ssEMG biofeedback groups ($p < 0.001$) as well as between the VF biofeedback and Mixed biofeedback groups ($p < 0.001$). There was no statistically significant difference between the ssEMG and the Mixed biofeedback groups ($p = 0.054$).

b. vLVC performance accuracy (2 sec duration) within the required time

window: Performance accuracy within the required time window among the three groups was statistically significantly different ($p < 0.001$). Performance accuracy was accurate within the time window 80% of the time with VF biofeedback, 52% of the time with ssEMG biofeedback, and 47% of the time with Mixed biofeedback. Pairwise analysis confirmed significant difference between the VF biofeedback group compared to both the ssEMG and Mixed biofeedback groups ($p < 0.0001$). There were no statistically significant differences between the ssEMG and the Mixed biofeedback groups for this comparison ($p = 0.39$).

c. Accuracy of clinician cues: A significant difference in the distribution of clinician accuracy was found among the three visual biofeedback groups ($p < 0.001$). The clinician provided accurate cues about whether the vLVC was being performed correctly 61% of the time for both ssEMG and Mixed biofeedback groups and 83% of time with the VF biofeedback group. Pairwise comparison revealed a significant difference in clinician accuracy when the VF feedback group was compared to either the ssEMG or the Mixed biofeedback group ($p < 0.001$). There was no significant difference between the ssEMG and the Mixed biofeedback groups ($p = 0.952$).

Please see Figure 2, a summary of the accuracy results.

Discussion

The purpose of this study was to objectively assess the effects of 3 different visual biofeedback protocols when training a novel-swallowing maneuver. Our data support our hypotheses that accuracy of clinician cues and accuracy of performing the vLVC maneuver was improved with kinematic feedback provided by videofluoroscopy. When no kinematic information was provided, as in the ssEMG and Mixed biofeedback groups, the accuracy of

both the clinician cues and vLVC performance were poor. A mis-match between the ssEMG signal and hyo-laryngeal kinematics likely explains the poor accuracy (Figure 3).

It has been previously shown that when training a similar, novel swallowing maneuver (Mendelsohn maneuver), ssEMG did not accurately indicate the duration that hyo-laryngeal elevation and LVC were prolonged (Azola et al 2014). This is likely due to the lack of kinematic specificity of the ssEMG signal compared to VF images. One goal of this study was to determine if the differences between ssEMG and VF impacted training. The findings of this study indicate that neither clinician nor participant could translate the ssEMG signal into accurate kinematic judgments about LVC. In particular, for the participants, it appears that ssEMG did not enhance internal feedback to increase accurately produced target LVC movements during training.

Despite confirming accurate vLVC performance in the Mixed biofeedback group, subsequent training with ssEMG biofeedback did not maintain accurate performance during the training phase. A possible explanation for this finding is the critical role played by both consistent kinematic information during training and the verbal cues on knowledge of performance and results (Buekers, 1992). It appears that even though the participants were able to initially properly perform the task under videofluoroscopy in the Mixed biofeedback group, ssEMG and erroneous clinician cues based on non-kinematic information from ssEMG during training reversed the gains that were previously made.

Previous work by Macrae et al (2014) provided evidence of the valuable role for extrinsic feedback in swallowing maneuver training. The verbal cues provided by clinicians in that study were based on real-time video fluoroscopic findings and, unlike our study, the subjects were not shown the videofluoroscopy images. This finding highlights the potential positive impact of clinician verbal cues when training kinematics that are hidden from the naked eye. Further studies to discern the specific roles played by verbal versus visual based feedback are needed with the goal of improving swallowing maneuver training (i.e. effortful swallow, supra-glottic swallow, etc.).

Clinical Implications

The goal of extrinsic feedback in rehabilitation settings is to aid patients in increasing intrinsic feedback and eventually improve a movement task. When ssEMG visual biofeedback was used, there was a potential mis-match between the participants' swallowing movements, the non-kinematic information being viewed, and the clinician's verbal cues. For instance, in trials when the participants were inaccurately performing the vLVC maneuver, the clinician was likely encouraging this behavior based on the ssEMG output. It is likely that this same type of mismatch is occurring in dysphagia rehabilitation where kinematic feedback is not possible and other forms of indirect feedback options are thought to be reliable (i.e. ssEMG, neck palpation). This puts patients at risk for learning maladaptive behaviors. Limitations of the current study prevent any conclusions about the prevalence of clinician-encouraged maladaptive training. However, patients may be more vulnerable to the negative impact of incorrect information from either a clinician or visual biofeedback since their underlying mechanism is disordered and they may rely more heavily

upon external representations of their internal movements. It is important to note that accuracy rates might differ in patients who likely require more than one training session of 20 trials to learn the maneuver as well as can differences in the level of clinician understanding and interpretation of videofluoroscopy and ssEMG – both are limitations of this study. Future studies are needed to understand the role of extrinsic feedback in individuals with dysphagia to improve outcomes in dysphagia rehabilitation.

Conclusion

The goal of the study is not to promote the use of videofluoroscopy in dysphagia rehabilitation therapy, but to better understand the role and potential limitations of ssEMG as a biofeedback tool (and potentially other non-kinematic options such as palpation) in swallowing. Our findings highlight the importance of clinician cues in swallowing rehabilitation and potential deleterious effects of misinterpretation of the most prevalent biofeedback tools. Surface EMG can be a powerful tool that enhances motor learning and motivates patients during the therapy sessions when paired with movements that the signal directly represents (as shown in the limbs) (18). Nevertheless, its proper use and limitations need to be clearly understood by clinicians involved in swallowing rehabilitation.

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Figure 1.
Sample of training time window: Start signal, followed by the 2 second task and end signal.

Figure 2.

Pairwise comparisons showed statistically significant differences in subject and clinician accuracy when VF biofeedback was compared to both the EMG and the Mixed biofeedback group ($p < 0.001$) (*). No significant differences were found when ssEMG and Mixed biofeedback groups were compared in terms of subject or clinician.

Figure 3.

Example of mis-match between ssEMG and VF biofeedback in a subject attempting the task of volitional LVC. Above, the EMG output with a consistent increase in signal for over 2 seconds, leading the clinician to the inaccurate conclusion that the task was completed. Below, the VIDEOFLUOROSCOPY still images showing an initial full LVC lasting <1 sec (A), followed by partial opening of the vestibule (B), failing to correctly perform the maneuver. Image C demonstrates the airway structures at rest.