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Infield masticatory muscle activity in subjects with pain-related temporomandibular disorders diagnoses

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Khawaja S. N., McCall W. Jr, Dunford R., Nickel J. C., Iwasaki L. R., Crow H. C., Gonzalez Y. Infield masticatory muscle activity in subjects with pain-related TMD diagnoses

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Structured Abstract

Objectives – Pain-related temporomandibular disorders (TMDs) are the most prevalent conditions among TMDs. There is contrasting evidence available for association of pain-related TMD and masticatory muscle activity (MMA). The present investigation assesses the associations between MMA levels of masseter and temporalis muscles during awake and sleep among pain-related TMD diagnostic groups.

Setting and Sample Population – The department of Oral Diagnostic Sciences, University at Buffalo. Twenty females and six males participated in this study.

Material and Methods – Using the diagnostic criteria for temporomandibular disorders (DC-TMDs), participants were diagnostically categorized. Subjects used a custom monitoring system, which recorded infield muscle activities. A factorial model tested for association between independent variable (muscle, time period, MMA level, and diagnostic group) effects and the logarithm of MMA. Greenhouse–Geisser test was used to determine any statistically significant associations ($p \leq 0.003$).

Results – No statistically significant association was found between four-way, three-way, and two-way analyses. However, among the main effects, range of magnitudes was the only variable to be statistically significant. Although the data suggest a trend of increased masseter MMA in the pain-related TMD diagnoses group both during awake and sleep time periods, such observation is not maintained for the temporalis muscle. In addition, temporalis MMA was found to be higher in the pain-related TMD diagnoses group only at extreme activity levels (<25 and $\geq 80\%$ ranges).

Conclusion – This data support the association between masticatory muscle hyperactivity and painful TMD conditions.

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Introduction

Temporomandibular disorder (TMD) is a collective term, embracing a number of clinical problems that involve the masticatory muscles, the temporomandibular joint (TMJ), and the associated structures (1). The pain-related TMD consist of myalgia, arthralgia, and headaches attributed to TMD (2). The prime manifestations of pain-related TMD consist of pain of a persistent, recurring, or chronic nature in the masticatory muscles, TMJ, or in the adjacent structures (3, 4). The other major symptoms include limitation in the range of mandibular motion and joint noises (1, 3, 4).

The prevalence of pain-related TMD is about 10% in the general population, and the incidence in the general population of the United States is about 3.9% (5, 6). The etiology of pain-related TMD is considered multifactorial resulting from a complex interaction between biological, psychological, social, and environmental variables (7). Historically, two competitive models have been presented to explain the presence of pain among individuals diagnosed with TMDs, the stress hyperactivity (8), and the pain adaptation models (9). The evidence for either of the two models has been inconsistent and poor, primarily due to the presence of multiple potential confounders, particularly at the diagnostic levels (10, 11). Recently through new data, based on methodologically solid designs, a better understanding of the multifactorial nature of the conditions is available leading into a peripheral/central sensitization model (12, 13). Risk factors identified with pain-related TMD including gender, psychological characteristics, sustained parafunctional activity, non-specific orofacial symptoms, and various comorbid preexisting pain conditions (6, 13).

The aim of this study was to evaluate the associations between masticatory muscle activity (MMA) levels of masseter and temporalis muscles

during awake and sleep time periods among groups of subjects with various pain-related TMD diagnoses. To test these associations, a standardized diagnostic criteria for temporomandibular disorder (DC-TMD) examination protocol (2) and a calibrated ambulatory electromyographic (EMG) monitoring system (14) to measure masticatory muscle activities were used.

Methods

Study participants

Recruitment

All participants were recruited at the University at Buffalo, School of Dental Medicine. Participants were consecutively recruited from direct referrals from local healthcare providers and in response to community advertisements.

Inclusion and exclusion criteria

Adult men and women were included. Individuals were excluded who were pregnant, had evidence of degenerative joint diseases [determined by cone beam computed tomography (CBCT)], had unilateral disk displacement [determined by magnetic resonance imaging (MRI)], had diagnoses of systemic musculoskeletal or rheumatological diseases (e.g., fibromyalgia and muscular atrophy), had missing teeth or large restorations, and were unable to read or follow tasks associated with the laboratory and field recordings.

This study was approved by the Institutional Review Boards of the State University of New York at Buffalo (HSIRB) and University of Missouri Kansas City (Adult IRB). Informed consent was obtained from each participant.

Appointments for study

To complete participation in the protocols of the study, each subject made a minimum of five visits. During an initial clinic visit, an examiner explained the study, obtained informed consent,

reviewed the participant's medical history, and performed a screening exam, particularly with reference to the exclusion and the inclusion criteria. During subsequent visits, temporomandibular joint MRI and CBCT images were obtained using standardized acquisition protocols for all study participants and interpreted by a calibrated radiologist. Those who qualified for participation underwent the standardized diagnostic criteria for temporomandibular disorder (DC-TMD) examination (2) by a calibrated examiner. In addition, maxillary and mandibular arch impressions, and face-bow recordings were obtained. Eligible participants presented for two laboratory visits during which bite forces along with EMG activities of masseter and temporalis muscles were recorded bilaterally using surface electrodes during static and dynamic bites on molars and incisors. Participants were also trained to use portable EMG recorders and surface electrodes on one side to make infield ambulatory EMG recordings during the first of the two laboratory visits.

Equipment

Bite force measurement

Custom bite force transducers made of electrically resistant film (Flexforce; Tekscan Inc., Boston, MA, USA) attached to a stainless steel wire handle, sandwiched by acrylic (Triad, TruTray; Dentsply Inc., York, PA, USA), and wrapped with clear plastic film were used (Fig. 1). Each transducer was pre-calibrated, so the electrical voltage output recorded (V) could be later converted to units of force in Newton (N).

Laboratory EMG recordings during biting

Bipolar surface electrodes, amplifiers, and a digital recording system were used as previously described (15, 16).

Ambulatory EMG activity of masticatory muscles

The EMG surface electrode signals were band-pass filtered (20–1000 Hz) and amplified (5000 \times) by means of the portable device with digital amplifier having an input impedance of 250 M Ω , noise level of 0.7 μ Volt, and common mode rejection ratio of 100 dB.

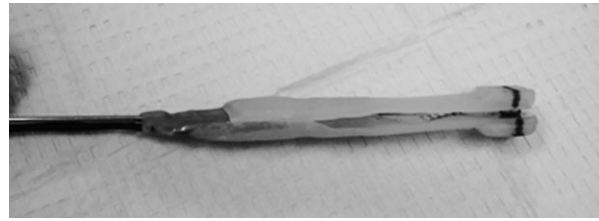


Fig. 1. Bite force transducer. Bite force transducer consisting of acrylic biting surfaces sandwiching sensor film (Tekscan Flexiforce®; Tekscan Inc.) attached to a wire handle. Shown without protective plastic film barrier (Photograph courtesy of Dr. Adam Reynolds).

During infield data collection, participants used the portable EMG recording equipment and supplies as instructed (Fig. 2), to capture unilateral electromyographic signals from the masseter and temporalis muscles. Subjects were asked to record for periods of at least six total hours for each of 3 days and three nights.

Data processing

Duty factor

Duty factor (DF) is the percentage of time when a respective muscle has been active above a certain threshold out of a total given time (duration of muscle activity/duration of recording period \times 100%). Thresholds used in the current study were (1) magnitude of muscle activity and (2) duration of muscle activity.

A custom software program (MATLAB; The MathWorks Inc., Natick, MA, USA) was used with the calibration information for the specific transducer to identify and calculate force (N) and root-mean-square EMG (μ V) outputs for each of the static and dynamic bite tasks over a 128-ms contiguous period. A total of 50 EMG:BF data points (five static bites and five dynamic bites for four frequencies on right and left molars) were plotted for each muscle, subject, and visit, and from the resulting regression relation (μ V/N), a threshold EMG activity for a 20 N bite force (T20N, μ V) was determined. T20N results from laboratory visits were then averaged (T20N_{ave}) for masseter and temporalis muscles in each subject and used to set four arbitrary magnitude (10, 25, 50, and 80% \cdot T20N_{ave}) and six arbitrary duration (1, 2, 5, 10, 15, and 20 s) activity thresholds to calibrate infield ambulatory EMG recordings for the same muscle type and subject.

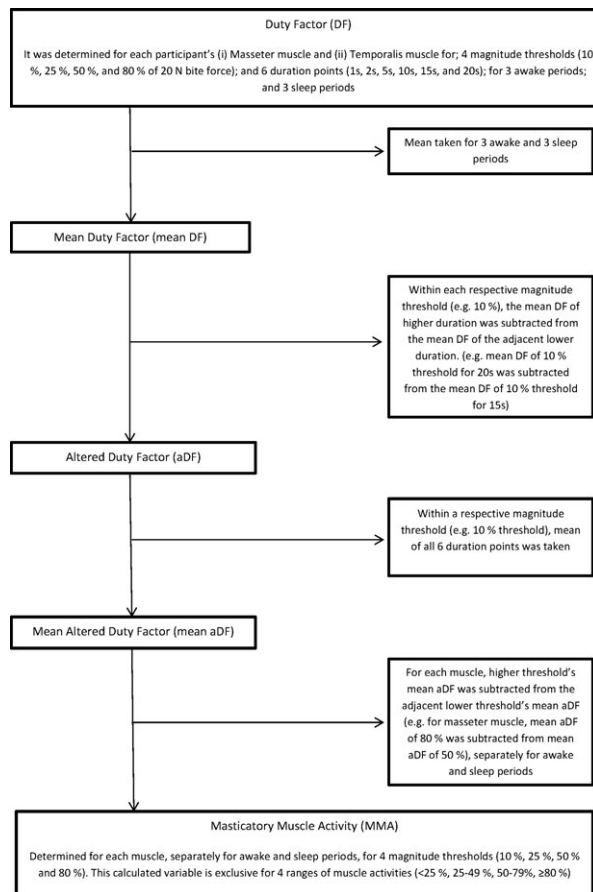


Fig. 2. Ambulatory electromyographic (EMG) setup. Picture illustrating ambulatory EMG setup, the two surface electrodes are attached with an adhesive tape over the anterior temporalis muscle and the body of masseter muscle. Electrodes are attached to a portable EMG device.

Each infield ambulatory EMG recording for each muscle type was viewed, noisy signals were identified and excluded, and then, task definers were applied to calculate DF for the desired thresholds using customizable software.

Masticatory muscle activity

For each muscle type and subject, DF was determined for four magnitude and six duration thresholds in two different time periods (awake and sleep) and across 3 days. The combination of duty factors allowed estimating 'Masticatory Muscle Activity' as outcome variable with mutually exclusive values (Fig. 3).

Statistical analysis

A multistep analytic approach identified associations of masseter and temporalis muscle MMA

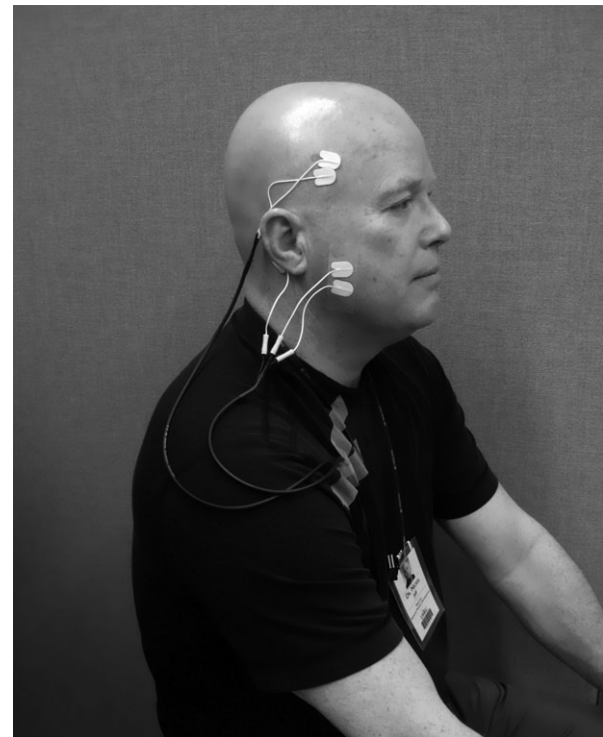


Fig. 3. Flow chart explaining the derivation of masticatory muscle activity (MMA).

during awake and sleep time periods with TMD pain diagnoses. The first step examined the distribution of the data across the two diagnostic groups using the Shapiro–Wilk test of normality. If data showed non-parametric distribution, logarithmic transformation would be applied.

The second step involved using a generalized linear model for repeated measurements with Mauchly's test of sphericity. The goal of this analysis was to determine any interaction between the main variables (diagnostic group, time period, muscles, and MMA ranges).

The third step involved evaluation of the trend of distribution of the dependent variables among the diagnostic groups. As four-way analyses of variance provide 15 tests, a Bonferroni correction was used, with alpha of 0.003 determining significance.

Results

Evaluation of the data showed a non-normal distribution, using a Shapiro–Wilk normality test

($p > 0.05$). Therefore, logarithmic transformation was used. Study population had 26 participants, 77% women ($n = 20$) with a mean age of 33.3 ± 12.3 years. Based on the DC/TMD diagnosis classification, subjects were classified as pain-related TMD diagnoses (myalgia and arthralgia) and no pain diagnoses. Among the pain-related TMD diagnoses group, the mean age was 30.6 ± 11 years and 84.6% were women ($n = 11$), while among the control group, the mean age was 36 ± 13.3 years and 69.2% were women ($n = 9$). No statistical differences were observed between the groups for age (t -test, $p = 0.272$) or gender distribution (chi-square, $p = 0.352$).

A full factorial model was used initially with factors for muscle (two levels, within subjects), time (two levels, within subjects), MMA range (four levels, within subjects), and diagnostic group (two levels, between subjects). The dependent variable was the logarithm of MMA. Mauchly's test for sphericity was found to be statistically significant ($p < 0.001$); therefore, it cannot be assumed that variances were equal. Consequently, Greenhouse-Geisser test to determine any statistically significant associations was used.

No significant interactions were observed between four-way, three-way, and two-way analyses. However, among the main effects, range of magnitudes was the only variable to be statistically significant (Table 1). MMA range and paired t -tests demonstrated that the differences in MMA at $<25\%$ and the rest of the ranges (25–49, 50–79, and $\geq 80\%$) were statistically significant ($p < 0.001$).

To illustrate the effect of logarithm of MMA for the masseter and temporalis muscles, Tables 2 and 3 present the data by diagnostic group within the awake and the sleep time periods. For the masseter muscle, during the awake time period, there was a linear pattern in which those with pain-related TMD diagnoses have higher activity than the no pain diagnoses group. This pattern is more perceptible at the $<25\%$ range. During the sleep time period, at extreme magnitude ranges (<25 and $\geq 80\%$), the masseter activity appears to be higher in the pain-related TMD diagnoses group.

For the temporalis muscle during the awake time period, the MMA of the pain-related TMD diagnoses group is higher at the <25 and $\geq 80\%$ ranges although this pattern is less distinct than the one observed for masseter muscle. Similar trends are also observed during the sleep time period (Table 3).

Discussion

The purpose of this study was to evaluate the association between MMA recorded in individual's natural environments during awake and sleep time periods among individuals with pain-related TMD diagnoses. Multistep analyses of the interactions between within-subject and between-subject variables indicated statistically no significant interactions between muscle, time period, MMA range, and diagnostic group. However, among the main effects, it was observed that there was statistically significant differences in MMA at $<25\%$ magnitude. There was a generalized trend for masseter and temporalis MMA, where subjects with pain-related TMD diagnoses had higher activities than during awake and sleep time periods.

Masseter MMA during the awake time period was higher among all threshold ranges, while during the sleep, more variability was observed. Studies evaluating the association between low-magnitude masticatory muscle activities during awake and sleep time periods and TMD have consistently reported similar results (17, 18). However, studies evaluating the association between high-magnitude masticatory muscle activities, such as during a defined parafunctional behavior-like bruxism, and TMD have reported inconsistent findings (11, 19–21). A reason for such inconsistency can be attributed to poor methodological quality (11). Most of the studies reporting an association between high-magnitude muscle activities and TMD have relied on non-standardized self-report questionnaires, or only on oral examination for tooth wear, both with poor reliability and validity in characterizing parafunction (11, 19).

The temporalis muscle activity trend suggests that at either low-magnitude muscle activities

Table 1. Results of generalized linear measurement test of repeated measurements, four-way interaction between the study variables

Factors	Type III sum of squares	df	Mean square	F	Sig.
Muscle	0.008	1	0.008	0.03	0.864
Time	0.687	1	0.687	9.182	0.006
MMA range	21.255	1.281	16.591	30.073	>0.001 [†]
Diagnostic group	1.225	1	1.225	1.217	0.281
Muscle*diagnostic group	0.788	1	0.788	3.089	0.092
Time*diagnostic group	0.005	1	0.005	0.064	0.803
MMA range*diagnostic group	1.805	1.281	1.409	2.554	0.113
Muscle*time	0.316	1	0.316	4.298	0.049
Muscle*MMA range	0.091	1.558	0.058	0.462	0.585
Time*MMA range	0.682	1.787	0.382	3.593	0.041
Muscle*MMA range*diagnostic group	1.3	1.558	0.834	6.608	0.006
Muscle*time*diagnostic group	0.249	1	0.249	3.393	0.078
Time*MMA range*diagnostic group	0.042	1.787	0.024	0.222	0.777
Muscle*time*MMA range	0.631	1.448	0.436	2.96	0.08
Muscle*time*MMA range*diagnostic group	0.15	1.448	0.104	0.704	0.458

[†]Statistically significant ($p \leq 0.003$).

Table 2. Summary of logarithm masseter muscle masticatory muscle activity (MMA) in participants of pain-related temporomandibular disorders (TMD) diagnoses and no pain diagnoses group

	Awake time period				Sleep time period			
	Pain-related diagnoses		TMD		Pain-related diagnoses		TMD	
	No pain diagnoses		No pain diagnoses		No pain diagnoses		No pain diagnoses	
MMA range (%)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<25	1.101	0.792	0.487	0.540	0.751	0.903	0.170	0.459
25–49	0.406	0.481	0.194	0.504	0.100	0.128	0.072	0.255
50–79	0.133	0.201	0.040	0.128	0.019	0.032	0.132	0.475
≥80	0.112	0.153	0.026	0.070	0.113	0.231	0.050	0.179

Table 3. Summary of logarithm temporalis muscle masticatory muscle activity (MMA) in participants of pain-related temporomandibular disorders (TMD) diagnoses and no pain diagnoses group

	Awake time period				Sleep time period			
	Pain-related diagnoses		TMD		Pain-related diagnoses		TMD	
	No pain diagnoses		No pain diagnoses		No pain diagnoses		No pain diagnoses	
MMA range (%)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
<25	0.663	0.637	0.585	0.512	0.672	0.583	0.658	0.703
25–49	0.181	0.208	0.261	0.333	0.125	0.217	0.038	0.080
50–79	0.060	0.089	0.180	0.484	0.104	0.311	0.115	0.385
≥80	0.119	0.271	0.079	0.167	0.184	0.467	0.021	0.072

(<25%) or high-magnitude muscle activities ($\geq 80\%$), MMA was higher in the pain-related TMD diagnoses group. However, at other magnitude levels, variability was observed. One possible explanation for such trends may be because differing muscle activities are associated with specific oral behaviors (22). Additionally, it has also been postulated that similar oral behaviors in participants with and without TMD may result in different levels of muscle activation (22, 23).

In general, our findings are consistent with those previously reported (18), in which investigators have shown a statistically significant association between background nocturnal low-magnitude masticatory muscle activities and myofascial TMD. Our study overcame several methodological limitations presented in the literature (24). First, there was no frequency spectral analysis of EMG recordings to decrease spillover of activity at one frequency into neighboring frequencies. This was overcome in our study design by calculating ranges activity magnitudes relative to those for a known bite force (20 N) to ensure mutually exclusive data (Fig. 3). Secondly, background masticatory muscle activity magnitudes were only recorded during the sleep time period, whereas in our study, masticatory muscle activity was recorded during both awake and sleep time periods. Additionally, masseter and temporalis muscle activity data were not differentiated during the analyses, although it has been shown previously that masseter and temporalis muscles are activated dissimilarly across different oral tasks (22, 23). In this study, however, masseter and temporalis muscle MMA were analyzed separately.

The observed variability between the diagnostic groups could be explained by the influence of Axis II variables on masticatory muscle activity. It has been proposed that anxiety, depression, and coping ability have an effect on the masticatory muscle activity (22, 24–26). Anxiety disorders in particular have been associated with parafunctional activities such as sleep-related bruxism, daytime clenching, and nail biting. It has been proposed that a high level of stress is a risk factor for hyperactivity

of masticatory muscles (9) (8, 26). However, clinical evidence in literature regarding this association has been poor and inconsistent (11, 24, 26).

There were several limitations in our investigation. First, we utilized non-invasive surface electrodes for ambulatory EMG recording. It has been shown that non-invasive electrodes are less accurate than intramuscular fine-wire electrodes for EMG recording (27). Nevertheless, surface electrodes may have an advantage over fine-wire electrodes when characterizing ‘whole muscle’ behavior rather than single motor units. Another reason for using surface electrodes was the extent and the nature of recording period (infield recording for total of six time periods, each lasting for at least 6 h). It would have not been practical to train the participants and send them into the field with fine-wire electrodes. Secondly, placement of electrodes for EMG recording was not standardized. All of the participants were instructed to place electrodes on themselves during the infield recording period. This may have introduced an error in measurement; however, investigators trained all of the participants so as to minimize errors associated with electrode position. Third, the smallest duration threshold in current study was set at ≥ 1 s. This means any rhythmic functional and parafunctional activity at rate of <1 hertz would have not been recorded. A final limitation is the use of conservative *post hoc* tests, which may increase the possibility of type II error. Therefore, further investigations with larger sample size are needed to elucidate the potential presence of interaction between the diagnostic groups.

Conclusion

Although the current study does not identify an explanatory mechanism through which pain-related TMD diagnoses group elicits relatively higher activity in masseter and temporalis muscles across various thresholds, it suggests that masticatory muscle activity is a risk indicator.

Clinical relevance

Pain-related TMDs have a poorly understood multifactorial etiology. There is contrasting evidence available for association of pain-related TMD and masticatory muscle activity. This is primarily due to presences of multiple potential biases and confounders, particularly at the diagnostic levels. In this publication, we assess if any associations exist between activity levels of masseter and temporalis muscles during awake and sleep time periods and groups of subjects with

pain-related TMD diagnoses using a standardized and validated TMD examination to categorize the participants and a state-of-the-art monitoring system to measure masticatory muscle activities.

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