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Electromyography as a Biofeedback Tool for Rehabilitating Swallowing Muscle Function

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1. Introduction

Dysphagia (swallowing impairment) is a common and serious problem in individuals who have suffered neurological injuries (strokes, acquired brain injury) as well as individuals with neurodegenerative conditions or head and neck cancer. The effortful swallow and Mendelsohn maneuver are two therapy techniques, recommended to address specific muscle-function related abnormalities in dysphagia due to neurological injury. The process of swallowing is a complex neuromuscular sequence, involving contributions from approximately 25 pairs of muscles in the upper aerodigestive tract. Contraction of the floor-of-mouth muscles (particularly the mylohyoid and geniohyoid) facilitates upward and forward movement of the hyoid and larynx in swallowing (Burnett et al., 2003; Pearson et al., 2010). Hyolaryngeal movement has two important functional consequences: 1) closure of the entrance to the airway; and 2) opening of the sphincter between the pharynx and the esophagus, i.e., the upper esophageal sphincter (UES), via traction forces (Cook et al., 1989). Patients with reduced hyolaryngeal excursion in swallowing are at risk for aspiration (entry of foreign material into the airway) and post-swallow residues, particularly in the pyriform sinuses, which lie just above the UES. The structures involved in swallowing are illustrated in Figure 1, which is a still shot taken from a videofluoroscopic swallowing study (VFSS) showing aspiration of material into the trachea as well as residues in the valleculae and pyriform sinuses.

Surface electromyography (sEMG) is useful for monitoring performance of the effortful swallow and Mendelsohn maneuver exercises, which are indicated as therapy techniques for patients with reduced hyolaryngeal movement in swallowing. SEMG can be used to collect and display information regarding performance of these maneuvers in treatment; such performance-contingent information can enhance motivation, compliance and task-performance. For the effortful swallow, sEMG can be used to measure the amplitude of muscle contraction used by a patient and to compare this to their regular swallowing. Amplitude targets can be used to guide a patient to work harder on this exercise, and sEMG information can be used to inform both the patient and the clinician of success in achieving these targets across the course of treatment. For the Mendelsohn maneuver, the goal is to

maintain submental muscle contraction and excursion of the hyolaryngeal complex, thereby prolonging opening of the UES (Mendelsohn & McConnel, 1987); sEMG can be used to measure and display the duration of muscle contraction used in this task.
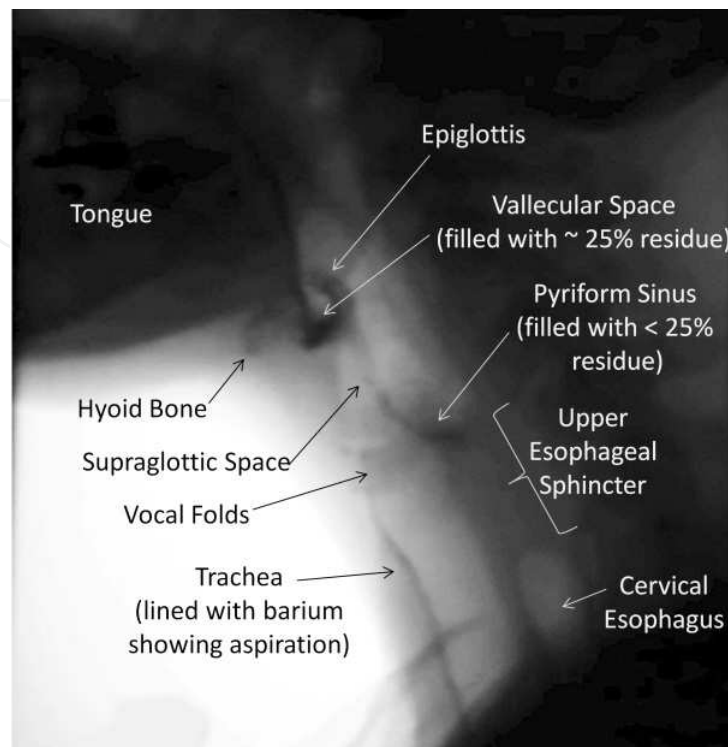

Fig. 1. A still x-ray image, taken from a videofluoroscopic swallowing study. This image shows the oropharyngeal anatomy, and includes evidence of mild residue (up to 25% of the available space) in the valleculae and pyriform sinuses. Additionally, evidence of prior aspiration is evident as a thin line of barium running down the front wall of the trachea.

In the Swallowing Rehabilitation Research Laboratory at the Toronto Rehabilitation Institute, we have developed a treatment protocol using sEMG biofeedback for patients with neurogenic dysphagia, for whom either the effortful swallow and/or the Mendelsohn maneuver are indicated. The protocol uses software that has been developed in conjunction with the Biofeedback Foundation of Europe (www.bfe.org), displaying a sEMG signal representing the composite muscle activity of the floor-of-mouth muscles (likely including the mylohyoid, geniohyoid, anterior belly digastric and genioglossus muscles). Patients who complete this protocol practice approximately 60 saliva swallows per treatment session, over 20-24 sessions, scheduled twice weekly. Tasks include amplitude target practice (for non-effortful and effortful swallows) and muscle contraction prolongation (for the Mendelsohn maneuver). Functional outcomes are measured using a standardized videofluoroscopic swallowing study (VFSS), comparing post-treatment function to baseline performance. Two videofluoroscopic measures are of particular interest: 1) the Penetration-Aspiration Scale, an 8-point ordinal scale measuring the depth of airway invasion; and 2) measures of post-swallow residue, captured using a 4-point ordinal scale reflecting the degree to which the available space in the pyriform sinuses is filled with residue (Eisenhuber et al., 2002). In this chapter, we will share sEMG and outcome data from several patients who have completed treatment using sEMG biofeedback.

2. Methods

2.1 Instrumentation

An adhesive triode electrode patch is attached under the participant's chin with the positive and negative electrodes positioned just lateral to midline, anterior to the hyoid bone (Figure 2). The reference (ground) electrode is positioned away from the muscles of interest. The electrodes are attached to an EMG device (MyoTrac Infiniti, Thought Technology, Montreal) using a sensor cable and the signal from the device is registered on a computer using specialized software (BioGraph Infiniti, Thought Technology, Montreal).
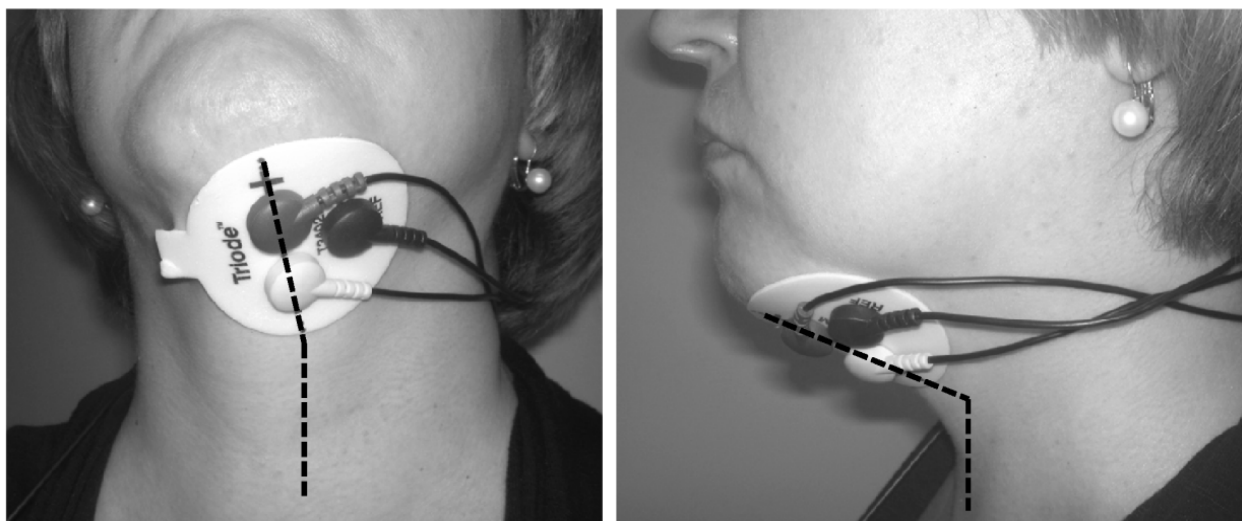
Fig. 2. Electrode attachment under the chin, just lateral to midline, with the reference electrode off to one side.

2.2 Treatment protocol

We recommend that a treatment session should include 60 swallows, practiced in 12 sets of 5 swallows. The protocol involves a progression of tasks from "regular effort saliva swallows" (RESS) to "effortful saliva swallows" (ESS) and, where indicated, "Mendelsohn Maneuver saliva swallows" (MM), as illustrated in Figure 3.

Step 1 in the protocol is a check of the submental sEMG signal to make sure that the electrodes are correctly displaying activity of the floor of mouth musculature. Once the electrodes have been positioned and connected, the clinician should ask the patient to perform some tasks that are expected to display variations in signal amplitude of the submental muscles, such as jaw opening.

Step 2 in the protocol involves a baseline measurement of sEMG amplitude during regular-effort saliva swallows. For this task, we recommend that the patient to produce one saliva swallow every 30 seconds, followed by a rest period. If the patient has extreme difficulty initiating a saliva swallow, a tiny amount of water may be taken to provide a stimulus. The 30-second cycle of resting and swallowing is repeated 5 times, allowing a measurement of the patient's average saliva swallow amplitudes for that session. All

amplitude targets for other tasks in the session are then set relative to the baseline swallow measures for the session. This ensures that artifacts in sEMG amplitude due to variations in electrode placement and contact across sessions and participants do not interfere with the treatment protocol.

```
┌─────────────────────────────────────────────┐
│  Attach  recording electrodes under the chin,│
│  between genium and hyoid bone, with reference│
│  electrode away from muscles of interest     │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Ensure signal quality and appropriate graded│
│  amplitude response to volitional tasks of varying effort│
│  (e.g., jaw opening)                         │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Record baseline series of 5 regular effort saliva swallows│
│  [RESS]: 1 per 30 seconds, with rest in between│
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Determine RESS reference range (peak amplitude minus│
│  rest amplitude, in microVolts), from baseline task│
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Practice RESS with target set at 100% of RESS Reference│
│  Range: 3-5 series X 5 swallows              │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Practice Effortful Saliva Swallows (ESS), with target set│
│  above 100% of RESS Reference Range and increasing in│
│  increments of 10-20%: 3-5 series X 5 swallows│
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Practice Mendelsohn Maneuvers (MM), with lower│
│  threshold set at 30% of RESS Reference Range.  Goal is│
│  to prolong contraction above this value for 2-3 seconds:│
│  3-5 series X 5 swallows                     │
└─────────────────────────────────────────────┘
                      ↓
┌─────────────────────────────────────────────┐
│  Session is complete after 60 swallows       │
└─────────────────────────────────────────────┘
```
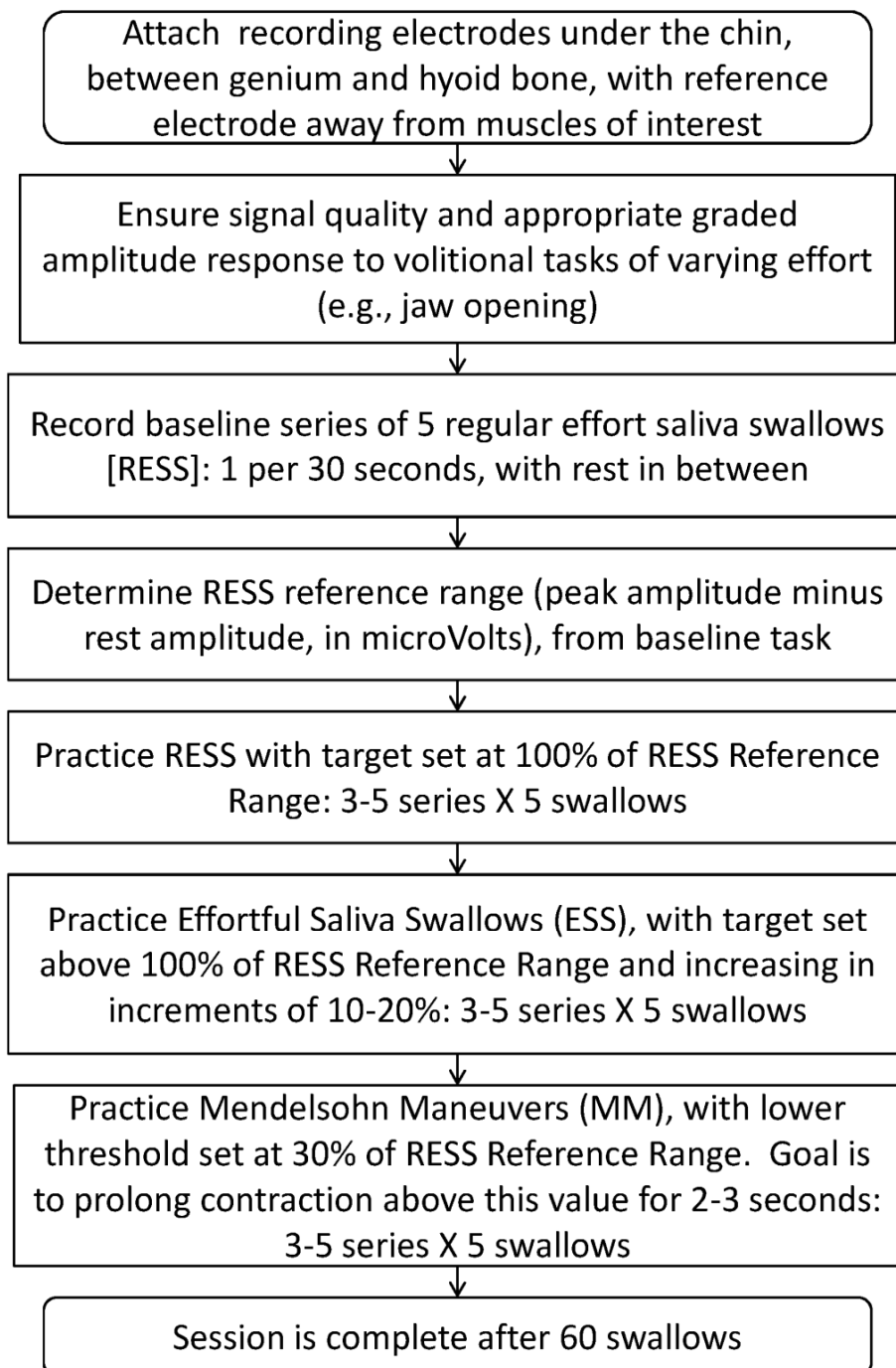
Fig. 3. Flow-chart of a typical sEMG biofeedback session for swallowing rehabilitation.

Step 3 in the treatment protocol involves further practice of RESS. The protocol proceeds in a similar manner to the previous baseline task, with alternating cycles of 20-second-long rests and 10-second intervals in which a saliva swallow should be produced. In contrast to the previous task, however, this step in the protocol involves establishing a target amplitude for the peak of each swallow. This target is set between 90% and 110% of the mean peak amplitude measured in the baseline task, and a target line appears on the screen. Success on this task is defined as a mean peak amplitude within 10% of target across a series of 5 repeated saliva swallows.

Step 4 in the treatment protocol proceeds to the practice of effortful saliva swallows (ESS). Here the goal is to contract the swallowing muscles with greater effort so that the signal amplitude reaches higher values. We begin working at 110% of the mean peak amplitude measured in the baseline reference task. Once the patient can produce swallows within 10% of this target on two successive series of 5 saliva swallows, the challenge level is increased incrementally by steps of 10%. We recommend increasing the difficulty in steps of 10%. Figure 4 displays a typical 2 ½ minute recording of submental muscle activity during practice of the ESS task.
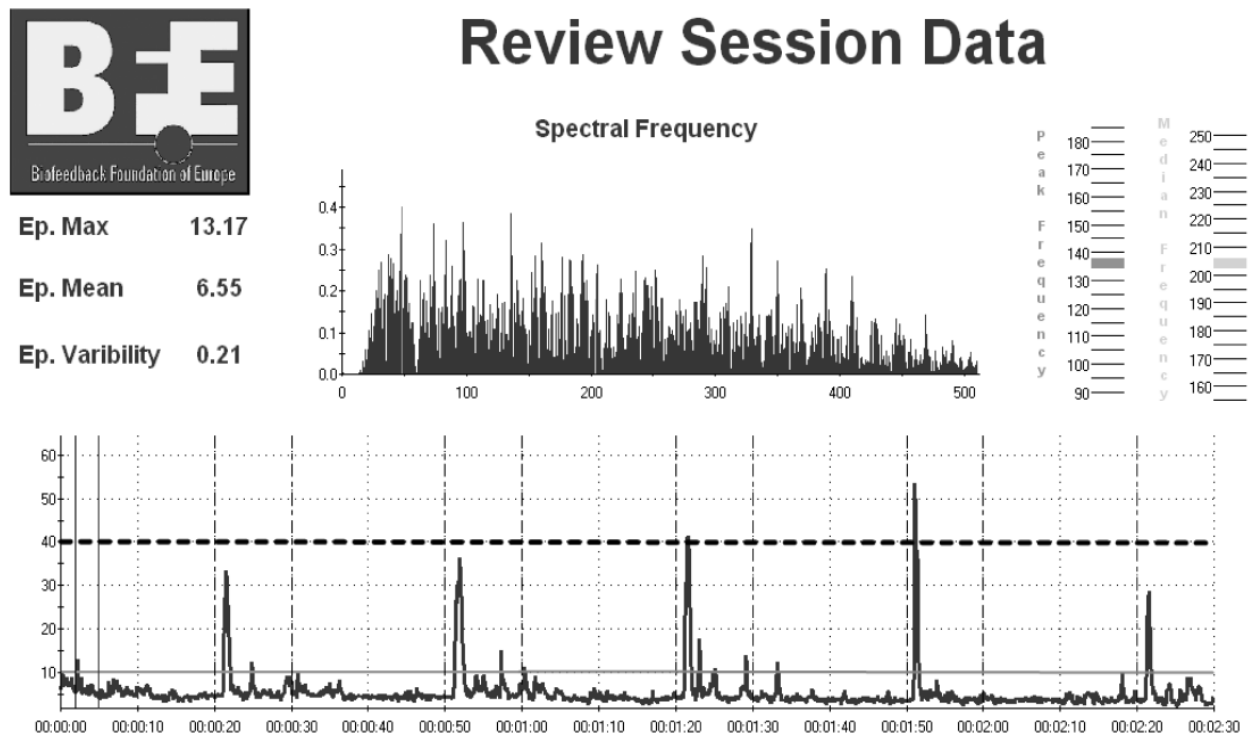
Fig. 4. A series of 5 effortful swallows is shown, one swallow per 30 seconds. The dashed black line shows an amplitude target line set at 40 microvolts. Success in reaching or surpassing this target is illustrated for the 3rd and 4th ESS of the series.

The final step in the treatment protocol is optional practice of the Mendelsohn Maneuver (MM). The goal of this task is to prolong the muscle contraction associated with swallowing. It is important that the event begins with a real swallow, leading into a sustained muscle contraction. The sEMG profile displayed on the screen is described to typically look like a straight-backed chair, where the signal first reaches a swallowing peak, then drops slightly, and is then maintained for 2-3 seconds (Figure 5). For this task, we recommend using a lower threshold of 30% of the reference amplitude range and measuring the duration of time that the patient maintains contraction above this level.
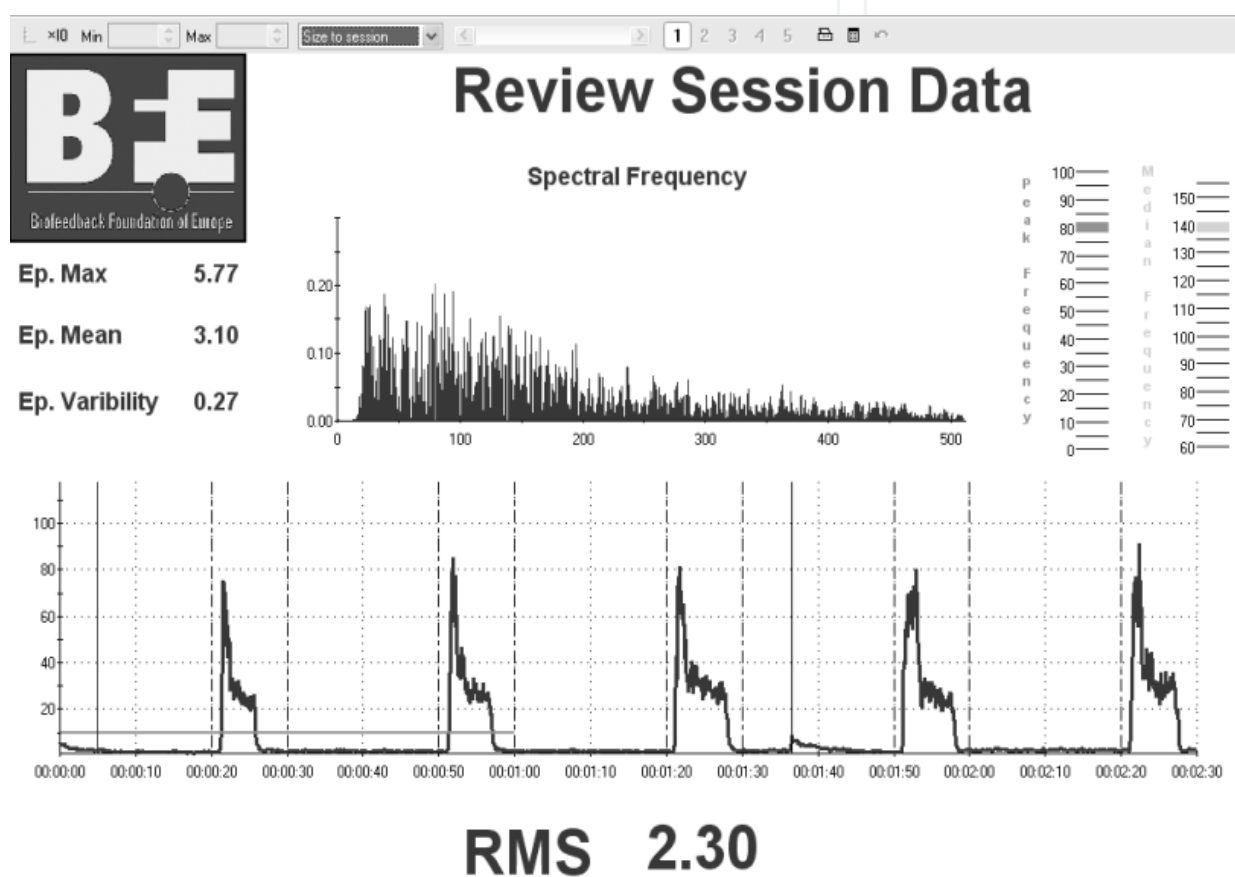
Fig. 5. A series of 5 Mendelsohn Maneuvers, displaying the characteristic straight-backed chair profile, beginning with a peak amplitude associated with a saliva swallow, and followed by prolongation of muscle contraction for 2-3 seconds, above a lower threshold set by the clinician (recommended value: 30% of regular effort saliva swallow amplitudes).

3. Case reports

Over the past three years, we have been following patients who participated in this treatment protocol at three hospitals. Patients are selected based on videofluoroscopic

evidence of reduced hyolaryngeal excursion or post-swallow residues in the pyriform sinuses on a standardized VFSS examination. In a retrospective review of patients, we were able to find several cases in which fairly complete sEMG signal data were available, together with pre- and post-treatment videofluoroscopy recordings. Complete data of this nature are not always available, due to signal quality issues, or decisions by the treating clinician to retain only a portion of the data from a particular session.

In this chapter, we will use the available data to explore five questions regarding the use of sEMG biofeedback in dysphagia therapy.

1. How variable are sEMG amplitudes for the submental muscles in regular-effortsaliva swallows across repeated sessions within individual participants?
2. To what extent do effortful swallow sEMG peak amplitudes increase over time in patients with dysphagia?
3. Do videofluoroscopic measures of swallowing function improve with increases in sEMG peak amplitudes on effortful swallows?
4. To what extent does the duration of muscle contraction increase in patients who practice the Mendelsohn Maneuver?
5. Do videofluoroscopic measures of swallowing function improve with increases in the duration of muscle contraction secondary to practice of the Mendelsohn Maneuver?

3.1 How variable are sEMG amplitudes for the submental muscles in regular-effort saliva swallows across repeated sessions within individual participants?

To answer this question, we extracted sEMG data for the baseline RESS task from the first 8 available treatment sessions in 8 patients and 2 healthy, young controls (one female, one male). Signals were first visually inspected for obvious artifact, combined with a review of notes recorded by the clinician during each session; where necessary, portions of the signal containing artifact were removed using an ignore-segment function in the sEMG software. Amplitude range (peak minus rest) for the RESS baseline task is plotted by participant in Figure 6, with dashed lines showing a one standard deviation confidence interval band around the mean.

As can be seen from the varying scales on the y-axes in Figure 6, the actual value of the peak-minus-rest amplitude range (in microVolts) varied considerably across participants. The majority of participants showed maximum peak values below 100 microVolts, but this was not true for Control 2, nor for patient participants 4 and 8. Previous literature suggests that sEMG amplitudes may vary as a function of the amount of fatty tissue between the surface of the neck and the underlying muscles; this may have been one of the factors contributing to the higher amplitudes seen in these individuals. Furthermore, it can be seen that both controls and all 8 patient participants showed at least one outlier session, for which the recorded amplitude range fell outside the boundaries of a one standard deviation confidence interval. Minor variations in electrode placement and contact from session to session may contribute to such fluctuations in sEMG amplitude. The presence of fluctuating amplitudes across these data supports the need to normalize all sEMG amplitude values to a within-participant within-session reference value prior to interpretation or groupwise statistical analysis. This is a standard step in our protocol, achieved by recording a series of RESS at the beginning of the session, and subsequently transforming all other amplitude measures to a percent of the mean baseline RESS range.
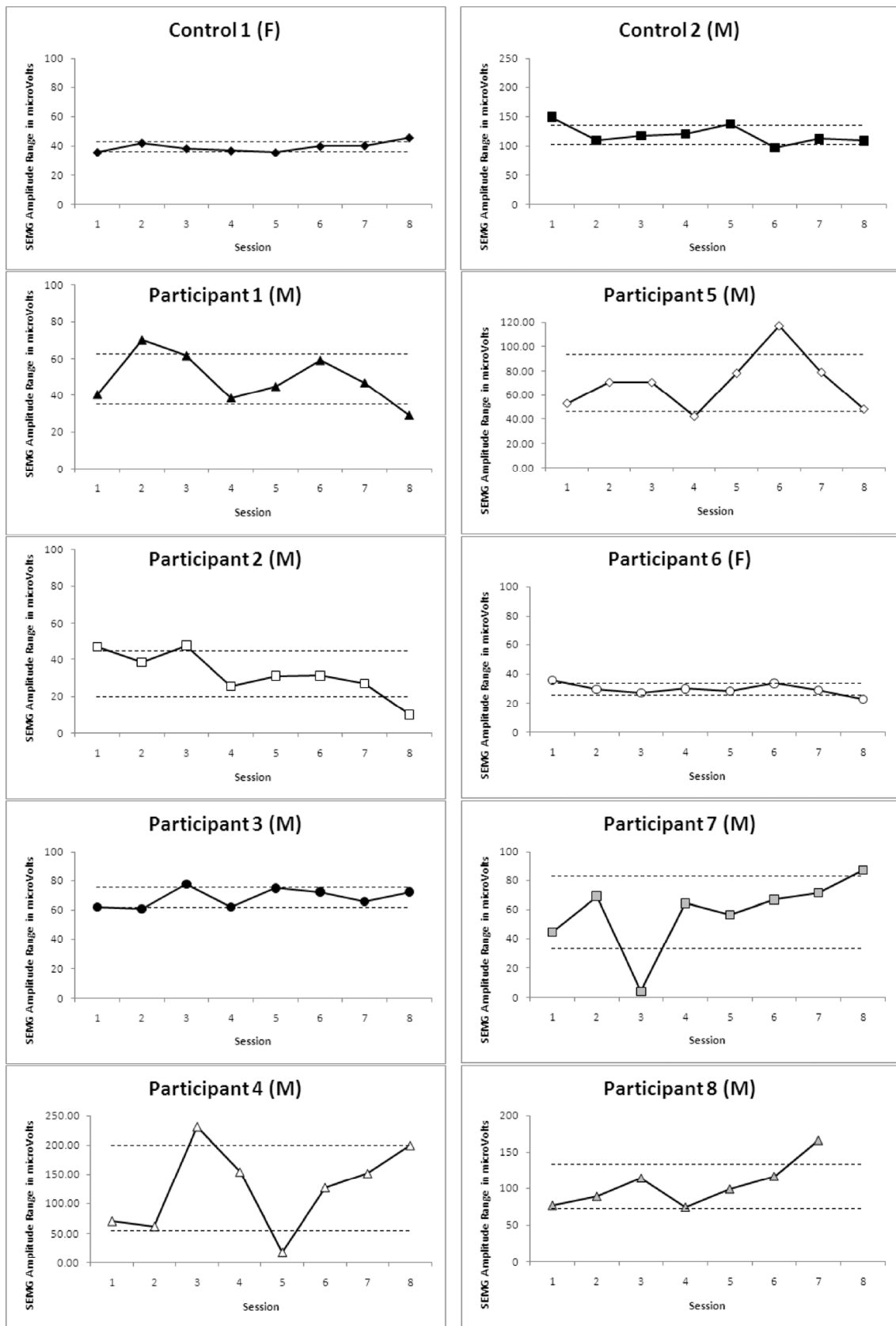
Fig. 6. Regular effort saliva swallow (RESS) amplitude range across repeated recording sessions in two healthy controls and eight patients with dysphagia.

3.2 To what extent do effortful swallow sEMG peak amplitudes increase over time in patients with dysphagia?

Six of the patient participants in this case series had available data for effortful swallows from at least 5 treatment sessions. Table 1 provides demographic information regarding these 6 participants.

Participant	Gender	Age	Primary Diagnosis
2	M	49	Acoustic neuroma; damage to adjacent cranial nerves
4	M	75	Stroke
5	M	68	Sudden onset of dysphagia with vocal fold paresis
6	F	88	Stroke
7	M	88	Stroke
8	M	69	Spinal cord injury with tetraplegia

Table 1. Demographic information regarding the cases discussed in this chapter.

For the purposes of calculating change in effortful swallow performance, all ESS amplitude data were first transformed into percentage values relative to RESS range, using the method described in section 3.1 (above). A baseline reference range for effortful swallows was then established by calculating the mean and standard deviation of all ESS values in the first two treatment sessions for each participant. As shown in Figure 7 one (grey) and two (black) standard deviation bands were plotted around the baseline mean on a control chart for each participant. Mean ESS amplitude range was then plotted for each treatment session.

Standard deviation banding methods for single subject analysis usually specify a criterion for concluding that a participant is showing change, namely the demonstration of two successive data points falling beyond a specified standard deviation boundary (Nourbakhsh & Ottenbacher, 1994). Applying a two standard deviation criterion, Figure 7 shows that participant 2 demonstrates an apparent increase in ESS values at probes 3 and 4, but this trend was not sustained and reverses at probe 5. The values seen at probe 4 are also sufficiently outlying to suggest the possibility that some sort of measurement artifact may have been affecting those data. Participants 5 and 7 both show a general trend towards increasing ESS values, but these changes fail to cross either the one or two standard deviation boundaries across more than a single session. The outlier value for probe 14 in participant 7's data is sufficiently larger than other probes to suggest an artifact effect. Participant 8 shows an overall upward trend in ESS values with the final two probes sitting at or above the two standard deviation bandwidth. Participant 6 shows very little evidence of change across treatment, remaining within the standard deviation bands. Participant 4 shows a general downward trend in ESS values across probes, but with values consistently falling within a single standard deviation band. Based on these graphs, it would appear that only participant 8 showed a convincing increase in effortful saliva swallow amplitudes, expressed as a percent of RESS range. Caution must, however, be used in accepting this interpretation, given the uneven number of data points available across participants.
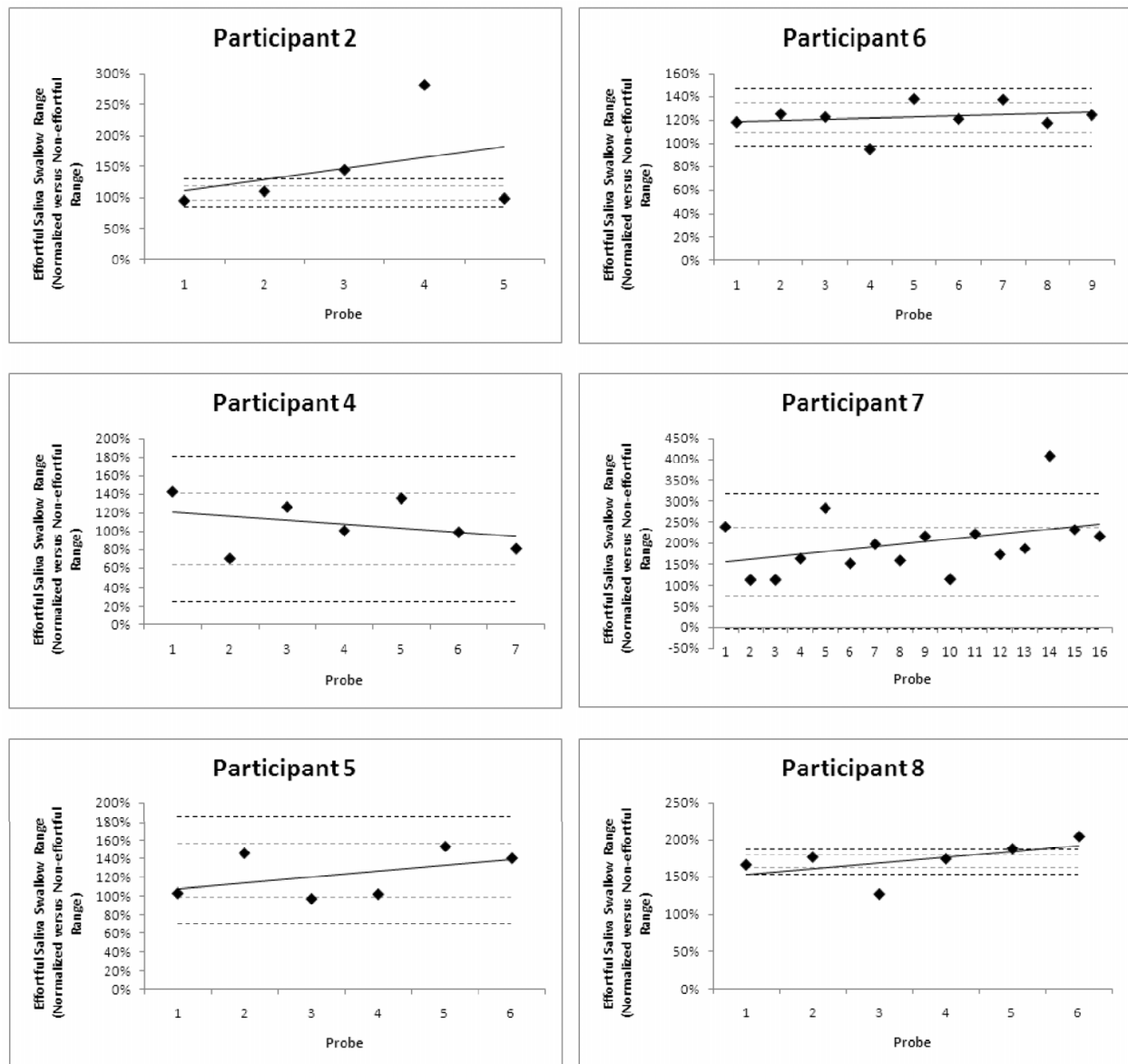
Fig. 7. Charts showing the standard deviation banding method of monitoring change in effortful saliva swallow (ESS) amplitudes, expressed as a percentage of regular effort saliva swallow (RESS) reference range, in six patients with dysphagia. Light-grey dashed horizontal lines represent a 1 standard deviation confidence interval around the patient's baseline ESS performance. Black dashed horizontal lines represent a 2 standard deviation confidence interval. Change is considered to have occurred when two consecutive data points fall outside the 2 standard deviation confidence interval boundaries.

3.3 Do videofluoroscopic measures of swallowing function improve with increases in sEMG peak amplitudes on effortful swallows?

The literature on swallowing intervention contains two impressive examples of case series, in which patients who have practiced effortful swallows and/or Mendelsohn maneuvers using sEMG biofeedback have shown dramatic functional improvement (Crary, 1995; Crary & Groher, 2000; Crary et al., 2004; Huckabee & Cannito, 1999). However, in these studies, change has been reported in terms of clinical measures of diet

texture tolerance rather than using objective blinded rating of standardized videofluoroscopies. It remains unclear whether specific physiological parameters in swallowing that are logically linked to the strength or duration of suprahyoid muscle contraction change following such treatment.

Our understanding of the effortful swallow is that it should enhance bolus propulsion and clearance through the oropharynx in swallowing (Bülow et al., 1999; Bülow et al., 2001; Hind et al., 2001). Therefore, the primary videofluoroscopic parameter expected to respond to this exercise would be post-swallow residue. Other parameters that are logically related to this treatment might include the range of hyolaryngeal excursion and measures of bolus flow velocity or kinematics (Clave et al., 2006; Hind et al., 2001). In our series, pre- and post-treatment videofluoroscopy recordings were available for analysis for four of the six patients discussed previously under question 2 (participants 2, 4, 7 and 8). These recordings were spliced into clips containing the swallowing sequence for each bolus presented. The first two thin liquid and two thick liquid swallow clips were then arranged in random order and rated by two experienced speech-language pathologists, blinded to the identity of the patient participant and the timepoint of each swallow. We chose to rate post-swallow residues in the valleculae and pyriform sinuses using 4-point ordinal rating scales developed by Eisenhuber and colleagues (Eisenhuber et al., 2002). We also used the 8-point Penetration-Aspiration Scale (Rosenbek et al., 1996) to measure airway invasion, although this feature was not necessarily expected to change as a function of treatment.

Scores for post-swallow vallecular residue remained unchanged for all participants across treatment. This finding is not particularly surprising, given that vallecular residue is thought to arise primarily from weak tongue propulsion forces in swallowing, and these were not directly targeted in therapy. Pyriform sinus residues, however, were expected to respond to block practice of the effortful swallow. In this respect, participant 7 showed a marked improvement with thickened liquids, from pre-treatment values of 3 (severe) to post-treatment values of 0 (no residue). Participant 4 showed a slight improvement on this variable for thin liquids, shifting from a severe to a moderate rating. Participants 2 and 8 showed no changes in pyriform sinus residue measures, which remained in the moderate-severe range for both thin and thick liquid stimuli. The change seen in participant 7 correlates with the overall upward trend seen in this participant's effortful saliva swallow strength, as indexed by sEMG amplitude data (refer back to Figure 7). Participant 4, however, did not display a noticeable increase in effortful saliva swallow sEMG amplitudes (Figure 7), hence the apparent change in residue scores is not obviously explained by their sEMG measures. Similarly, it is important to note that participant 8, who displayed noticeable increases in effortful saliva swallowing amplitudes (Figure 7) showed no measurable change in swallowing residues, thus challenging the assumption that an association can be expected between these measures.

Penetration-Aspiration Scale scores were not seriously impaired at baseline in this subgroup of four patients. The worst baseline performance on this measure was seen in participant 7, who displayed a score of 3 (i.e., airway invasion into the supraglottic space, above the vocal folds) with thickened liquid stimuli. Participant 4 also displayed airway invasion to this level with both thin and thickened stimuli, but this was noted to clear spontaneously (score of 2). Post-treatment, all four participants showed normal scores on

the Penetration-Aspiration Scale, with the exception of participant 2 who had a single episode of aspiration (entry of material into the airway below the level of the vocal folds) with a thin liquid stimulus.

3.4 To what extent does the duration of muscle contraction increase in patients who practice the Mendelsohn Maneuver?

For two of the patients in our retrospective series, the Mendelsohn Maneuver was the primary focus of treatment. As mentioned previously, this technique emphasizes prolongation of muscle contraction. The functional goal of this exercise is to enhance the degree and duration of UES opening, via biomechanical traction forces related to suprahyoid muscle contraction. In our protocol, the sEMG measures associated with performance of the Mendelsohn Maneuver include the time duration (in seconds) for which muscle contraction is maintained above a 30% lower threshold value, calculated relative to the patient's non-effortful saliva swallow sEMG amplitude range in that session. Additionally, we monitor the mean amplitude of sEMG contraction across the entire duration of the maneuver, normalized to a percentage of the patient's RESS range. It should be noted that the duration rather than a high amplitude of muscle contraction is the focus of the exercise.

Participant 1 in our series was an 82-year-old gentleman who displayed a particular impairment in UES opening, with a visible cricopharyngeal prominence suggesting failed muscle relaxation at the sphincter. The onset of his dysphagia had been sudden, and remained medically unexplained. Figure 8 shows that this patient improved in his ability to maintain muscle contraction from 0.5 to 1.23 seconds across 11 probes. Using a standard deviation banding method similar to that described previously, this patient shows convincing evidence of improvement in Mendelsohn Maneuver durations, beginning around probe 5. This contrasts with his average Mendelsohn Maneuver amplitudes, which remained fairly constant around 30% of the RESS range across treatment (Figure 9).
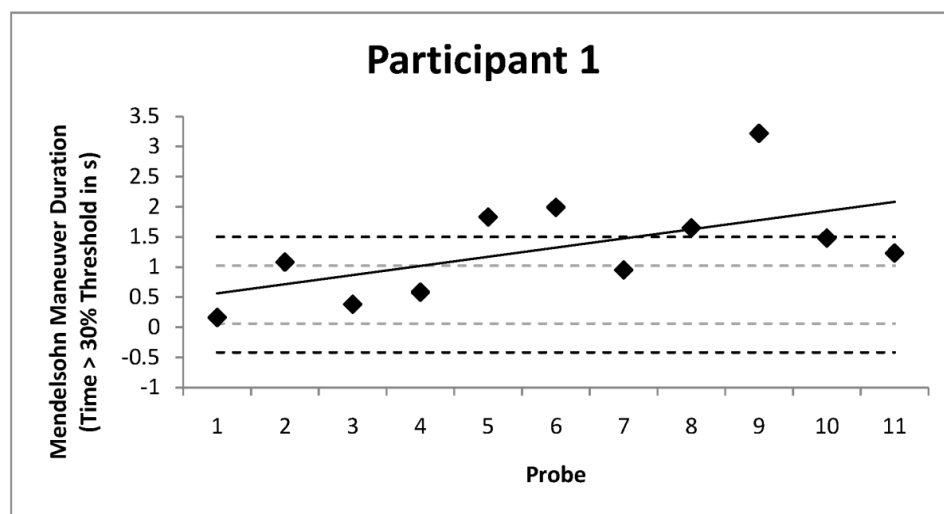

Fig. 8. Change in Mendelsohn Maneuver durations over time for participant 1. This individual showed an increase from baseline durations of 0.5 seconds to 1.23 seconds after 11 probes. The later data points approach the 2 standard deviation band confidence interval boundaries, suggesting that change has occurred.
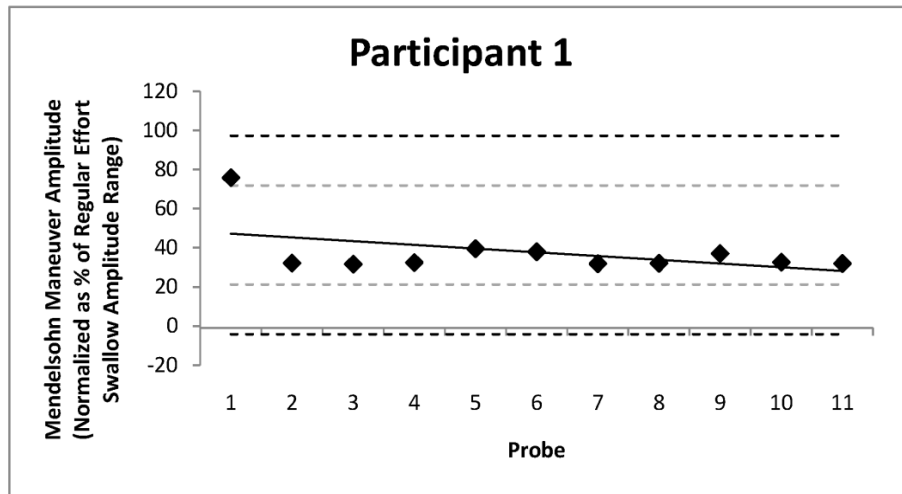
Fig. 9. Mendelsohn Maneuver amplitudes, expressed as a percentage of RESS range, plotted over time for participant 1. In contrast to the duration data shown in Figure 8, this plot shows that sEMG amplitude for this task has remained stable without evident change over 11 probes.

Participant 3 was a 55-year-old gentleman with dysphagia secondary to cervical spine surgery. He displayed a particular impairment with persistent moderate post-swallow residues, together with reduced excursion of the hyoid and larynx. Although this patient showed a slight upward trend in his Mendelsohn Maneuver duration data, he failed to show a marked change that reached or surpassed the 2 standard deviation band criterion, as illustrated in Figure 10. However, it should be noted that he started treatment with an ability to sustain the maneuver for 2 or more seconds, which is notably longer than the values seen for participant 1. His average sEMG amplitudes show a contrasting result to the
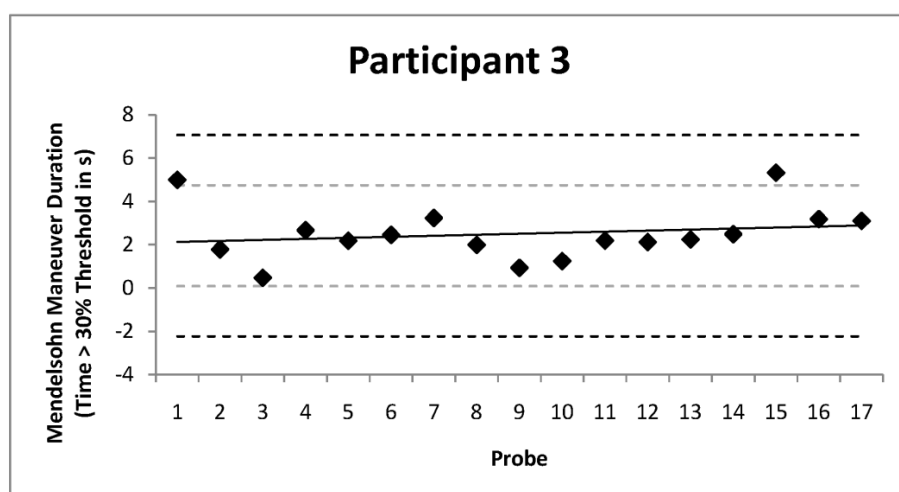
Fig. 10. Mendelsohn Maneuver durations over time for participant 3. In contrast to the data shown for participant 1 in Figure 8, this individual showed stable durations, which failed to exceed the 2 standard deviation band confidence interval boundaries, suggesting that no change occurred.

durational data, with an upward trend that surpassed the 2 standard deviation band criterion at probe 14 (Figure 11). Thus, this patient improved in his ability to sustain a strong level of muscle contraction throughout the duration of the maneuver.
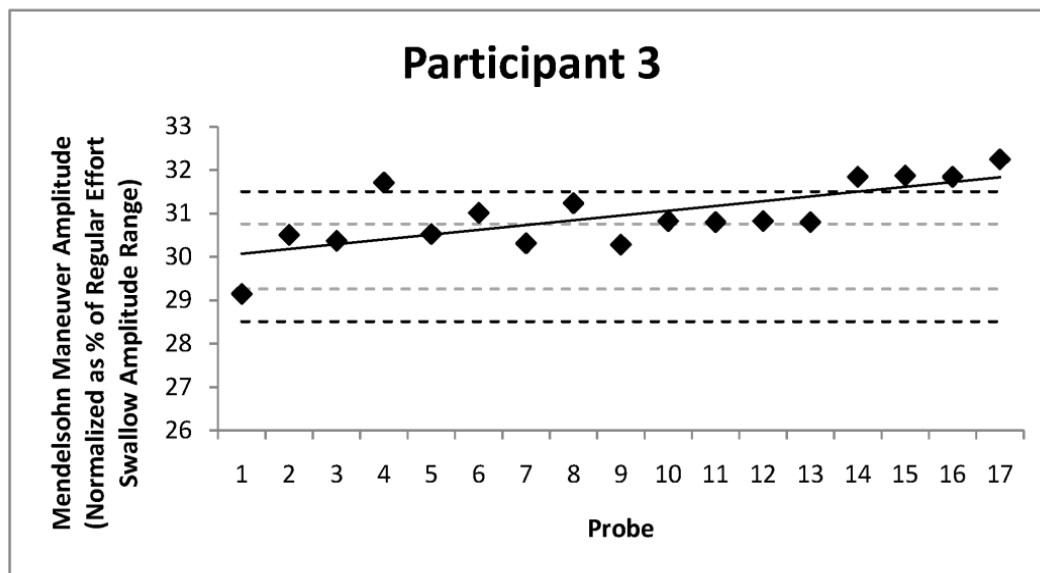

Fig. 11. Mendelsohn Maneuver amplitudes over time for participant 3, normalized to RESS range. In contrast to the durational data shown in Figure 10, an apparent increase in this measure is seen between probes 14 and 17, with data points surpassing the 2 standard deviation band confidence interval boundary.

3.5 Do videofluoroscopic measures of swallowing function improve with increases in the duration of muscle contraction secondary to practice of the Mendelsohn Maneuver?

The primary physiologic outcomes related to practice of the Mendelsohn Maneuver include upper esophageal sphincter opening width and duration, range and duration of hyoid excursion, and post-swallow pyriform sinus residues. As with the cases discussed previously, we collected pre- and post-treatment videofluoroscopies for participants 1 and 3 using a standardized protocol, and recordings were then spliced into individual swallow clips for blinded rating by expert speech-language pathologists.

From these recordings, we also extracted the following still frame images, which were used to measure UES opening width, and hyoid position and displacement in Image J software:

a. Frame of UES opening
b. Frame of maximum superior hyoid excursion
c. Frame of maximum anterior hyoid excursion
d. Frame of UES closure
e. Frame of minimum hyoid position after UES closure

All spatial measurements were performed in a coordinate system rotated into alignment with the cervical spine, using an origin positioned at the anterior inferior corner of the C4

vertebral body and normalizing all displacement and position-distance measures to the participant's height by transforming position and displacement measures to a percent of the participants C2 to C4 neck length (Steele et al., 2011). These methods correct for differences in x-ray magnification across images and control for differences in participant height. During the process of extracting these images, the timepoints of UES opening and closing were also recorded, allowing the calculation of the duration of UES opening.

Superior hyoid displacement is thought to arise primarily from contraction of the mylohyoid muscle while anterior displacement is principally achieved through geniohyoid contraction (Pearson et al., 2010). The Mendelsohn Maneuver likely engages both of these muscles; consequently, increases in hyoid excursion in both the superior and anterior direction might reasonably be anticipated as outcomes of this maneuver. Hyoid excursion in this study was measured as a percentage of the C2-C4 anatomical distance, henceforth called a "cervical unit" (CU). Current best evidence in the field suggests that vertical movements that fall below 44% and anterior movements that fall below 27% of this anatomical reference are associated with penetration-aspiration and post-swallow residues (Steele et al., 2011).

Participant 1 in our case series began treatment with substantially reduced upward movement of the hyoid (36% for thin liquids and only 22% for thick liquids); his anterior movement was not markedly impaired, falling at 46% and 51% for thin and thick liquids, respectively. Post-treatment, this patient demonstrated almost a doubling in his superior hyoid movement excursion, at 44% (thin) and 43% (thick). Anterior excursion remained stable at 44% in both planes of movement. By contrast, participant 3 began with a substantial reduction in the degree of anterior hyoid excursion at 12% and 16% for thin and thick liquids, respectively. Superior excursion was of less obvious concern, at 45% (thin) and 58% (thick). Post-treatment, anterior excursion had improved to approximately double the baseline values, at 25% (thin) and 36% (thick). Superior excursion remained fairly stable at 49% with thin liquids, but fell to 39% with thick liquids. Thus, it appears that both of these patients achieved improvements in the aspect of hyoid excursion that was most impaired following practice of the Mendelsohn Maneuver using sEMG biofeedback.

Participant 1 had average pre-treatment UES opening widths of 16% for thin liquids and 17% for thick liquids. Pre-treatment UES opening durations were 0.5 seconds for thin liquids and 0.7 seconds for thick liquids. Post-treatment his UES opening widths remained stable at 16% for thin liquids but actually decreased to 13% for thick liquids. Post-treatment UES durations increased to 0.6 seconds with thin liquids but remained stable at 0.5 seconds for thick liquids. These changes in durational and spatial measures are best appreciated in conjunction with the functional measures of interest, namely post-swallow residues. Participant 1 showed complete resolution of severe vallecular and pyriform sinus residue with thick liquids. Residues with thin liquids remained unchanged in the mild range. Thus, even though the width of UES opening decreased and durational measures remained stable for thick liquids, this patient was better able to achieve complete bolus transport from the pharynx into the esophagus post treatment.

Participant 3 had average pre-treatment UES opening widths of 19% (CUs) for thin liquids and 22% for thick liquids. Pre-treatment UES opening durations were 0.37 seconds for thin liquids and 0.33 seconds for thick liquids. Post-treatment his UES opening widths decreased to 11% for thin liquids and to 18% for thick liquids. Post-treatment UES durations decreased

to 0.27 seconds for both stimuli. Participant 3 showed an improvement in vallecular residues with thick liquids from moderate to mild, and complete resolution of mild vallecular and severe pyriform sinus residues with thin liquids. Thus, like participant 1, he can be considered to have shown functional improvement related to his practice of the Mendelsohn Maneuver, with increased efficiency of pharyngo-esophageal bolus transfer represented by greater clearance despite shorter and narrower UES opening. Penetration-Aspiration Scale scores were not expected to necessarily change as a result of Mendelsohn Maneuver practice, but did improve from a level 3 to 2 with thin liquids in participant 3.

4. Discussion

These data illustrate the challenges inherent in extracting and interpreting measures of physiological change in swallowing using surface EMG signals and videofluoroscopy recordings. In this series of patients, we chose to measure penetration-aspiration and post-swallow residues as our primary functional measures, but also explored more detailed physiological change through measures of hyoid excursion and UES opening.

Several important findings can be extracted from this case series:

1. Surface EMG amplitudes should not be compared across individuals, due to fluctuations in amplitude attributable to tissue composition differences.
2. In order to track changes in sEMG amplitudes across time within an individual, care must be taken to position the recording electrodes in the same location at each session, and a data normalization procedure should be used to transform amplitudes relative to a reference task. Additionally, an adequate number of data points is needed to support single-subject monitoring for change across sessions using standard deviation banding methods.
3. Change in effortful saliva swallow performance will vary across individuals, perhaps as a function of initial strength, task load and treatment intensity.
4. Effortful saliva swallow practice appears to contribute to improvements in swallowing safety, as measured by the Penetration-Aspiration Scale (Rosenbek et al., 1996), although this interpretation should be treated with caution given that these were not compared to data from controls. Post-swallow residues appear to remain unchanged after practice of the effortful saliva swallow.
5. Change in Mendelsohn maneuver performance may vary across individuals, with change either in durational aspects or amplitude aspects of the maneuver.
6. Mendelsohn maneuver practice appears to influence hyoid excursion during swallowing, as well as swallowing efficiency, reflected by the degree of post-swallow residue achieved, despite narrower diameters and shorter durations of UES opening.

These data support the use of sEMG biofeedback to facilitate practice of the effortful swallow and Mendelsohn maneuver techniques in select patients with dysphagia, based on careful analysis of baseline videofluoroscopic swallowing studies showing evidence of the target physiological deficits. We caution that post-treatment outcome measurements require a repeat videofluoroscopic swallowing examination, to ensure that function has improved. Interpretations of swallowing function should not be made on the basis of sEMG signals alone.

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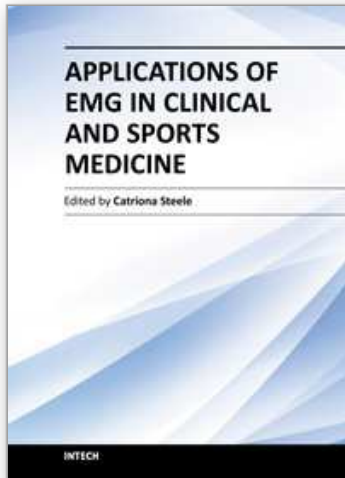
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