# Variability in Clinical Surface Electromyography Recording of Submental Muscle Activity in Swallowing of Healthy Participants

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Surface electromyography (sEMG) is criticised for potential intra- and intersession variability. As a result, the validity of the technique as a clinical measurement tool in swallowing rehabilitation is debatable. However, variability in sEMG recordings has not been comprehensively examined. This study examined the variability of peak amplitude of submental sEMG recordings during conditions of noneffortful dry and liquid swallows us-

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ing two electrode types (surface triode patch electrodes and single electrodes). Twenty young, healthy participants attended 10 assessment sessions over 5 consecutive days. During each session, participants executed 10 dry and 10 liquid swallows (10 mL). A general linear model two-way repeated measures analysis of variance (RM-ANOVA) showed no significant variability in sEMG peak amplitude within or across sessions. Furthermore, the covariates of electrode type and swallowing type did not significantly influence intersession variability. Therefore, submental sEMG peak amplitude recordings were documented to be a reliable measure of one feature of swallowing behavior in young healthy participants. From these results, it can be inferred that changes in submental sEMG recordings across treatment sessions in the dysphagic population reflect valid changes in swallowing behavior rather than measurement error.

**Key Words:** electromyography, submental, swallowing, variance, measurement

## Introduction

The consequences of dysphagia can be complex and impact a person's overall medical condition, nutritional status, quality of life and psychosocial well-being (Logemann, 1998; Lieu, Chong, & Seshadri, 2001; Marik & Kaplan, 2001). Management may include simple dietary adjustments (Logemann, 1998), pharmacological treatments (Loeb, Becker, Eady, & Walker-Dilks, 2003), invasive surgical or medical interventions (Kelly, 2000; Zaninotto, Marchese, Ragona, et al., 2004), compensatory swallowing strategies (Huckabee & Pelletier, 1999, Klor & Milianti, 1999) and swallowing exercises or maneuvers (Bryant, 1991; Crary, 1995; Huckabee & Cannito, 1999; Klor & Milianti,1999). The prescribed treatment depends on the nature and severity of the swallowing disorder, with the overall aim of improving the dysphagic patient's swallowing status to allow for successful, safer oral intake (Huckabee et al, 1999; Langmore, 1995).

Swallowing rehabilitation techniques may be difficult to master, particularly in patients with associated cognitive impairment, due to the abstract nature of tasks and difficulty in objectively measuring behavior and providing accurate clinical feedback. As a result, the use of biofeedback modalities has gained popularity in clinical rehabilitation settings. Surface electromyography (sEMG) is one modality of biofeedback that uses surface electrodes to record the electrical activity of underlying muscle (Lenman & Ritchie, 1970). This procedure allows the patient to observe even small changes in muscle behavior (Cooper & Perlman, 2003) and use this external feedback to voluntarily improve muscle control (Carmen & Ryan, 1989). This technique aids the clinician in teaching a patient voluntary control over muscle behavior, thereby increasing self-confidence and self-regulatory abilities. The patient is eventually weaned off the device, reducing the use of electronic cues and increasing voluntarily control over muscles (Miller, 1989).

Several single case reports or case series have described positive outcomes when utilising sEMG biofeedback as an adjunct to traditional behavioral rehabilitation (Bryant, 1991; Crary, 1995; Crary, Carnaby, Groher, & Helseth, 2004; Huckabee et al., 1999). Although outcome measures of recovery were based primarily on diet level tolerance and/or physiologic changes documented with videofluoroscopy, there are suggestions that sEMG measures may also change as a function of rehabilitation. The single case report described by Bryant (1991) found increased peak and average submental sEMG amplitudes over the course of treatment, which appeared to correlate clinically with improvement in overall physiology. In the case series offered by Crary (1995), higher peak and average sEMG amplitudes were measured from the infrahyoid site posttherapy, indicating progressive increase in muscle strengthening. In addition, sEMG waveform analysis also reflected an improvement in what Crary described as "swallow coordination" for all patients. However, for both studies, the trends in sEMG data were not subjected to statistical scrutiny and were only reported as clinical observations. Therefore, although patients appeared to improve clinically when using this as a treatment adjunct, it is yet unknown if sEMG amplitude is a reliable measure of patient progress.

Only one published study has attempted to evaluate within-subject variability in sEMG amplitude during swallowing (Fitzgerald, Huckabee, Lin, Coombes, & Bryant, 2003). This research demonstrated greater variation in submental sEMG measurement during swallowing in elderly adults when utilizing biofeedback to monitor performance compared to a nonbiofeedback swallowing condition. This difference did not carry over to a population of patients with swallowing impairment. Although the authors investigated between-task differences they did not specifically report the degree of intrasubject sEMG variance for any condition.

Ding, Larson, Logemann, and Rademaker (2002) sought to evaluate task difference in sEMG amplitude for two conditions of swallowing. Because of concerns for intrasubject variance for data were across several sessions, the sEMG data set was normalized by expressing the maximum amplitude of EMG activity across swallow trials as a percentage of the mean amplitude across nonmaneuver swallows. The normalization of the data accounted for intrasubject, intersession variability, thus allowing for the data to be pooled across participants and across sessions. However, the raw data were not evaluated before normalization to determine if intersession variability was a substantive factor. Clinically, normalization of data is impractical given the complexity of analysis required and the limited time available to clinicians. If sEMG is used in the clinical setting, it is important to ensure that the recorded signals are adequately reliable for comparisons within and across sessions.

A number of potential sources of variability may arise during sEMG recording. These include variations in electrode placement, the use of different types of electrodes, and the performance of differing swallowing tasks. Regarding electrode placement, sEMG measures the electrical activity of a collective group of muscles rather than a specific muscle. When muscles overlap, it is difficult to locate the targeted muscles and, therefore, it can be difficult to reproduce the exact electrode location (Hermens, Freriks, Disselhorst-Klug, & Gunter, 2000). This is particularly problematic when muscles are small and overlapping and thus may potentially affect the repeatability of the procedure. Furthermore, electrode placement is complicated by the influence of the interelectrode distances on sEMG measurement. The electrodes, when spaced farther apart than targeted, may also measure the electrical activities from neighbouring muscles, which may interfere with sEMG recordings of the targeted muscle group. The distances between the electrodes therefore must be kept consistent for measurement, as this may influence the amplitudes of the sEMG signals (Castroflorio, Farina, Bottin, Piancino, Bracco, & Merletti, 2005).

The types of surface electrodes used vary across different clinical settings. Both independent single surface electrodes (Crary, 1995; Crary & Baldwin, 1997;Ding et al., 2002; Gupta, Reddy, & Canilang, 1996; Vaiman, Eviatar, & Segal, 2004) and commercially available surface triode patch electrodes (Huckabee et al., 1991; Fitzgerald et al., 2003) have been employed. The commercially available surface triode patch electrodes have positive, negative and ground electrodes contained on circular adhesive pads. Therefore, it seems logical that the use of single, independent surface electrodes would increase the possibility of variability, as keeping the interelectrode distance consistent would be less likely than for triode patch electrodes. Thus, the type of electrodes used may have an effect on the reliability of the sEMG measurements of muscle activity. To date, studies have not addressed which type of electrodes (i.e., patch versus single electrodes) will provide a more reliable measurement of electrical muscle activity.

Finally, the presence of a bolus (i.e., liquid or dry swallows) during swallowing exercises may influence sEMG amplitude measurements. Cunningham and Basmajian (1969) reported that lingual EMG was greater for dry swallows than for liquid swallows. This suggests that sEMG signals are more variable due to "undesirable" lingual movements during dry swallows. Therefore, liquid swallows (i.e., water) may be more stable as an objective measure of sEMG amplitude. However, the risk of aspiration in some individuals with dysphagia may preclude the use of liquid boluses in completing swallowing exercises. Thus, it would be of clinical interest to delineate the influence of bolus on sEMG variability.

In conclusion, review of the literature indicates that sEMG biofeedback in combination with conventional swallowing rehabilitation has a positive effect on some dysphagic patients. However, the measurement technique may produce significant variability of sEMG recordings, potentially influencing the accuracy of clinical measurements and the validity of sEMG as an objective measure of progress. The primary aim of this study was to determine whether there is significant intersession variability in sEMG peak amplitude recordings of submental muscle activity of swallowing within individual healthy participants. Electrode type and swallowing condition were evaluated to determine their influence on reliability of the recorded signal.

# Methods

## Participants

Twenty young healthy participants (10 males and 10 females), between the ages of 20 to 35 years, were recruited for the study. The mean age of both male and female groups was 24 years. All participants were surveyed regarding their health status prior to the start of the investigation. They reported no known history of medical or neurological conditions, or dysphagia. None of the participants were taking prescribed medications that would potentially affect swallowing. All procedures were reviewed and approved by the institution's Human Ethics Committee; voluntary written informed consents were obtained.

## Equipment

A portable sEMG biofeedback device (MyoTrac3, Thought Technology, Inc) was used to measure electrical activity of the submental muscles during swallowing. The electromyography biofeedback device was connected to a laptop via fiberoptic cabling. Signals were displayed as time ($x$-axis) by amplitude ($y$-axis) waveforms. Silver chloride triode patch electrodes (with a recording diameter of 10 millimeters) and single disposable surface electrodes (with a recording diameter of 11 millimeters) (Thought Technology, Inc.) were used in the study. Triode patch electrodes housed two recording electrodes and one ground electrode on a circular adhesive pad, whereas single electrodes were separated and independently placed.

## Procedure

Participants attended a total of 10 sessions over 5 consecutive days, with two sessions conducted per day with a minimum rest period of 90 minutes between sessions. Triode patch surface EMG electrodes and single surface EMG electrodes were used in five sessions each. The type of electrode used in the sessions was counterbalanced to reduce order effect. Specifically, on each assessment day, either triode patch electrodes or single electrodes were used at the first recording session of the day with the opposite order employed on the second recording session of the day. At each recording session, 10 trials of both dry and liquid swallows were performed by the participants. Again, counterbalancing was employed to control for order effect. This resulted in 20 swallows per session to a total of 100 swallows with triode patch electrodes over 5 days and 100 swallows with single electrodes over 5 days.

Four combinations of conditions were used: (i) triode patch electrodes with dry swallows, (ii) single electrodes with dry swallows, (iii) triode patch electrodes with liquid swallows, and (iv) single electrodes with liquid swallows. Conditions were counterbalanced from session to session. By the end of the study, each participant had performed a total of five sets of swallows for each condition (i.e., a total of 20 sets for four conditions).

For data recording, each participant was seated comfortably in a chair in a relaxed upright position. The skin surface overlying the submental muscles was cleaned with an alcohol swab before placement of electrodes. Regardless of type, electrodes were carefully placed on the skin overlying the submental muscles using conductivity gel to reduce electrical impedance. The two active electrodes were placed at midline between the spine of the mandible and palpable thyroid protrusion. The ground electrode was placed lateral to the active electrodes. The interelectrode distance between centers was approximately 2 centimeters.

A short trial was conducted in the first session only to familiarise participants with the procedure and to clarify instructions. During the trial period, the participant was asked to perform three normal relaxed swallows of each condition. The participant was requested to swallow only when cued to do so. Once the participant understood the procedures of the study, data collection commenced. Similar verbal instructions were given to all participants before the start of each data recording session. They were advised to refrain from extraneous head movements during swallowing as this would potentially influence the recorded sEMG signals. For both swallowing conditions, participants were instructed to swallow on the researcher's command at a rate of approximately one swallow per minute. For the bolus swallowing condition, the participant was provided a calibrated 10 mL of tap water via a medicine cup, which they were instructed to hold in the oral cavity until cued to swallow.

### Surface Electromyographic Measurements

Prior to sEMG measurements, it was ensured that the resting baseline for each participant reflected a low level of impedance. When a swallow was executed, the peak amplitude of sEMG activity was recorded. The peak sEMG amplitude of an attempted swallow was identified as the highest microvolt value between the onset and offset of that swallow. When more than one waveform peak was apparent during a swallow, the last peak amplitude of the swallow was recorded with the assumption that initial peak activity was related to lingual activity for bolus transfer.

### Statistical Analysis

A commercial software program, SPSS for Windows (Version 13.0; SPSS, Chicago, IL) was used to perform statistical analysis. The level of significance for all analyses was set at $p < 0.05$. Descriptive statistics were used to obtain the means and coefficient of variance (CoV) values of sEMG peak amplitude recordings of the swallows for within and across sessions, as well as for the four swallowing conditions. Additional within subject means and CoV were derived for the four swallowing conditions.

The dependent variable for this study was sEMG peak amplitude. The independent variable of trial (intrasession variability) was initially evaluated using general linear model repeated measures analysis of variance (RM-ANOVA). After ruling out significant intrasession variability, data were averaged within a session and the mean sEMG amplitude for each session was used in two subsequent analyses. Two RM NOVAs were used to evaluate the intersession variability and the influence of: (1) electrode type and (2) swallow type [dry and liquid swallows] on variability in sEMG peak amplitude recordings. For all analyses, when the Mauchly's Test of Sphericity was significant, ($p$ <.05), the more conservative Greenhouse Geisser adjustment was applied to interpretation of the data. General linear model variance components analyses were used to determine the relative contribution of the independent variables to the dependent variable. The percentage of variance distribution of these variables was calculated by dividing the individual variance by total variance and multiplying by 100 (i.e., individual variance/ total variance × 100).

Interrater reliability of sEMG peak amplitude measurements was evaluated on 20% of the entire data set using intraclass correlation coefficient (ICC) analysis. A second researcher that was unfamiliar with the purpose of the study, but familiar with sEMG waveform interpretation, analyzed the data. Intraclass correlation coefficient (ICC) revealed extremely high interrater reliability of 1.0 and $p < 0.001$.

## Results

### Descriptive Statistics

Table 1 contains mean and calculated CoV data across the 10 trials and 20 participants for the five sessions of each condition. Examination of these averaged data

**Table 1.** Surface EMG Peak Amplitude Means and Coefficient of Variations (in parentheses) for Triode Patch and Single Surface Electrodes Across Dry and Liquid Swallows Across Sessions.

| | Triode patch electrodes | | Single electrodes | | |
|---|---|---|---|---|---|
| **Sessions** | **Dry Swallow** | **Liquid Swallow** | **Dry Swallow** | **Liquid Swallow** | **Overall** |
| 1 | 49.25 (56.75) | 52.46 (51.64) | 53.21 (48.53) | 63.12 (43.24) | 54.51 (50.43) |
| 2 | 47.62 (49.10) | 54.47 (53.57) | 57.96 (50.78) | 57.06 (39.85) | 54.28 (49.06) |
| 3 | 46.31 (58.19) | 50.87 (59.39) | 48.95 (48.58) | 60.18 (48.52) | 51.58 (54.44) |
| 4 | 43.60 (47.98) | 49.53 (45.27) | 55.13 (49.50) | 63.22 (47.33) | 52.87 (49.8) |
| 5 | 43.75 (54.60) | 50.89 (64.29) | 52.39 (50.49) | 59.80 (47.37) | 51.71 (55.23) |

*Note.* The means are expressed in microvolts (μV).

*N* = 10 trials per cell for a total of 200 trials per participant across all sessions and conditions.

suggests little difference between the sEMG recorded peak values for each condition and session. However, CoV data were quite large. Table 2 represents a breakdown of data by research participant to reflect intrasubject variance. Again, means and CoV data across sessions and trials are presented for each condition and session. Within subject CoV values across tasks range from 12.58 to 35.14, with an average of 22.86.

## Within Session and Condition Variability

A series of RM ANOVAs were completed to evaluate for differences in sEMG measures across trials but within a session, which would provide a reflection of variability in intrinsic research participant behavior. Separate analyses were completed for each session (1–5) and condition combination

**Table 2.** Individual Participant Surface EMG Peak Amplitude Means and Coefficient of Variations (in parentheses) for Triode Patch and Single Surface Electrodes Across Dry and Liquid Swallows Across Sessions.

| | Triode patch electrodes | | Single electrodes | | |
|---|---|---|---|---|---|
| **Participant** | **Dry Swallow** | **Liquid Swallow** | **Dry Swallow** | **Liquid Swallow** | **Overall** |
| 1 | 39.2 (19.90) | 51.60 (13.43) | 52.98 (20.06) | 69.33 (15.33) | 53.28 (17.18) |
| 2 | 32.38 (39.78) | 26.43 (26.30) | 30.94 (36.01) | 26.59 (25.05) | 29.08 (31.78) |
| 3 | 91.53 (25.02) | 29.13 (18.13) | 99.61 (20.50) | 100.99 (9.99) | 80.32 (18.41) |
| 4 | 63.00 (10.17) | 60.17 (10.45) | 67.46 (11.93) | 69.99 (10.94) | 65.16 (12.58) |
| 5 | 45.09 (24.61) | 59.03 (18.82) | 48.08 (15.41) | 66.1 (14.99) | 54.58 (18.46) |
| 6 | 20.3 (24.88) | 19.32 (19.82) | 25.55 (25.91) | 24.97 (24.47) | 22.54 (23.77) |
| 7 | 50.8 (19.47) | 43.97 (19.92) | 44.71 (27.71) | 49.66 (20.72) | 47.28 (21.96) |
| 8 | 64.97 (27.47) | 80.82 (21.44) | 73.76 (17.79) | 75.1 (16.35) | 73.62 (20.76) |
| 9 | 72.1 (27.05) | 65.46 (26.02) | 65.53 (27.24) | 73.17 (18.44) | 69.06 (24.68) |
| 10 | 20.06 (27.17) | 25.50 (41.37) | 21.33 (23.49) | 28.59 (31.13) | 23.87 (30.54) |
| 11 | 20.12 (6.22) | 21.37 (26.53) | 30.77 (28.89) | 33.54 (23.49) | 26.45 (27.46) |

*(continues)*

**Table 2.** *(continued)*

| | Triode patch electrodes | | Single electrodes | | |
|---|---|---|---|---|---|
| Participant | Dry Swallow | Liquid Swallow | Dry Swallow | Liquid Swallow | Overall |
| 12 | 60.89 (24.45) | 46.76 (27.31) | 83.68 (15.26) | 70.65 (14.31) | 65.49 (20.33) |
| 13 | 48.69 (13.21) | 50.84 (16.66) | 60.12 (15.70) | 67.71 (11.50) | 56.84 (14.27) |
| 14 | 39.1 (31.76) | 81.43 (34.72) | 53.48 (24.59) | 100.88 (18.67) | 68.72 (27.43) |
| 15 | 88.58 (14.62) | 64.8 (19.97) | 101.69 (11.34) | 77.83 (14.42) | 83.22 (14.84) |
| 16 | 41.55 (25.99) | 63.54 (25.20) | 52.93 (31.87) | 71.02 (26.61) | 57.26 (27.39) |
| 17 | 52.89 (34.07) | 99.86 (40.40) | 65.14 (43.05) | 103.62 (23.05) | 80.38 (35.14) |
| 18 | 23.45 (24.09) | 20.73 (25.42) | 28.55 (31.98) | 25.93 (27.84) | 24.67 (27.33) |
| 19 | 26.07 (28.27) | 27.86 (14.21) | 34.99 (31.84) | 38.07 (14.05) | 31.75 (22.09) |
| 20 | 21.46 (25.58) | 29.13 (17.75) | 29.51 (25.72) | 41.01 (14.05) | 30.28 (20.77) |

*Note.* The means and standard deviations are expressed in microvolts (μV).

$N$ = 50 trials per cell, with an overall 200 trials per participant.

(triode dry, triode liquid, single dry, single liquid). These analyses, summarized in Table 3, revealed no significant effect of trial ($p > .05$) within a single session on the dependent variable of submental sEMG peak amplitude. As no trial linear trial effect was identified, data within a session and condition were averaged for subsequent analyses.

## Session by Electrodes

Two RM ANOVA were completed to evaluate influence of: (1) electrode and (2) session on sEMG amplitude. On both dry swallows and liquid swallows, statistical analyses revealed a significant main effect of electrode [dry: $F(1) = 21.789$, $p < .001$; liquid: $F(1) = 39.948$, $p < .001$], with the triode patch electrode measuring significantly lower amplitude than the single electrode. No main effect of session [dry: $F(1) = 1.538$, $p = 0.20$; liquid: $F(1) = .304$; $p = .803$] or interactions between session and electrode [dry: $F(4, 1) = 2.242$, $p = 0.672$; liquid: $F(4,1) = 1.153$, $p = .324$] were identified.

## Session by Swallowing Condition

The RM ANOVAs identified no significant main effect of session [triode: $F(4)$ = ,.745, $p = .509$, single: $F(4) = 1.865$, $p = .149$], swallowing condition [triode: $F(1)$

**Table 3.** Results of Repeated Measures ANOVA to Evaluate the Effect of Trial Within Session for 4 Condition Combinations

| Session | Triode patch electrodes | | | | Single electrodes | | | |
|---|---|---|---|---|---|---|---|---|
| | Dry Swallow | | Liquid Swallow | | Dry Swallow | | Liquid Swallow | |
| 1 | 1.264 | [0.288] | 0.982 | [0.327] | 1.110 | [0.360] | 0.877 | [0.312] |
| 2 | 0.796 | [0.550] | 1.023 | [0.423] | 0.658 | [0.656] | 1.162 | [0.332] |
| 3 | 1.83 | [0.135] | 0.605 | [0.701] | 0.367 | [0.874] | 1.044 | [0.396] |
| 4 | 1.558 | [0.187] | 1.258 | [0.291] | 0.422 | [0.712] | 0.483 | [0.810] |
| 5 | 0.41 | [0.834] | 1.003 | [0.405] | 0.972 | [0.465] | 0.962 | [0.435] |

Data represent *F*-values, followed by Greenhouse Geisser adjusted *p*-value in brackets.

= 2.125, $p$ = .161; single: $F(1)$ = 4.066, $p$ = .058], or an interaction between session and condition [triode: $F(4, 1)$ = .327, $p$ = .718, single: $F(4, 1)$ = 2.501, $p$ = .09 ] when using either type of electrode.

### Distribution of Variance Components

The distribution of variance (percentage) for the variables (intrasession, intersession, participants and unaccountable random errors) showed that the greatest proportion of variability was contributed by individual participants. This was followed by unaccountable random errors. Variability due to intrasession and intersession were minimal. The distribution of variance of these four components is illustrated in Figure 1.

## Discussion

The purpose of this study was to provide data regarding inter-session variability of submental sEMG peak amplitude recordings and to determine if electrode type and swallowing type would influence sEMG measures in a group of 20 normal healthy participants. The results clearly revealed that within participants, sEMG peak amplitude recordings of swallowing trials were consistent within and across sessions and that electrode and swallow type did not appear to systematically influence measurement across sessions. There was a significant main effect of electrode, thus the clinician would be advised to be consistent in electrode type usage throughout the course of repeated assessment. With this exception, for the purpose of clinical measurement, submental sEMG peak amplitude recordings may be considered statistically reliable for charting the swallowing behavior of a young healthy person.

The current study has established the statistical reliability of submental sEMG peak amplitude recordings in the normal population. On this basis, clinicians may infer that changes in sEMG recordings provide a reasonable estimate of an individual's behavior and that comparison of a patient's performance across sessions using sEMG peak amplitude values may provide a fast and reliable means of estimating rehabilitation progress. However, it should be noted that within-session performance of a given task, although not statistically different, varied widely across our normal participants. Although this was not statistically significant, it may be clinically significant. Given this intraindividual variation however, the astute clinician would base session comparisons on averaged performance within a session, rather than single trials.

Although sEMG measurement is higher when using single electrodes, compared to patch electrodes, electrode type did not sig-

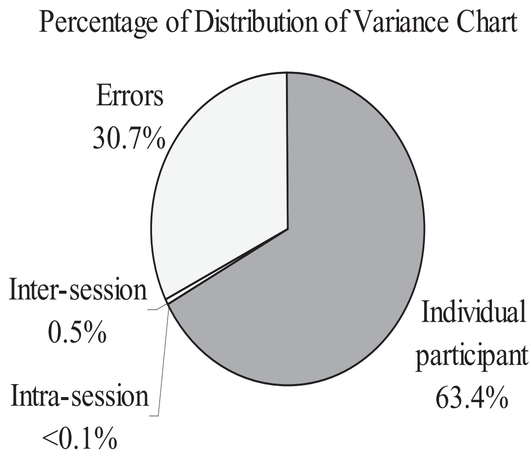


**Figure 1.** Distribution of variance in recorded sEMG amplitude.

nificantly influence the consistency of submental sEMG peak amplitude recording. This indicates that either electrode type is acceptable for clinical recording but they are not interchangeable. In this research setting, great care was taken with electrode placement for both types of electrodes, reproducing placements as similarly as possible with each new session, thus reducing potential inaccuracies in electrode placements. This practice should carry over to routine clinical practice to ensure generalization of these results.

The results of this study also suggest that variability of sEMG peak amplitude signals is not influenced by swallowing condition. The current findings were surprising as previous research has indicated that when a person performs a dry swallow, the increase oral gestures to collect saliva (Cunningham et al., 1969). This might imply that lingual EMG would then interfere with submental sEMG recordings for dry swallows, increasing variability. However, as the results suggested, this was not the case for the purpose of measurement in this healthy population. It would be of interest in future research to identify if this carries over to patients with swallowing impairment.

A further possible explanation for the lack of differences in variability in sEMG peak amplitude recordings between dry and liquid swallows could be the way instructions were given to participants and how swallows were measured. Before each swallow was executed, early cuing was given to the participant to prepare their swallow. The swallow was only executed and measured when the participant was ready. Thus, the expected lingual EMG in saliva recruitment might already have taken place prior to the recorded swallows and these lingual EMG signals might not have been captured in the recordings and caused interference to the recorded submental sEMG signals.

Finally, it was noted from calculations of distribution of variance of the variables (i.e., intrasession variability, intersession variability, participants and random errors) on submental sEMG peak amplitude measurements that variability for the present study was mainly contributed by participants. This finding has been reported in numerous studies (Ding et al., 2002; Gupta et al., 1996; Perlman, Palmer, McCulloch, & VanDaele, 1999) where interparticipant variability was also significant and confirms that absolute sEMG amplitude values cannot be compared across participants or collected to derive a normative data set. The possible reasons for participant variability could be differences in anatomical structure or physiological patterns of swallowing. However, the present study was not comparing the variability of submental sEMG signals between participants but, rather, examining the variability within participants.

## Conclusions

This was a clinically driven study that aimed to investigate the variability in submental sEMG peak amplitude recordings within healthy young participants across sessions. The findings revealed no significant differences in intra- and intersession variability in sEMG peak amplitude recordings and that the covariates of electrode type and swallowing type did not have a significant influence on variability across sessions. Thus, for the practicing clinician, it may be inferred that given a carefully controlled clinical setting, submental sEMG peak amplitude recordings are reliable in charting a patient's swallows over time. Importantly, electrode-type measures significantly different amplitudes and thus should remain constant throughout a patient's treatment for reliable measurement. sEMG cannot be considered a diagnostic method, due to the lack of specificity of muscle measurement; however, its use a clinical outcome measure to assess relative gains in muscle behavior may be justified.

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