

# Surface Electromyographic Assessment of Swallowing Function

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Received: 23 December 2015

Revised: 30 January 2016

Accepted: 07 February 2016

## What's Known

- Over the past few decades, surface electromyography (sEMG) has been used to evaluate and treat swallowing function.
- Assessment of the reliability of sEMG during swallowing is necessary to determine the potential usefulness of this technique in the evaluation and treatment of swallowing function and standardization of the EMG methodology.

## What's New

- Reliability of sEMG was influenced by age and swallowing types.
- While amplitude and some time-related parameters have been commonly used in the previous studies on swallowing, MDF showed greater reliability and higher precision in assessing the function of swallowing muscles in this study.

## Abstract

The reliability of surface electromyographic (sEMG) variables during swallowing determines the potential usefulness of these measures in swallowing assessment and treatment. This study aimed to establish the reliability of the sEMG measures of the swallowing function of muscles during different swallowing conditions in healthy young and old volunteers. Two groups of volunteers (24 older adults, 10 younger adults) participated in this cross-sectional study during 2014. The activity of masseter, submental, and infrahyoid groups were measured using sEMG during three repetitions of different swallowing tasks. Both the relative and absolute reliability (characterized respectively by ICC, SEM%, and SRD%) were calculated for the sEMG indices of muscle activity during swallowing events. Statistical analyses were performed by the SPSS 19.0 and Microsoft Excel 2007 software packages. Statistical significance was set at  $P \leq 0.05$ . The relative reliability calculations showed significant agreements between repetitions for the mean and peak amplitude and the average of median frequency (MDF) of the studied muscles function during most swallowing types in both groups. However, the duration and particularly the time to peak of muscle activity showed significant agreements during fewer swallowing conditions. Excluding MDF, we found high SEM% and SRD% for the studied measures (particularly timing measures) of muscles function during most swallowing types in both groups. The reliability of sEMG measures was influenced by the age and swallowing types. Our findings suggest that the MDF of muscle function during almost all studied swallowing types can be a reliable measure for the sEMG assessment of swallowing function in both younger and older adults.

Please cite this article as: Poorjavad M, Talebian S, Nakhostin Ansari N, Soleymani Z. Surface Electromyographic Assessment of Swallowing Function. *Iran J Med Sci*. 2017;42(2):194-200.

**Keywords** • Electromyography • Deglutition • Reproducibility of results

## Introduction

Surface electromyography (sEMG) is a non-invasive and inexpensive technique for investigating muscle activity.<sup>1</sup> It has been used to investigate swallowing function over the past few decades. Despite extensive use of sEMG to study swallowing function, there is little information regarding the reliability of sEMG characteristics of the muscle groups during different swallowing tasks. Assessing the reliability of sEMG measures<sup>2</sup> during swallowing is necessary to determine the potential usefulness of this technique in the evaluation and treatment of

swallowing function and to standardize EMG methodology. This study aimed to establish the relative and absolute reliability of the sEMG measures of swallowing muscle groups activity during different swallowing tasks in healthy young and old volunteers. This information will help clinicians to better design their assessment protocols in order to achieve the most reliable characteristics of muscle function during swallowing.

## Materials and Methods

### Participants

The swallowing function is reported to change in healthy aging.<sup>3,4</sup> Consequently, two groups of healthy volunteers were examined in this cross-sectional study; namely the older adults (n=24, 3 males and 21 females, mean±SD age: 67.38±6.09 years) and the younger adults (n=10, 3 males and 7 females, mean±SD age: 27.40±4 years). The volunteers were included if they did not have any history of difficulties in swallowing, neurological disorders, and head and neck cancer. Moreover, because dysphagia is more prevalent among aging adults, the older volunteers were clinically assessed using “the oral-pharyngeal and clinical swallowing examination”.<sup>5</sup> This non-invasive screening test provides comprehensive data from oral motor structure and function. Moreover, it includes a clinical swallowing examination to identify clinical features of swallowing disorders. The volunteers were observed during drinking calibrated volumes of water and laryngeal elevation was identified by palpation for each swallow.<sup>5</sup>

The study was approved by the Medical Research Ethics Committee of Tehran University of Medical Sciences and was carried out between June and September 2014. All participants provided informed consent.

### EMG Data Collection

The activity of three muscle groups (masseter, submental, and infrahyoid) involved in swallowing was simultaneously investigated. sEMG signals were recorded by three pairs of silver/silver chloride electrodes (diameter of 1 cm, center-to-center distance of 2 cm).<sup>6</sup> The signals were passed through a differential amplifier (sampling frequency=1000 Hz, input impedance>10,000,000 ohms, CMRR>96 dB, bandwidth=20-450 Hz) (type NOS SX230, Biometrics Ltd., UK).

The positions of the three pairs of electrodes were as follows:

1. The masseter: Vertically parallel to the muscle fibers on the right side of the face,

approximately halfway between the origin and insertion of the muscle.<sup>1,4</sup>

2. The submental group: Beneath the chin, midway between the mandible and the hyoid bone, 1 cm from midline to the right.<sup>6</sup>
3. The infrahyoid group: Approximately 2 cm lateral to the thyroid cartilage on the left side of the neck.<sup>1,6</sup>

The reference electrode was placed on the left wrist.

### Experimental Protocol

After electrode placement, the following tests were carried out in the older adults:

1. Voluntary single swallows of saliva (“dry” swallow)
2. Voluntary single water swallows as normal (“normal testing” swallow)
3. Voluntary single swallows of excessive amount of water (“stress testing” swallow) to check adaptation abilities of the muscles<sup>4</sup>
4. Voluntary single swallows of 2 mL of pudding (cookie pudding dessert)
5. Voluntary single effortful swallows of saliva (“effortful” swallow).

In the “normal” and “stress” testing swallows, we respectively used 13.5 and 17 mL of water. These volumes were described by Vaiman et al.<sup>4</sup> as the mean volume of the normal and large bolus for the older adults, respectively. The younger adults performed “dry”, “normal”, and “effortful” swallows.

Each participant performed three trials of each task. However, the first trial of each swallowing type was considered as a familiarization task and was excluded from the analysis. Thus, intra-session reliabilities were obtained based on two repetitions. All tests were conducted and analyzed by the same investigator in both groups.

### Data Analyses

The raw EMG signals were smoothed by the root mean square method with an average time window of 50 ms<sup>7</sup> using DataLog PC Software (version 7.50). Measurements were made of the peak sEMG amplitude, mean, duration, time to peak (the latency between the onset time of a swallow and the peak sEMG amplitude within a swallow), and the average of median frequencies (MDF) of electrical activity for each channel during the swallowing events. To detect the onset and offset time of each swallowing event, we considered 10% of the peak amplitude as a threshold level. The “onset” of a swallow was defined as the point at which the EMG trace exceeded the threshold level and the “offset” of a swallow was defined as the point at which a trace returned to below the threshold level.

### Statistics

Intraclass correlation coefficients (ICC) were used to determine the relative reliability of sEMG measures. Absolute reliability was characterized by calculating the standard error of the measurement (SEM) and the smallest real difference (SRD). SEM and SRD indicate the measurement errors for a group of individuals and a single person, respectively.<sup>8</sup> The SEM, SRD, SEM%, and SRD% were calculated as follows:

$$SEM = s_x \sqrt{1 - ICC}$$

$$SRD = 1.96 * \sqrt{2} * SEM$$

$$SEM \% = \left( \frac{SEM}{mean} \right) * 100$$

$$SRD \% = \left( \frac{SRD}{mean} \right) * 100$$

Where  $s_x$  is the pooled standard deviation and "mean" is the mean of all observations from the repetitions.<sup>9</sup>

Statistical analyses were performed using the SPSS 19.0 (SPSS Inc., Chicago, IL) and Microsoft Excel (version Office 2007) software packages. Statistical significance was set at  $P \leq 0.05$ .

## Results

### Relative Reliability

Tables 1 and 2 represent the reliability levels of the sEMG variables in the older and younger adults during different swallowing conditions. Most studied indices of the masseter and infrahyoid functions showed significant correlations between the repetitions of different swallowing types in both groups, except for the duration and time to peak of activity during some swallowing conditions. Significant correlations were also found in most EMG measures of the submental function in both groups. The MDF, peak amplitude, duration and time to peak of the submental activity during a few swallowing types did not show significant correlations.

### Absolute Reliability

The SEM% and SRD% for the studied indices of the masseter, submental, and infrahyoid functions during different swallowing types are presented in tables 1 and 2. The obtained values vary considerably depending on the swallowing types.

## Discussion

Surface EMG is extensively applied to measure the function of swallowing muscles.

Nevertheless, before using the sEMG measures, we need to know which ones are reliable and sufficiently precise to detect clinically important changes.<sup>9</sup> The aim of the current study was to establish the reliability of the sEMG measures for the swallowing function of muscles.

In recent years, a comprehensive set of statistical methods has been recommended in medical research studies to establish the reliability of measurements.<sup>9</sup> While ICC is introduced as the preferred retest correlation coefficient<sup>9</sup> and an appropriate indicator of the reliability,<sup>9,10</sup> it is affected by the inter-subject variability.<sup>10</sup> It means that when the inter-subjects variation is large, the ICC values can be high even if trial-to-trial variability is large.<sup>10</sup> Some other measures such as the SEM and SRD values were therefore introduced to address absolute reliability.<sup>10</sup> Using such a set of statistical methods, we found that the reliability of sEMG measures was influenced by the age and swallowing types and the MDF of muscle function can be a suitable candidate for sEMG assessment of swallowing function in both the younger and older adults.

Measurements of the amplitude parameters (mean and peak amplitude) and the MDF for the masseter and infrahyoid group showed a significant agreement during all studied swallowing conditions in both groups, indicating that these measures are repeatable. Repeatability, however, cannot completely certify the suitability of measurements for clinical use. The magnitude of the measurement errors is also important.<sup>9</sup> The SEM% and particularly SRD% values were relatively high for the amplitude parameters of the masseter and infrahyoid functions during many swallowing types in both groups. The relative and absolute reliability values, however, demonstrated that the MDF of the masseter and infrahyoid functions could be a suitable candidate for sEMG assessment of swallowing function in both the younger and older adults. According to the observed non-significant agreements between trials and relatively high SEM% and SRD% values, the time to peak of electrical activity of the masseter and infrahyoid functions and the duration of the masseter activity would not be reliable measures for many of the swallowing conditions.

Significant agreements and relatively acceptable SEM% values were obtained for the amplitude parameters and duration of the submental group function during almost all swallowing tests in both groups. Because of the relatively high SRD% values obtained for these measures during most swallowing conditions, however, they may have limitations in detecting

**Table 1:** Reliability of the sEMG measures for the masseter, submental and infrahyoid groups during different swallowing conditions in the older adults

	Masseter				Submental				Infrahyoid			
	ICC (LB-UB)	P value	SEM%	SRD%	ICC (LB-UB)	P value	SEM%	SRD%	ICC (LB-UB)	P value	SEM%	SRD%
<b>Dry</b>												
Peak	0.87 (0.69-0.95)	<0.001	29.1	80.7	0.79 (0.48-0.92)	<0.001	19.4	53.8	0.78 (0.48-0.91)	<0.001	30.8	85.5
Mean	0.89 (0.73-0.95)	<0.001	28.8	78.3	0.71 (0.29-0.88)	0.004	19.4	53.6	0.81 (0.53-0.92)	0.000	18.4	51.0
Duration	0.50 (-0.24-0.79)	0.07	38.8	107.4	0.77 (0.42-0.91)	0.001	23.9	66.2	0.70 (0.30-0.88)	0.003	26.9	74.5
Time to peak	0.13 (-1.23-0.65)	0.38	77.5	214.9	0.61 (-0.03-0.85)	0.03	51.1	141.6	0.58 (-0.02-0.83)	0.03	47.3	131.2
MDF	0.86 (0.65-0.94)	<0.001	8.1	22.5	0.54(-0.23-0.83)	0.06	8.3	23.1	0.59 (-0.12-0.82)	0.04	12.2	33.8
<b>Normal</b>												
Peak	0.81 (0.50-0.92)	0.001	27.6	76.6	0.74 (0.36-0.89)	0.002	22.5	62.4	0.88 (0.71-0.95)	<0.001	20.7	57.4
Mean	0.81 (0.54-0.92)	<0.001	15.6	43.2	0.70 (0.28-0.88)	0.004	17.3	47.9	0.90 (0.76-0.96)	<0.001	13.8	38.2
Duration	0.76 (0.41-0.90)	0.001	17.4	48.2	0.64 (0.18-0.85)	0.01	17.3	47.9	0.80 (0.52-0.92)	<0.001	16.0	44.3
Time to peak	0.75 (0.37-0.90)	0.002	26.3	73.0	0.71 (0.32-0.88)	0.002	23.8	65.9	0.39 (-0.51-0.75)	0.14	41.7	115.6
MDF	0.87 (0.67-0.95)	<0.001	8.3	22.92	0.87 (0.69-0.95)	<0.001	5.7	15.7	0.81 (0.54-0.92)	<0.001	5.7	15.9
<b>Stressed</b>												
Peak	0.58 (0.02-0.83)	0.02	54.8	152.0	0.52 (-0.17-0.81)	0.06	30.4	84.2	0.72 (0.34-0.88)	0.002	26.3	72.8
Mean	0.89 (0.60-0.96)	<0.001	17.8	49.4	0.57 (-0.05-0.83)	0.03	17.5	48.5	0.86 (0.67-0.94)	<0.001	15.4	42.6
Duration	0.45 (-0.50-0.79)	0.12	29.8	82.6	0.60 (-0.04-0.84)	0.03	22.0	61.1	0.77 (0.47-0.90)	0.001	16.0	44.3
Time to peak	0.35 (-0.77-0.75)	0.19	41.9	116.1	0.62 (0.05-0.85)	0.02	27.7	76.91	0.62 (0.10-0.84)	0.02	21.5	59.7
MDF	0.84 (0.60-0.94)	<0.001	10.8	29.9	0.84 (0.60-0.94)	<0.001	4.7	12.9	0.53 (-0.06-0.80)	0.04	8.5	23.5
<b>Pudding</b>												
Peak	0.78 (0.48-0.91)	0.001	28.6	79.2	0.92 (0.80-0.97)	<0.001	11.1	30.7	0.73 (0.35-0.88)	0.002	33.7	93.4
Mean	0.83 (0.60-0.93)	<0.001	24.8	68.8	0.88 (0.70-0.95)	0.000	13.2	36.64	0.79 (0.51-0.91)	<0.001	22.7	62.9
Duration	0.76 (0.41-0.90)	0.001	19.2	53.2	0.72 (0.29-0.89)	0.004	17.6	48.9	0.52 (-0.16-0.80)	0.05	22.7	62.91
Time to peak	0.52 (-0.20-0.80)	0.06	41.3	114.4	0.62 (0.00-0.85)	0.03	27.0	75.02	0.19 (-0.97-0.66)	0.31	38.1	105.5
MDF*	0.77 (0.44-0.90)	0.001	12.1	33.6	0.61 (0.04-0.84)	0.02	9.7	27.0	0.83 (0.58-0.93)	<0.001	7.0	19.5
<b>Effortful</b>												
Peak	0.90 (0.73-0.96)	<0.001	19.1	53.0	0.86 (0.65-0.94)	<0.001	18.1	50.1	0.87 (0.69-0.95)	<0.001	21.0	58.2
Mean	0.92 (0.81-0.97)	<0.001	18.8	52.2	0.90 (0.75-0.96)	<0.001	15.3	42.3	0.89 (0.73-0.95)	<0.001	18.7	51.7
Duration	0.25 (-0.94-0.70)	0.27	38.8	107.6	0.75 (0.39-0.90)	0.002	19.6	54.3	0.81 (0.54-0.92)	<0.001	20.9	58.0
Time to peak	-0.84 (-4.23-0.29)	0.90	108.0	299.4	-0.26 (-2.52-0.52)	0.68	75.3	208.6	0.14 (-1.07-0.64)	0.37	52.0	144.0
MDF	0.93 (0.82-0.97)	<0.001	5.7	15.8	0.94 (0.84-0.98)	<0.001	3.8	10.7	0.69 (0.24-0.87)	0.005	7.9	21.8

MDF: Median frequency, ICC: Intraclass correlation coefficients; LB: Lower bound; UB: Upper bound; SEM: Standard error of the measurement; SRD: Smallest real difference

**Table 2:** Reliability of the sEMG measures for the masseter, submental and infrahyoid groups during different swallowing conditions in the younger adults

	Masseter			Submental			Infrahyoid					
	ICC (LB-UB)	P value	SEM%	SRD%	ICC (LB-UB)	P value	SEM%	SRD%	ICC (LB-UB)	P value	SEM%	SRD%
Dry												
Peak	0.99 (0.99-1.00)	<0.001	8.5	23.4	0.71 (-0.06-0.93)	0.04	24.3	67.3	0.88 (0.57-0.97)	0.002	16.6	46.1
Mean	0.94 (0.75-0.98)	<0.001	35.6	98.7	0.80 (0.20-0.95)	0.02	19.5	54.1	0.86 (0.55-0.97)	0.002	20.4	56.5
Duration	0.46 (-0.34-0.84)	0.07	19.5	54.0	0.88 (0.53-0.97)	0.002	7.3	20.4	0.87 (0.49-0.97)	0.002	13.5	37.5
Time to peak	0.01 (-1.59-0.72)	0.49	53.8	149.0	0.20 (-1.03-0.77)	0.35	32.1	88.9	0.68 (-0.09-0.92)	0.04	33.7	93.3
MDF	0.85 (0.44-0.96)	0.004	10.0	27.8	0.60 (-0.60-0.90)	0.10	10.1	28.0	0.89 (0.59-0.97)	0.001	7.7	21.3
Normal												
Peak	0.99 (0.94-1.00)	<0.001	12.5	34.5	0.89 (0.56-0.97)	0.002	14.8	41.1	0.96 (0.84-0.99)	<0.001	11.7	32.4
Mean	0.96 (0.85-0.99)	<0.001	31.1	86.3	0.95 (0.81-0.99)	0.000	8.5	23.6	0.81 (0.18-0.95)	0.01	23.7	65.6
Duration	0.72 (-0.09-0.93)	0.04	20.0	55.3	0.69 (-0.41-0.92)	0.06	10.2	28.3	0.76 (-0.06-0.94)	0.03	15.6	43.3
Time to peak	0.65 (-0.28-0.91)	0.06	29.8	82.6	0.78 (0.17-0.94)	0.02	12.8	35.5	0.34 (-2.39-0.84)	0.29	35.1	97.4
MDF	0.93 (0.70-0.98)	<0.001	5.3	14.6	0.92 (0.65-0.98)	0.001	3.1	8.5	0.92 (0.68-0.98)	0.001	4.6	12.7
Effortful												
Peak	0.92 (0.66-0.98)	0.001	25.8	71.6	0.84 (0.40-0.96)	0.006	18.7	51.7	0.91 (0.63-0.98)	0.001	12.3	34.1
Mean	0.92 (0.71-0.98)	<0.001	28.1	78.0	0.86 (0.49-0.97)	0.002	16.0	44.2	0.90 (0.60-0.98)	0.001	12.8	35.5
Duration	0.86 (0.46-0.97)	0.004	10.8	29.9	0.73 (-0.16-0.93)	0.04	14.6	40.3	0.29 (-1.71-0.82)	0.31	22.8	63.1
Time to peak	0.58 (-0.92-0.90)	0.12	27.5	76.3	0.48 (-1.37-0.88)	0.18	47.2	130.9	-0.54 (-6.86-0.64)	0.73	42.3	117.3
MDF	0.91 (0.63-0.98)	<0.001	6.2	17.1	0.86 (0.48-0.97)	0.003	4.9	13.6	0.83 (0.18-0.96)	0.001	7.6	21.2

MDF: Median frequency; ICC: Intraclass correlation coefficients; LB: Lower bound; UB: Upper bound; SEM: Standard error of the measurement; SRD: Smallest real difference

real changes in the muscle function during many swallowing types of a single healthy person. Based on the small values obtained for the SEM% and SRD% and significant agreements during almost all studied swallowing types, the MDF of the submental group function can be estimated with high repeated-measures precision in both groups. The time to peak of the submental group function showed a significant agreement and acceptable values for the SEM% and SRD% only during "normal" swallows in younger adults.

Compared to the other studied muscle groups, the fewer parameters of the masseter function indicated acceptable reliability values. The test protocol is a factor that can influence the reliability.<sup>8</sup> The detection of the masseter and the electrode attachment on it, however, were much easier compared to that of the submental and infrahyoid groups. The less reliability of the masseter function, therefore, can be due to its role in the oral phase of swallowing. Unlike the pharyngeal stage of swallowing, the oral phase is completely under voluntary control.<sup>11</sup> The masseter muscle works during the oral phase and some of the observed variability of its function may be due to the voluntary nature of its control.<sup>4</sup>

Considering the studied swallowing types in both groups, the results indicated lower ICC and higher SEM% and SRD% values for most measures in older adults compared to younger adults. The well-known changes in the muscle structure with aging, including reduction in muscle mass and an increase in adipose tissue,<sup>12</sup> can influence the precision for detecting the muscles and recording the sEMG signals in the older adults.<sup>13</sup> Furthermore, previous studies have also reported increased movement variability<sup>12</sup> and swallowing variability<sup>14</sup> in advanced ages.

To the best of our knowledge, no study has used such a set of statistical methods to establish the reliability and the measurement precision of sEMG measures of the swallowing function of muscles. Different statistical indices used in this study indicated that the sEMG amplitude and timing measures should be used with caution when assessing the swallowing function of muscles. Our findings showed that the reliability of these measures varies extremely in different swallowing muscles and during different swallowing tasks. MDF, however, was an index with the high ICC and the lowest SEM% and SRD% values for all studied muscles and during almost all studied swallowing types in both the older and younger adults. This measure, therefore, can be used as a reliable index to assess the muscle function during swallowing.

Previous studies have demonstrated the effects of age, volume and consistency of bolus on swallow physiology.<sup>3,4,15</sup> Our results also indicated that age and swallowing conditions can relatively change the reliability indices of sEMG measures. The current study was, however, limited to healthy volunteers. The reliability of the measures may also be impacted by different swallowing disorders. Therefore, further studies will be needed to investigate the reliability of sEMG measures during swallowing in patients with different swallowing disorders.

## Conclusion

The results of this study indicated that the reliability of sEMG measures was influenced by the age and swallowing types. Our findings can provide clues about suitable sEMG measures in swallowing assessment. The findings also clarified that utilizing various reliability indices provide a complete perspective on the sEMG measures in the assessment of swallowing function. While the amplitude and some of the time-related parameters have been commonly used in previous studies on swallowing, the MDF showed greater reliability and higher precision in assessing the swallowing function of muscles in this study. Therefore, in order to reach a more reliable and useful approach in swallowing assessment using surface electromyography, other aspects of EMG signals may deserve consideration.

**Conflict of Interest:** None declared.

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