Effect of Amplitude Normalization on Surface EMG Linear Envelopes of Masticatory Muscles during Gum Chewing

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Various amplitude normalization procedures for surface electromyographic (EMG) signals have been utilized to reduce the inter- and intrasubject variability of data collected on gait analysis. We examined two normalization methods (normalization to mean of ensemble average: NME, and normalization to peak of ensemble average: NPE) for intersubject variability and reproducibility surface EMG profiles for the masticatory muscles during unilateral gum chewing. The EMG profiles for the anterior temporal (Ta), posterior temporal (Tp), masseter (M) and anterior belly of the digastric (Da) muscles on the chewing side from five normal subjects were made at three different sessions. Coefficients of variation and intraclass correlation coefficients were used to assess variability and reproducibility. Each normalization procedure the intersubject variability of unnormalized EMG profiles for Ta, Tp and M. The NME procedure provided lower intersubject variability for Da. The reproducibility of unnormalized profiles for Ta, Tp and M was significantly improved by both procedures (p<0.05). NME on Da was more effective in its reproducibility (p<0.05). We found that the phasic characteristics of muscular activity influenced the outcome of amplitude normalization. (J Osaka Dent Univ 1995; 29: 19–28)

Key words: Electromyography; Masticatory muscles; (Normalization); (EMG profiles)

INTRODUCTION

Masticatory movements result from an exceedingly complex coordination of the neuromuscular unit. Several studies relating to electromyographic (EMG) patterns of masticatory muscles during mastication have been performed to monitor the stomatognathic system, and different approaches for quantifying raw EMG have been devised\(^1\)\(^2\). In particular, time parameters for EMG activation of masticatory muscles have been determined. However, Winter\(^3\) pointed out that
such on–off measurements for EMG burst overlooked the time course of muscle activation during dynamic movements. The myoelectronic signal is a useful indicator of its mechanical effect since it essentially parallels the intensity of muscle action. Conventional analyses cannot determine detailed changes in EMG intensity.

The linear envelope has been found to be one of the most reliable methods of interpreting muscle activity during gait. We also studied the surface EMG linear envelope for the masticatory muscles, normalized with respect to both time and amplitude, as a means of directly tracking muscle activity to facilitate comparisons between individuals. Various amplitude normalization procedures for surface EMG signals have been utilized to reduce the inter– and intrasubject variability of collected data.

We examined the intersubject variability and reproducibility of surface EMG profiles for masticatory muscles during unilateral gum chewing for each amplitude normalization method.

**MATERIALS AND METHODS**

**Effect of intersubject variability of EMG profiles for different normalization procedures**

Five healthy male volunteers, between 25 and 26 years of age participated in this experiment. All had complete natural dentition that included at least the second molars. None showed any signs or symptoms of problems in the stomatognathic system. Informed consent was obtained from all volunteers after a brief explanation of the study. They were instructed to chew gum (Green Gum®; Lotte, Tokyo, 3.0 g) unilaterally on their side of preference for 90 seconds. Before measurements were taken, the volunteers were given a few minutes to practice unilateral gum chewing so that they could become familiar with the experimental conditions.

The EMG signals were detected from the anterior temporal (Ta), posterior temporal (Tp), masseter (M) and anterior belly of the digastric (Da) muscles. EMG recordings were made on the volunteer’s muscle on the preferred chewing side using bipolar pairs of Ag/AgCl surface electrodes of 5 mm diameter (NT–611U, Nihon Kohden, Tokyo) separated by 20 mm (center–to–center) along the direction of the muscle fibers. Ground reference electrodes were clipped to the ear lobes. A mandibular kinesiograph (MKG K–6, Myo–tronics Research, USA, hereafter called the MKG) was used for recording incisal point movements during chewing. The analysis period was 60–75 seconds after initiation of chewing. Between 8 and 10 stable chewing strokes without movement artifacts were selected from those displayed on the CRT for the 15–second chewing sequence. We obtained interpolated EMG linear envelopes (EMG...
LEs) in microvolts of the selected chewing strokes for each masticatory muscle for each volunteer using previously reported procedures. EMG LEs of selected strokes were averaged at each consecutive 0.3% interval over the chewing stroke to produce within-ensemble averages (WEA) for each muscle.

Each volunteer's WEA was then normalized as follows:
1. No amplitude normalization (UN) in microvolts.
2. EMG amplitude normalization by setting the mean ensemble value over a single stroke to 100% (NME).
3. EMG amplitude normalization by setting the maximum ensemble value over a single stroke to 100% (NPE).

Intersubject variability was determined for each muscle group for each of the normalization methods by comparing the phasic similarity of the WEA for all volunteers.

**Effect of reproducibility (intrasubject variability) of EMG profiles for different normalization procedures**

Five healthy volunteers, three men and two women, between 24 and 26 years of age participated in this experiment. EMG profiles for each normalization method for each volunteer were generated from three different registration sessions on two separate days one week apart. The first day included two sessions, one each at 10:00 am and 3:00 pm and a third session at 3:00 pm on the second day.

The electrode pairs were placed with a specially fabricated transparent sheet that ensured a consistent inter-electrode distance and electrode location. Similarly, orientation of the MKG magnet was carefully controlled with a reference bar that was part of the MKG equipment, thus minimizing errors due to positioning differences. There were no changes in the occlusal conditions of the volunteers during the one-week test period.

Reproducibility (intrasubject variability) was determined for each muscle group and each normalization method, by determining the phasic similarity among three sessions for each volunteer.

**Statistical analysis**

Phasic similarity was evaluated among the obtained EMG LEs by calculating the coefficient of variation (CV) and the intraclass correlation coefficient (ICC (3, 1)).

Differences in reproducibility for each muscle during the three normalization procedures were tested by nonparametric analysis of Friedman's test. The Dunn test was employed for the post-hoc multiple comparison. A level of p<0.05 was adopted as the criterion of significant difference in statistical tests.
RESULTS

**Intersubject variability**

Figs. 1 and 2 graphically represent the superimposed WEA for M and Da of the

![EMG profiles](image)

Fig. 1  EMG profiles for masseter muscle (M) on chewing side. Top: unnormalized EMG (UN), Middle: normalized to mean EMG (NME), Bottom: normalized to peak EMG (NPE). Left column: superimposed within-subject ensemble averages (WEA) for five volunteers, Right column: across-subject ensemble average.
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Fig. 2  EMG profiles for anterior belly of the digastric muscle (Da) on chewing side. Same as Fig. 1.

volunteers with their matching grand ensemble average and standard deviation for each normalization procedure (UN, NPE, and NME). A wide range of amplitudes was registered for each volunteer’s WEA derived from the UN procedure.

In contrast, the NME and NPE procedures produced high phasic similarity
Table 1  Coefficient of variation (CV) of different normalization procedures for four muscles on chewing side

<table>
<thead>
<tr>
<th>Muscle</th>
<th>UN</th>
<th>NPE</th>
<th>NME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>0.483</td>
<td>0.465</td>
<td>0.467</td>
</tr>
<tr>
<td>Tp</td>
<td>0.518</td>
<td>0.468</td>
<td>0.470</td>
</tr>
<tr>
<td>M</td>
<td>0.637</td>
<td>0.392</td>
<td>0.397</td>
</tr>
<tr>
<td>Da</td>
<td>0.233</td>
<td>0.267</td>
<td>0.219</td>
</tr>
</tbody>
</table>

Ta: Anterior temporal muscle, Tp: Posterior temporal muscle, M: Masseter muscle, Da: Anterior belly of the digastric muscle

Table 2  Intraclass correlation coefficient (ICC (3,1)) of different normalization procedures for four muscles on chewing side

<table>
<thead>
<tr>
<th>Muscle</th>
<th>UN</th>
<th>NPE</th>
<th>NME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>0.798</td>
<td>0.899</td>
<td>0.908</td>
</tr>
<tr>
<td>Tp</td>
<td>0.694</td>
<td>0.778</td>
<td>0.782</td>
</tr>
<tr>
<td>M</td>
<td>0.558</td>
<td>0.772</td>
<td>0.787</td>
</tr>
<tr>
<td>Da</td>
<td>0.776</td>
<td>0.889</td>
<td>0.931</td>
</tr>
</tbody>
</table>

in all volunteers’ EMG curves for each muscle group.

Table 1 summarizes the CV results. Intersubject variability (CV) was quite large in UN, ranging from 0.233 in Da to 0.637 in M. The CV values for elevator muscles were reduced by NPE and NME. This effect was especially marked in M.

Table 2 summarizes the ICC results. Intersubject variability (ICC) ranged from 0.558 in M to 0.798 in Ta for UN. The ICC values of each muscle group for the NPE and NME procedures were greater than 0.77.

Reproducibility (intrasubject variability)

Figs. 3 and 4 show the superimposed WEA for M and Da (UN, NME and NPE) of a typical volunteer from three recording sessions. The amplitude normalization procedures also reduced intrasubject variability of the EMG patterns for other muscles.

Table 3 shows ICC (3,1) results from the reproducibility over three trials. Presentation of results was concentrated on the three most representative values, the median (50 percentile), and the 25 and 75 percentile values. To determine whether the ICC values reported in Table 3 were significantly different for different normalization procedures, a Friedman’s test of nonparametric data was performed for each muscle group. This test found significant differences in the three normalization procedures for each muscle group. The follow-up Dunn test for Ta, Tp and M showed the ICC values were significantly greater (p<0.05) for NME and NPE than they were for UN. The Dunn test for Da
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**Fig. 3** Superimposed within-subject ensemble averages (WEA) of $M$ for same volunteer on three different sessions.

**Fig. 4** Superimposed within-subject ensemble averages (WEA) of $D_a$ for same volunteer on three different sessions.
Table 3 Reproducibility of different normalization procedures for four muscles (25, 50 and 75 percentiles of intraclass correlation coefficients) and results of Friedman's test

<table>
<thead>
<tr>
<th>Muscle</th>
<th>UN</th>
<th>NPE</th>
<th>NME</th>
<th>Friedman's test ($X^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ta</td>
<td>0.863</td>
<td>0.896</td>
<td>0.885</td>
<td>8.400 (p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td>0.864</td>
<td>0.904</td>
<td>0.888</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.894</td>
<td>0.978</td>
<td>0.975</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.765</td>
<td>0.887</td>
<td>0.885</td>
<td></td>
</tr>
<tr>
<td>Tp</td>
<td>0.841</td>
<td>0.892</td>
<td>0.890</td>
<td>8.400 (p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td>0.865</td>
<td>0.916</td>
<td>0.905</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.879</td>
<td>0.926</td>
<td>0.917</td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>0.891</td>
<td>0.927</td>
<td>0.919</td>
<td>8.400 (p&lt;0.05)</td>
</tr>
<tr>
<td></td>
<td>0.919</td>
<td>0.972</td>
<td>0.966</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.762</td>
<td>0.801</td>
<td>0.822</td>
<td></td>
</tr>
<tr>
<td>Da</td>
<td>0.793</td>
<td>0.814</td>
<td>0.837</td>
<td>10.000</td>
</tr>
<tr>
<td></td>
<td>0.885</td>
<td>0.910</td>
<td>0.929</td>
<td>(p&lt;0.01)</td>
</tr>
</tbody>
</table>

showed the ICC value for NME was significantly greater than it was for NPE. Also, the ICC value for NPE was significantly greater than for UN.

DISCUSSION

Dentists must continually refine their evaluation techniques in order to provide the best diagnosis and most effective treatment. Clinical examination methods must also be reproducible. This is especially important when clinical researchers do treatment outcome studies where repeated examinations are performed on the same patient to assess changes resulting from the treatment.

The importance of documenting measurement reliability cannot be over emphasized in EMG research, since a variety of factors affect EMG amplitudes. For this reason, muscular activity during mastication is usually described with time parameters, e.g. mean values and variations in the duration and interval of EMG activities. In the past decade, investigators have suggested using alternative normalization values in order to observe changes in EMG curves. The techniques used to collect and analyze the data may have influenced the data. Suggestions regarding EMG amplitude normalization for gait study have included using the EMG associated with a percentage of the maximum voluntary contraction (MVC) of the given muscle, the peak value, and the mean EMG during a dynamic activity. The normalization technique of maximum amplitude among all selected strokes was utilized by Hannam et al. on the EMG LE for masticatory muscles. This method and the NPE of this study are very similar for amplitude normalization. In fact, we confirmed this for amplitude normalization in our pilot studies. Yang and Winter demonstrated that both peak and mean EMG techniques drastically decreased intersubject
variability in the muscle group for EMG activity of lower limbs. Because these methods were studied only for gait analysis, the results may be different for masticatory muscles. It is difficult if not impossible to elicit isolated controlled isometric contractions required for calibration (i.e. clenching in the intercuspal position) during MVC calibration of patients with temporomandibular disorders (TMD). In addition, although the calibration contraction level for normal subjects might be stable\textsuperscript{12}, the muscle conditions for TMD patients may vary widely from day to day.

We used the coefficients of variation (CV) and intraclass correlation coefficients (ICCs (3,1)) to assess variability and reproducibility. ICC is similar to CV used by Yang et al.\textsuperscript{5} in that they both represent a measure of similarity among more than two wave forms. ICC (3,1) values close to 1.0 indicate high phasic similarity. We used the ICC parameter for intersubject variability to compare intersubject variability and reproducibility. The ICC results were similar to those for CV. Normalization procedures for the ensemble average reduced intersubject variability of raw EMG profiles for Ta, Tp and M. NME procedures provided lower intersubject variability for Da (Tables 1 and 2). Since the peak EMG value of WEA for Da was lower than that for other muscles, NPE procedures for Da generated large amplitude variability of between 0 and 50 % over the chewing stroke. Shiavi et al.\textsuperscript{13} suggested that the standard deviation across the stride produced by NME was less during period of quiescence, and therefore was better for periods of activity. For this reason, they recommended NME as a normalizing factor.

The reproducibility of unnormalized profiles for Ta, Tp and M was significantly improved by NPE and NME. NME was most effective on Da (Table 3). These results indicate that different phasic characteristics of muscular activity between the elevator and depressor muscles influence the outcome of amplitude normalization. When Fleiss’s criteria\textsuperscript{8} for ICC values were used (less than 0.4 : poor, 0.4 to 0.75 : fair–to–good, and 0.75 and above : excellent), all muscle groups showed excellent reliability (Table 3). This indicates that the outcome for raw EMG LEs were reproducible when the settings for inter–electrode distance and electrode orientation were maintained. However, intersubject comparisons are still a problem (Tables 2 and 3). The median estimated ICC for NPE and NME was greater than 0.77, which is acceptable by Fleiss guidelines.

These results indicate that both methods used in this study are reliable and reproducible in measuring phasic muscle activity of masticatory muscles during gum chewing. This study may contribute to clinicians’ understanding of the effects of EMG processing methods on computer averaged EMG profiles.
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REFERENCES