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Running Head: **Normalise EMG to Submaximal Bite Force**

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Abstract

The combination of bite force and facial electromyography (EMG) provides an insight into the performance of the stomatognathic system, especially in relation to dynamic movement tasks. Literature has extensively investigated possible methods for normalising EMG data encapsulating many different approaches. However, bite force literature trends towards normalising EMG to a maximal voluntary contraction (MVC), which could be difficult for aging populations or those with poor dental health or limiting conditions such as temporomandibular disorder. The objectives of this study were to (i) determine whether jaw-closing muscle activity is linearly correlated to incremental sub-maximal and maximal bite force levels, and (ii) assess whether normalising maximal and submaximal muscle activity to that produced when performing a low submaximal bite force (20N) improves repeatability of EMG values. Thirty healthy adults (15 male, 15 female; mean age 21±1.2 years) had bite force measurements obtained using a custom-made button-style compression load cell. Masseter and anterior temporalis muscle activities were collected bilaterally using surface EMG sensors whilst participants performed maximal biting, and three levels of submaximal biting. Furthermore, a small group (n=4 females) were re-tested for reliability purposes. Coefficients of variation and intraclass correlation coefficients showed markedly improved reliability when EMG data were normalised compared to non-normalised. This study shows that facial EMG may be successfully normalised to a very low bite force. This may open possibilities for comparisons between at-risk sample groups that may otherwise find it difficult to produce maximal bite force values.

Keywords: Normalisation, Masticatory muscles, Masseter muscle, Temporal muscle, Muscle activity, Bite force.

Introduction

Bite force and masticatory muscle activity can be used to assess the functional performance of the jaw within research studies, and may be of some use within clinical studies. Previous investigations have combined bite force measurements with electromyography (EMG) to explore differences in masticatory muscle symmetry (1), masticatory function of participants with different facial types (2, 3), and masticatory function of healthy individuals versus those with a limiting condition such as temporomandibular disorder or migraines (4).

Clinical and research investigations using muscle activity and masticatory tasks have varied considerably in their approach to measuring and analysing EMG data. Not only do the recording systems, electrode parameters, and operational processes differ amongst EMG studies (5), the techniques for processing and normalising EMG data in craniofacial and bite force research differs depending on the purpose of each investigation. Studies investigating chewing, speech, or other common submaximal tasks have tended to employ intercuspal Maximal Voluntary Contractions (MVCs) as a means of normalising EMG data (2). Although this approach allows for experimental tasks to be compared as a proportion of a maximal task, the MVC may underestimate true muscular contraction ability due to pain and/or discomfort experienced when attempting to generate 'maximal' bite force with bare dentition (6). Studies investigating bite force and clenching have used a device or dampening material to produce the MVC. For example, Ferrario *et al*. (1) asked participants to bite maximally on cotton rolls to normalise EMGs from intercuspal MVCs and clinical movements. In a later study the same group (7) acknowledged that normalising bite force to an action, whether it be maximal or submaximal, performed on a different surface to the experimental conditions, may incur a greater level of variability. These functional differences may be due to changes in muscle length at mouth opening height (8, 9), the level of protection of occlusal surfaces to reduce discomfort (6), or stability and position of bite force devices (10). Using a reference voluntary contraction, such as a nominal bite force level of 98N, to normalise EMG data from simple chewing tasks is one possible technique (11). Employing reference voluntary contractions has become a commonly used practice in EMG studies when participants are unable or unwilling to perform MVCs (12, 13).

Some previous studies have presented facial EMG data as absolute values rather than normalising them to a common EMG signal (4, 7, 14). However, the amount of variation due to differences in sex, skin thickness, and electrode placement can be reduced if the results are normalised. In the absence of normalisation, Kemsley *et al*. (15) reported higher EMG inter-volunteer versus intra-volunteer, and inter-session variation during chewing tasks. Thus, a well-controlled EMG protocol is fundamental to increase results reproducibility (5).

This study investigated the suitability of an alternative sub-maximal bite force normalisation process. The objectives of the study were to: (i) evaluate whether jaw-closing muscle activity is linearly correlated with incremental sub-maximal and maximal bite force levels, and (ii) assess whether normalising maximal and submaximal muscle activities to that produced when performing a low submaximal bite force level (i.e., 20N) reduces between session experimental variability in a small cohort.

Materials and Methods

Ethical approval was obtained from the Department of Exercise and Sport Science Ethics Committee, Manchester Metropolitan University. Exclusion criteria for the study were a history of facial fracture or surgery, current or recent orthodontic treatment, dental treatment within 6 months, musculoskeletal disease, long-term parafunctional habits such as bruxism, temporomandibular dysfunction, or masticatory pain. Thirty white Caucasian participants were recruited (15 males and 15 females, age range 18-25 years, mean age 21.0 ±1.9 years). All participants gave written informed consent before participating in the study.

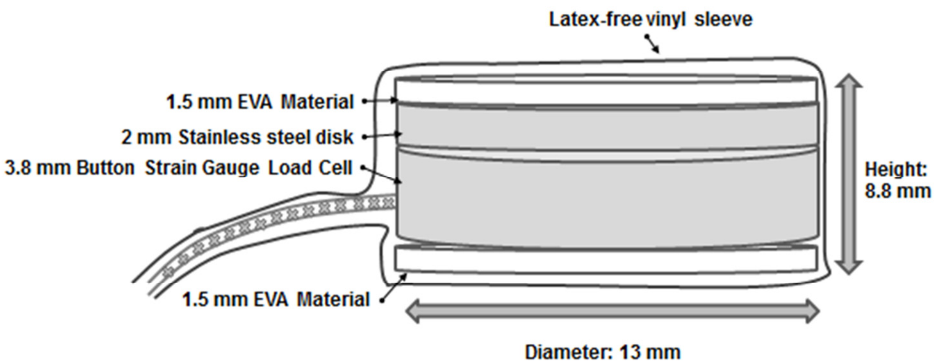

Figure 1: Custom made bite force device set up.

Reliability Measures

A participant sub-cohort (n=4 females) were invited to repeat the testing session 6 months later. All repeat participants complied with the previous inclusion criteria at the time of testing. Each participant followed the same protocol as previously detailed with no evident learning effect.

Bite force measurements were obtained using a custom-made device consisting of two button-style 1kN compression load cells (Omega Engineering, Manchester UK) that were 3.8 mm height × 13 mm diameter, each fitted with a 2-mm-thick stainless steel disk of the same diameter situated on top of the button. The load cell with disk were then sandwiched between two 15 mm-diameter, 1.5-mm-thick ethyl vinyl acetate (EVA) disks (Bracon Dental Supplies, East Sussex, UK) and held together with electrical insulation tape. Each device (8.8 mm total height) was inserted into a latex-free vinyl sleeve, which provided additional waterproofing for the load cell and the initial 40-50-mm of the attached wire (Figure 1). The bite force devices were then connected to a DelSys® Bagnoli 8-channel EMG system (Delsys Inc., Boston MA, USA) through a custom-made amplifier box. Jaw-closing muscle activity and bite force were measured simultaneously using DelSys® EMGWorks Acquisition software (Delsys, Inc.). Prior to testing, the bite force devices were calibrated using an LRX Plus Materials Testing Machine 5kN (Lloyd Instruments Ltd., Hampshire, UK) under compressive loading, with a custom made cylindrical compression loading arm of 18 mm-diameter. Each device was calibrated from 0-800N, at incremental static compressive loads of 50N. Differential surface electrodes (Delsys, Inc.) consisting of silver bars (10 mm × 1 mm) with an inter-electrode distance of 10 mm were used to detect raw EMGs. The sensors including pre-amplifiers had an input impedance $>10^{15}$ Ω, noise 1.2 µV root mean square (RMS), and CMRR (Common Mode Rejection Ratio) -92 dB.

Figure 2: EMG sensor placement.

Procedures

Sensors were placed bilaterally over the main portion of the masseter, 20 mm from the inferior edge of the mandibular angle, in a straight line to the point where the frontal bone external angular process meets the malar bone frontal process. This line runs parallel to the superficial masseter muscle fibres. Sensors were also placed bilaterally on the anterior portion of the temporalis, on the skin covering the junction of the external angular process with the malar bone frontal process. The sensors were placed posterior and parallel to the eyebrow line, so that the electrode bars were perpendicular to the anterior temporalis muscle fibres (Figure 2). Positioning of the electrodes was verified through palpation during clenching. Prior to attaching the electrodes, the areas of skin were shaved and cleaned with an alcohol wipe.

During testing, participants sat upright facing a monitor positioned at eye level. EMGs were recorded at rest, maximal- and sub-maximal bite force. First, 10-second recordings were made during complete rest, gentle occlusion, and occlusion with the bite force devices held simultaneously on the left and right sides, between the upper and lower molar dentition. This was used to identify anyone with high levels of resting muscle activity, of which there were none. The participants placed the bite force devices between their molar teeth, where they were most able to bite evenly across the two devices. Participants then performed three repetitions of maximal voluntary biting held for 2-3 seconds, with adequate rest between repetitions. During this phase, the investigator provided positive encouragement whilst the participants viewed the feedback monitor, which displayed their bite force. The investigator noted the maximum voluntary bite force (MVBF) from all repetitions and calculated 75%, 50%, and 25% force values. Subsequently, each participant then completed three sub-maximal bite force recordings; with a horizontal target line placed on the feedback screen at 75%, 50%, and 25% MVBF in turn. Each participant was instructed to clench for ~2 seconds to reach the intended target and then to relax for ~2 seconds repeatedly for a period of 20 seconds. This period was chosen to allow participants enough time to identify the correct level of force and tempo to use. Finally, each participant repeated the task to a 20N bite force target.

Data Reduction and Analysis

The DelSys EMGWorks® analysis software (Delsys Inc.) facilitated simultaneous analysis of two bite force and four muscle activity channels. The RMS of each repetition was processed using a 0.3 s moving window. The maximal and submaximal bite force values for both left and right sides, were identified for each participant from a 0.15-0.20 s period. The values obtained from the clench-relax test were selected from the first 5 peaks, to allay the effects of fatigue. These values were exported to Microsoft Excel together with the synchronised mean EMG values for all four muscles (left and right temporalis; left and right masseter) from the same 0.15-0.20s period.

Processed EMG data from each task were normalised by dividing these values by the muscle activity recorded during a 20N bite force. Initially, left and right muscles were normalised separately. Comparisons of left- and right-side data using a t-test (SPSS statistical analysis software v.19; IBM Corp., Chicago, IL, USA) found no significant differences ($p > 0.05$) for bite force or muscle activity in either muscle, in both males and females. Therefore, left and right activities for each muscle were pooled for all individuals. Mean normalised EMG data at every bite force level (25%, 50%, 75%, and Max), were plotted against the mean non-normalised data for each muscle, and grouped according to subject gender (Figures 3 and 4). Pearson's correlation coefficients were calculated (SPSS statistical software) for each muscle across the four levels of bite force, subdivided by gender and normalisation.

Reliability Analysis

Individual and group Coefficients of Variation (CV) were calculated for non-normalised and normalised EMG data between both testing sessions using Equation 1:

$$CV = \frac{\sigma}{\mu}$$

Equation 1: Coefficient of Variation where σ is standard deviation and μ is the mean of the sample.

The average CV was calculated separately for the left and right sides, at each maximal and submaximal level, for both muscles. Furthermore, a two-way mixed model Intraclass Correlation Coefficient (ICC) was calculated with SPSS statistical software, using pooled left and right data, at each maximal and submaximal level for both muscles.

Results

Figures 3 and 4 show a linear relationship between jaw elevator muscle activity and incremental sub-maximal and maximal bite force levels, in both male and female cohorts.

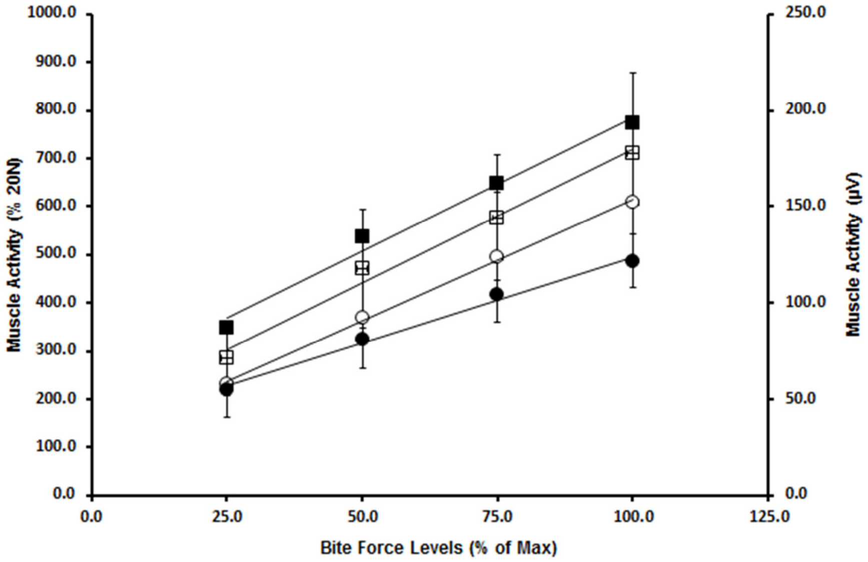

Figure 3: <25-yr-old Male cohort masseter and temporalis muscle activities (Mean ±SD) at each bite force level. Key: Mean (±SD) ☐ Masseter; ○ Temporalis EMG normalised to 20N bite force (%); ■ Masseter; ● Temporalis non-normalised EMG values, (µV).

Despite small differences between normalised and non-normalised data, each data set had a high Pearson's correlation coefficient (r>0.94), indicating that the vast majority of variance in the muscle activity is attributable to the sequential changes in bite force level.

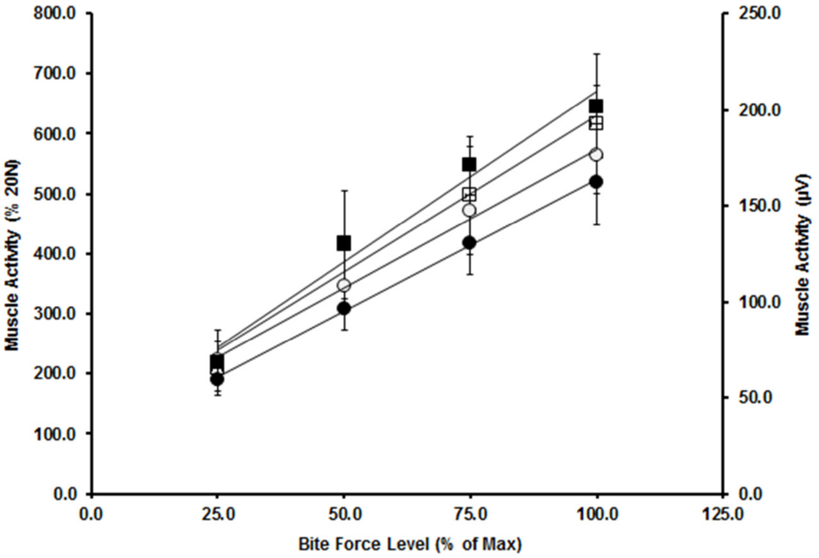

Figure 4: <25-yr-old Female cohort muscle activities (Mean ±SD) at each bite force level. Key: ☐ Masseter and ○ Temporalis EMGs normalised to 20N bite force (%); ■ Masseter and ● Temporalis non-normalised EMG values (µV).

Reliability Results

The between-session CVs (Table 1) predominantly demonstrate reduced variance when the EMGs were normalised, with the only exception being the anterior temporalis muscle at 75% of maximal bite force. The ICCs (Table 1) indicate an improved reliability between testing sessions when data are normalised, with the exception of the anterior temporalis muscle at maximum bite force.

Coefficient of Variation (%)					
Muscle	**Bite Force Level**	**Left Non-Normalised**	**Left Normalised**	**Right Non-Normalised**	**Right Normalised**
Masseter	Max	60.5	27.9	64.3	40.1
	75%	43.6	31.0	49.6	40.0
	50%	54.4	44.8	55.0	48.0
	25%	59.1	24.0	58.9	27.1
Anterior Temporalis	Max	51.3	39.4	80.1	48.2
	75%	50.2	59.7	55.5	47.4
	50%	56.1	52.0	66.0	58.9
	25%	55.7	32.2	74.5	53.1

Intraclass Correlation Coefficient			
Muscle	**Bite Force Level**	**Non-Normalised**	**Normalised**
Masseter	Max	-0.366	0.169
	75%	-1.171	0.342
	50%	-0.271	0.245
	25%	-0.187	0.698
Anterior Temporalis	Max	0.265	-0.409
	75%	-0.92	0.672
	50%	-1.115	0.434
	25%	0.29	0.566

Table 1: Coefficients of Variation (CV) and Intraclass Correlation Coefficients (ICC) for each muscle and bite force level.

Discussion

This study examined an alternative method for normalising EMG data recorded from the masticatory muscles during maximal and submaximal biting tasks. We expected jaw-closing muscle activity would have a linear relationship with incremental sub-maximal bite force levels, up to maximal bite force, and that normalising EMG data to a low bite force (20N) would reduce the amount of variation between testing sessions.

The results (Figure 3 & 4) show that jaw-closing muscle activity is linearly correlated with incremental submaximal and maximal bite force levels, across male and female groups and masticatory muscles. Pearson r-values were >0.94 for all comparisons, indicating very strong positive correlations between muscle activity and 25%, 50%, 75% and 100% bite force intervals. These findings are an improvement on previous work that found similar positive correlations up to 80% of maximal biting (16) and are similar to the findings of Ferrario *et al.* (7) who reported a correlation >0.964 for bite force and submaximal EMG in healthy young participants.

The present study showed that normalising to a low bite force (20N) decreased the CV and increased the ICC in most comparisons, in a small cohort (*n*=4). The majority of published bite force and EMG studies normalise to an MVC, as the focus of their investigations were submaximal tasks such as chewing (2), clinical movements of the jaw (17), or biting at prescribed levels of force (9). The present study used a low bite force (20N) reference value for normalisation, which allowed for successful normalisation from 25%-100% bite force. Other researchers have used MVCs performed on transducers or dynamometers to normalise an array of submaximal tasks on different biting (or non-biting) surfaces (4, 17). Although biting different surfaces may create greater variation in EMG or bite force results (1), normalisation is necessary for comparison of individual versus group results but also enables researchers to compare their results with prior studies (18). The present study used the same bite force devices throughout all experimental tasks, therefore potential variability caused by mouth opening height and biting technique was reduced. Furthermore, through normalisation, these results are suitable for cross-group comparisons. Other studies using EMG have employed normalisation to submaximal bite force levels for analysing everyday tasks. Burnett *et al.* (19) found that normalising posterior and posterolateral neck muscles to 60% MVC was reliable for both surface and intramuscular EMG electrodes. Similarly, in non-facial EMG, Healey *et al.* (13) normalised paraspinal muscle activity in participants suffering from chronic lower-back pain, to a reference voluntary contraction obtained whilst they held a weight outstretched. . Although the reference contraction was recorded during a different movement to the experimental conditions, it prevented any additional pain or discomfort to the participants that may have been caused by performing a MVC. Saifuddin *et al*. (11) measured EMG of the masticatory muscles during daily tasks such as chewing gum, sleeping, and eating a meal. Similar to the present study, they normalised muscle activity to a chosen submaximal level (a 98N bite force), which reduced mealtime EMG variation between sessions.

The current study used CVs and ICCs to quantify the reliability of the normalisation process. The CVs markedly decreased when EMG data were normalised, with one exception highlighted in Table 1. Moreover, the ICC results improved dramatically when EMG data were normalised. Studies that have measured EMG data reliability, regardless of anatomical position, have employed a number of statistical analyses to quantify the repeatability of the measurement technique: ICCs, CVs, standard error of measurement, and repeated measures analysis of variance are commonly used (20-23). Burdette & Gale (24) reported between-session reliability (Pearson's r-values) for the masseter muscle ranging between 0.56-0.65 and 0.33-0.48 for the temporalis. Although they used interclass rather than intraclass correlation statistics for reliability measures, their results indicated increased variability within the anterior temporalis versus the masseter muscle, which they attributed to the temporalis' role in maintaining mandibular postural rest. Greater variability found in this and the present study may indicate innate differences in muscle activity between the elevator muscles. Suvinen *et al*. (25) presented between-day ICC values for the masseter and anterior temporalis muscles during mouth opening and closing tasks, with ICC results ranged from 0.877-0.899 during clenching. The present study observed a greater ICC range and lower ICC values (0.16-0.69) compared to Suvinen *et al*. (25), which could be explained by differences in EMG equipment and placement.

In conclusion, normalising EMG data to a submaximal bite force level of 20N, highlighted a linear relationship of jaw elevator muscle activity with sub- and –maximal bite force levels. Normalisation successfully reduced between-session variability in comparison to non-normalised data. The prescribed low bite force of 20N will facilitate inter-group comparisons and reduce natural variations in masticatory muscle activity. This will prove particularly useful when studying bite force/EMG relationships in patients with musculoskeletal conditions or in ageing populations. This study shows that normalising EMG values to a reference level other than MVC, a technique which has been used in other disciplines that utilise EMG (12)(13), can successfully be applied to dental and craniofacial research with good effect.

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