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# Impaired orofacial motor functions on chronic temporomandibular disorders

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A B S T R A C T

Because temporomandibular disorders (TMDs) rehabilitation continues to be a challenge, a more comprehensive picture of the orofacial functions in patients with chronic pain is required. This study assessed the orofacial functions, including surface electromyography (EMG) of dynamic rhythmic activities, in patients with moderate-severe signs and symptoms of chronic TMD. It was hypothesized that orofacial motor control differs between patients with moderate-severe chronic TMD and healthy subjects. Seventy-six subjects (46 with TMD and 30 control) answered questionnaires of severity of TMD and chewing difficulties. Orofacial functions and EMG during chewing were assessed.

Standardized EMG indices were obtained by quantitative analysis of the differential EMG signals of the paired masseter and temporal muscles, and used to describe muscular action during chewing.

TMD patients showed significant greater difficulty in chewing; worse orofacial scores; longer time for free mastication; a less accurate recruitment of the muscles on the working and balancing sides, reduced symmetrical mastication index (SMI) and increased standardized activity during EMG test than healthy subjects. SMI, TMD severity and orofacial myofunctional scores were correlated ($P < 0.01$). Impaired orofacial functions and increased activity of the muscles of balancing sides during unilateral chewing characterized the altered orofacial motor control in patients with moderate-severe chronic TMD. Implications for rehabilitation are discussed.



## 1. Introduction

Temporomandibular disorder (TMD) has multiple clinical manifestations involving dysfunctions and pain in the masticatory muscles, temporomandibular joints (TMJs), and associated structures, and affects a considerable number of adults (Bakke and Hansdottir, 2008; Ratnasari et al., 2011; Schmid-Schwap et al., 2013). Despite several studies, no specific therapies have been proven to be more effective than others to promote pain relief and functional improvement (Michelotti et al., 2012). Therefore, this warrants further exploration of the stomatognathic system and functions. In particular, alterations in muscular function and coordination have been hypothesized to be at the base of several TMD signs and symptoms (Douglas et al., 2010).

During orofacial motor functions various muscles may be combined in a particular manner according to the task. Especially during chewing, the tongue, facial and jaw muscles act in coordination to position the food between the teeth, cut it up and prepare it for swallowing (Trulsson et al., 2012). Potential modifiers of orofacial functions are dental occlusion, neuromuscular system, periodontal mechanoreceptors and pain (Bakke and Hansdottir, 2008; Trulsson et al., 2012). The neuroplastic capabilities of sensorimotor cortex areas may reflect or allow for functional adaptation to an oral state or oral motor behaviour, but also maladaptation (Avivi-Arber et al., 2011), with resulting negative behaviours that may lead or aggravate dysfunction, pain, and disease.

Surface electromyography (EMG) is a useful tool for determining muscle function during standardized tasks (Al-Saleh et al., 2012), and it has been employed as a measurement of motor

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adaptation (Hellmann et al., 2011). EMG can be used to record both static (isometric; rest, teeth clenching) and dynamic rhythmic (chewing) activities. Both kinds of tasks use the same group of muscles, but rhythmic movements require a different control of muscular activities, where contraction and decontraction should be carefully coordinated among agonist and antagonist muscles. To describe complex harmonic motion and investigate the combined and coordinate action of couples of structures, the Lissajous plot has been proposed since 1857. In dental research, the method has been used to graphically show the co-operative work of masticatory muscles since 1988 (Kumai, 1988, 1993). Ferrario and Sforza, 1996; Ferrario et al., 2004; Tartaglia et al., 2008; Sforza et al., 2010) devised a quantitative analysis of the differential EMG signals of the paired masseter and temporal muscles, and used them to describe the coordinated action of these muscles during human standardized chewing. Even if the first papers using this method analyzed patients with TMD (Kumai, 1993), it seems that its potentialities have been little explored in TMD.

Additionally, clinical evaluation is considered essential for diagnosis of orofacial myofunctional disorders (Mangilli et al., 2012). The Orofacial Myofunctional Evaluation with Scores Protocol (OMES Protocol) provides information about the components and functions of the stomatognathic system and was validated for patients with TMD (De Felício et al., 2012b). This protocol has been combined with a subjective scale about difficulties to chew and a validated questionnaire to determine the perception severity of TMD, the ProTMDmulti-Part II, that allows differentiating between control subjects and TMD patients (De Felício et al., 2009, 2012a,b, 2013).

The objective of the present study was to investigate the characteristics of the orofacial motor functions of subjects with chronic TMD (duration longer than 6 months) showing moderate-severe signs and symptoms.

It was hypothesized that the orofacial motor control differs between patients with moderate-severe chronic TMD and healthy subjects, and it is correlated with TMD severity.

According to our knowledge, this is the first study to investigate orofacial motor functions by using valided clinical protocols and analysis of the differential EMG signals (Lissajous plot).

## 2. Materials and methods

### 2.1. Subjects

Ninety-seven consecutive patients who came to our institution for treatment of orofacial pain and TMD, and 50 healthy subjects without TMD complaints, were examined for diagnosis and responded to a questionnaire of signs and symptoms. Healthy subjects were recruited among institution staff and relatives of the patients. Forty-six patients with chronic TMD (duration > 6 months) of moderate-severe intensity (TMD group: 46 women, mean ± SD age 33.7 ± 11.0 years), and 30 healthy women (Control group, mean ± SD age 29.2 ± 8.9 years), matched for age to TMD patients, were selected.

#### 2.1.1. Inclusion criteria

TMD group: to present TMD, according to the Research Diagnostic Criteria for TMD (RDC/TMD), axis I (Dworkin and LeResche, 1992), with chronic and moderate-severe symptomatology based on the ProTMDmulti-part II questionnaire (De Felício et al., 2009).

Control group: to present Angle occlusal Class I, overbite and overjet between 2 and 4 mm, and no TMD based on the RDC/TMD.

The selected patients showed bilateral TMD, with muscle diagnoses (RDC/TMD group I) associated to disk displacement with reduction (DDR) (RDC/TMD group IIa, $n = 3$), or DDR and arthralgia ($n = 25$), or arthralgia alone ($n = 18$).

The exclusion criteria, for both groups, were: tooth absence; denture use; crossbite; dental pain or periodontal problems; pregnancy; neurological or cognitive deficits; previous or current tumors or traumas in the head and neck region; current or previous orthodontic, orofacial myofunctional or TMD treatments; current use of analgesic, anti-inflammatory and psychiatric drugs.

This study was approved by the institutional Ethics Committee and all subjects gave written informed consent to participate.

### 2.2. Data collection

During data collection, each examination was performed by independent examiners, blinded to the outcome of the other ones.

Subjects were examined by an experienced examiner and calibrated for classification according to the RDC/TMD (Dworkin and LeResche, 1992). Also, during muscle and TMJ palpations the subjects were asked to assign a value on a numeric rating scale (VAS; endpoints: 0 no pain and 10 extreme pain).

Another examiner applied the ProTMDmulti-part II questionnaire. Subjects were asked to indicate the severity of muscular pain, joint pain, neck pain, otalgia, tinnitus, ear fullness, tooth sensitivity, joint noise, difficulty to swallow and to speak by means of a numerical scale. The total severity score varies between zero (absence) and 400 (the highest possible severity). For detailed information see De Felício et al. (2009, 2012a).

#### 2.2.1. Self-perception of difficulties to chew

Next, subjects were asked to think about their difficulty in chewing each of nine foods (Fig. 1), and to attribute scores on a 10-point scale in which 1 indicated the lowest difficulty to chew and 10 the highest. The difficulty to chew was obtained by the sum of the scores attributed.

#### 2.2.2. Orofacial myofunctional evaluation

An experienced speech pathologist evaluated the subjects individually and later complemented by analysis of recorded images. Appearance/posture, mobility performance of stomatognathic system components, respiration, deglutition, bite and signs of alteration during chewing were assessed according to the OMES Protocol (De Felício et al., 2012b).

To test chewing from a clinical point of view, a chocolate-flavored stuffed Bono® cookie (Nestlé, São Paulo, SP, Brazil) was used. The subject was instructed to chew in the usual manner (free chewing). Masticatory type analysis was performed using the expanded OMES protocol (Felício et al., 2010) which contains a 10-point scale, with 1 indicating failure to chew and 10 indicating

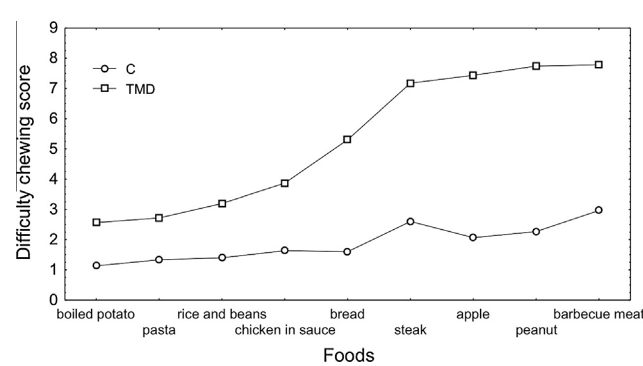


**Fig. 1.** Chewing difficulties scores in the Control and TMD patients groups. $P < 0.001$ for all comparisons in Mann–Whitney test.

bilateral and alternate chewing. Intermediate scores were assigned according to masticatory strokes side/local of the oral cavity as follows:

- Simultaneously bilateral: on both sides 95% of the times = score 8.
- Unilateral preference grade 1: on the same side 61–77% of the times = score 6.
- Unilateral preference grade 2: on the same side 78–94% of the times = score 4.
- Chronic unilateral: on the same side 95–100% of the times or masticatory strokes occurring in the region of the incisors and canines = score 2.

The total score of orofacial myofunctional condition was obtained from the sum of the scores attributed to each item.

The time spent to consume the food was measured with a digital chronometer (Q&Q Stop Watch HS43, Mailand, China) which was started after the food was placed in the oral cavity and stopped after the final deglutition of each portion. The total time was obtained by sum of the partial times.

#### 2.2.3. Electromyographic (EMG) recordings and measurements

The masseter and anterior temporal muscles of both sides (left and right) were examined. Disposable silver/silver chloride bipolar surface electrodes (diameter 10 mm, interelectrode distance 21 ± 1 mm; Double; Hal Ind. Com. Ltda., São Paulo, SP, Brasil) were positioned on the muscle bellies parallel to the muscle fibers (Hermens et al., 2000). A disposable reference electrode was applied to the forehead. Before electrode placement, the skin was cleaned with ethanol to reduce its impedance.

EMG activity was recorded using a computerized instrument (Freely, De Götzen srl; Legnano, Milano, Italy). The analogue EMG signal was amplified and digitized (gain 150, peak-to-peak input range 28 μV, 12 b resolution, 2000 Hz A/D sampling frequency, theoretical resolution 16 μV) using a differential amplifier with a high common mode rejection ratio (CMRR = 105 dB in the range 0–60 Hz, input impedance 10 GΩ), and filtered (analogue filtering: low-pass filter with a bandwidth in the frequency range 0–580 Hz; digital filtering: range 30–400 Hz; band-stop for common 50 Hz interference with a notch filter, approximate range 47–53 Hz).

To standardize the EMG potentials, two 10 mm-thick cotton rolls were positioned on the mandibular second premolar/first molars of each subject, and a 5 s of maximum voluntary contraction (MVC) was recorded. Subsequently, EMG activity was recorded in the dynamic condition over a period of 15 s – unilateral, left and right, chewing (Sforza et al., 2010; Tartaglia et al., 2008) of pre-softened sugarless gum (1.5 g; Trident® Cadbury Adams, Bauru, SP, Brazil). An observer monitored the execution of the task so that the gum would be kept on the programmed side. The recordings were started after the third masticatory stroke. The tests were repeated in the same session. To avoid any fatigue effect, a rest period of at least 3 min was allowed between trials.

For each of the four analyzed muscles, the mean EMG potential evaluated on the most constant 3-s interval of MVC with cotton trial (mean of the root mean squared, RMS, calculated in 25-ms temporal windows) was set at 100%, and all EMG potentials obtained during chewing were expressed as a percentage of this value.

Bivariate analysis of the EMG potentials recorded from the four tested muscles during each chewing test was performed. In a Cartesian axis representation (Lissajous plot), the *x*-coordinate represents the differential left–right masseter activity and the *y*-coordinate the temporal differential activity. Within each subject and chewing test, differential data were normally distributed: from the pairs of co-ordinates, Hotelling's 95% confidence ellipses were calculated (unit: $\mu V^2/\mu V^2 \times 100$) (Ferrario et al., 2004; Tartaglia et al., 2008; Sforza et al., 2010; De Felício et al., 2013). The following indices were computed:

Dynamic condition (chewing test)

- The masticatory frequency, resulting as the number of cycles/s.
- The area of the confidence ellipse (Hotelling's 95%) of the simultaneous differential right–left masseter and temporal standardized activity extracted from each cycle (Lissajous's plot). The confidence ellipse is a statistic computed to assess the repeatability of the masticatory muscle pattern of contraction. In subjects with a normal neuromuscular coordination, the centers of the ellipses describing unilateral chewings plotted as a Lissajous figure should be located in the first (right-side chewing) and third (left-side chewing) quadrants of a Cartesian coordinate system.
- The amplitude, the distance of the center of the ellipse from the center of the coordinate axes, which represents the differential activity of the muscles on the working side and on the balancing side.
- The phase angle (degree), angle between the *x*-axis and the line joining the center of the ellipse with the origin of the axes of a Cartesian coordinate system; it represents the relative activity of the masseter and temporal muscles. For right-side chewing, the phase range is 0–90 deg (first quadrant), and for left-side chewing the phase range is 180–270 deg (third quadrant). To directly compare right- and left-side chewing, this latter's phase was mirrored, subtracting 180 deg from its value.
- The global masticatory Impact Coefficient (IC,%), represents the global muscular activity computed as the mean EMG standardized potentials over time.
- The Impact per cycle (IC/cycle,%), calculated as the Impact/number of chewing cycles.
- The Symmetrical Mastication Index (SMI,%) was computed using the centers of the two confidence ellipses to assess whether the left- and the right-side chewing tests were performed with symmetrical muscular patterns. Two symmetrical tasks should have about the same amplitude (distance of the center of the ellipse from the origin of the axes) and a 180 deg difference between phases (angle between the *x*-axis and the center of the ellipse), before mathematical mirrowing. A symmetrical muscular pattern would then produce an SMI close to 100%.

Fig. 2a and b are examples of the Lissajous Plot.

### 2.3. Realiability/data reproductibility

Clinical diagnostic measures were determined for a second time in 20% of the subjects by a different examiner who was unaware of the previous results, and the following intra-class correlation coefficients (ICC) were found: jaw motion excursion range = 0.86, tenderness to palpation = 0.95; ProTMDmulti = 0.96; self-perception of difficulties to chew = 0.92; OMES categories: appearance/posture = 0.88, mobility = 0.90, functions = 0.90.

The reproducibility of the EMG indices was calculated by the Student *t*-Test for paired samples, considering test–retest of 50% of the sample assessed during the same session. The Technical Error of Measurement (random error) was also computed as $[\Sigma(D^2)/2 \times N]^{0.5}$, where $D$ is the difference between the two repeated measurements, and $N$ is the number of subjects (De Felício et al., 2009). There were no statistically significant differences between EMG indices obtained in test and retest values, assessed during the same session ($P > 0.05$). For all indices, the test–retest random error was lower than or close to the intragroup standard deviation, showing the good reproducibility of the indices.

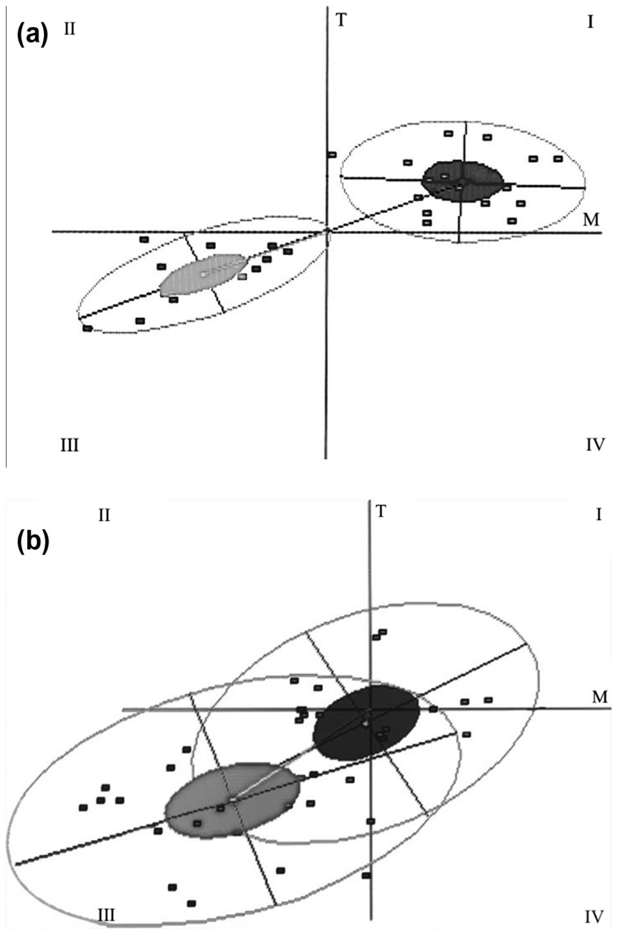


**Fig. 2.** Lissajous plot of differential left–right masseter activity ($x$-coordinate = M) and differential left–right temporal activity ($y$-coordinate = T). Unit: % of maximum voluntary clench on cotton rolls. Each dot represents a single chewing cycle. The Hotelling's 95% confidence and standard ellipses are also drawn (left side: light grey; right side: dark grey). (a) Example of a control healthy subject, with good coordination and symmetry index (SMI) = 93.76%. The symmetry. (b) Example of a TMD patient with impaired coordination and asymmetry. Neither ellipse is significant ($P > 0.05$). The SMI was 1.74%.

### 2.4. Statistical analysis

Descriptive statistics were computed for all variables. Categorical variables were analyzed by the nonparametric Mann–Withney or Chi-square tests, and continuous data by parametric statistics. Two-way ANOVA – group × side was used to analyze baseline data of tenderness to palpation of the Control and TMD groups. Because neither differences between side nor group × side interactions were observed, in the remaining comparisons Student $t$-test for unpaired samples were used. Spearman Correlations coefficients were calculeted to analyze the correlations between the masticatory symmetry index (SMI), myofunctional orofacial and ProDTM-multi scores. The Statistica software was used (StatSoft Inc., Tulsa, Oklahoma, USA). Significance was set at $P < 0.05$.

The percentage of subjects having a SMI values lower than 55%; and the activity on the balancing side greater than working side (IC balancing side > IC working side) were also computed separately for each group, as well as the distribution of the masticatory types according to the expanded OMES protocol.

## 3. Results

Table 1 shows characteristics of the groups and comparisons

### 3.1. Difficulties to chew

The TMD group showed greater difficulty in chewing than Control group (mean ± SD = 47.78 ± 17.58 vs. 17.0 ± 10.34, $P < 0.001$). The differences between groups were greater for foods considered to be harder (Fig. 1).

### 3.2. Orofacial myofunctional evaluation

Patients with TMD showed impairment of appearance/posture, mobility, mastication and swallowing functions, with a significant difference when compared to the Control group, except for breathing (Table 2). TMD patients showed higher frequency of unilateral mastication (TMD group 54%; Control group = 26%, $P = 0.017$, Chi-square test, see distribution in Fig. 3) and spent more time to eat the food than the Control subjects (mean ± SD: TMD group = 51.13 ± 11.15 s; Control group 42.38 ± 10.8 s, $P < 0.001$, Mann–Withney test).

### 3.3. Electromyographic analysis

During the EMG test, chewing frequencies were similar in patients and control subjects. An altered co-ordination was found between the masseter and temporal muscles of the TMD group during gum chewing: the center of the ellipse of the Lissajous Plot describing their unilateral chewing was located out of the expected Cartesian quadrant more frequently than in the Control group. The mean phase differed significantly between groups. More standardized (as a percentage of MVC on cotton rolls) muscular activity was expended by the TMD group for gum chewing (IC) compared to the Control group, with increased standardized activity per cycle (IC/cycle). SMI was lower in the TMD group ($P < 0.05$) (Table 3).

During chewing, no significant differences were found between groups for area of the confidence ellipse. Even though this area computed for the TMD group was, on average, approximately three times larger than that obtained for control, wide intragroup variability was observed (Table 3).

The coordination between the muscles on the working and balancing sides also showed greater variability in the TMD group, with amplitude values (distance of the center of the ellipse from the origin of the axes) ranging of 37% to 3384% (right side), and 34% to 6731% (left side). The values for the control group ranged from 87% to 506% and from 110% to 587%, respectively. While 13% of the Control subjects showed a SMI value of less than 55%, this was observed for 56% of patients. A higher activity on the balancing side compared to the working side was observed in 41% of TMD subjects and in 10% of the controls.

### 3.4. Correlation analysis

SMI (EMG), orofacial myofunctional score and ProTMDmulti score were significantly correlated ($P < 0.01$). Overall, the larger the SMI, the larger the orofacial myofunctional score ($r = 0.31$), and the smaller that of the ProTMDmulti ($r = -0.33$). The smaller the orofacial myofunctional score, the larger the scores of the ProTMDmulti ($r = -0.59$).

## 4. Discussion

In the current study, we examined the orofacial myofunctional status and the EMG characteristics of mastication of subjects with chronic TMD. The main finding was that TMD patients showed impairment of orofacial motor functions, with changes in the recruitment of the masseter and temporal muscles during mastication.

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**Table 1**
Characteristics and comparisons of the Control and TMD groups.

| | | Control ($n$ = 30) Mean (SD) | TMD ($n$ = 46) Mean (SD) | $P$ |
|---|---|---|---|---|
| Age (years) | | 29.20 (8.87) | 33.72 (11.04) | 0.06[a] |
| TMD severity – ProTMDmulti | | 2.90 (4.8) | 147.59 (76.48) | <0.001[b] |
| *Range of jaw movements (mm)* | | | | |
| Active mouth-opening | | 52.56 (4.77) | 47.17 (7.35) | 0.015[a] |
| Lateral excursion right | | 8.49 (1.60) | 7.55 (2.80) | 0.002[a] |
| Lateral excursion left | | 8.85 (1.58) | 7.77 (2.63) | 0.005[a] |
| Protrusion | | 7.61 (1.75) | 7.09 (2.66) | 0.29[a] |
| *Tenderness to palpation (0–10 scale)* | | | | |
| Temporal right | Anterior | 0.23 (0.97) | 3.85 (3.27) | <0.001[c] |
| | Middle | 0.30 (0.70) | 2.76 (3.14) | <0.001[c] |
| | Posterior | 0.07 (0.25) | 2.41 (2.92) | <0.001[c] |
| Temporal left | Anterior | 0.07 (0.25) | 4.22 (3.09) | <0.001[c] |
| | Middle | 0.10 (0.40) | 2.70 (3.10) | <0.001[c] |
| | Posterior | 0.07 (0.25) | 2.24 (2.81) | <0.001[c] |
| Masseter right | Origin | 0.37 (0.85) | 4.72 (3.15) | <0.001[c] |
| | Body | 0.97(1.03) | 5.50 (3.15) | <0.001[c] |
| | Insertion | 0.40 (0.97) | 4.83 (3.10) | <0.001[c] |
| Masseter left | Origin | 0.27 (0.64) | 5.20 (3.14) | <0.001[c] |
| | Body | 0.70 (1.06) | 5.93 (3.15) | <0.001[c] |
| | Insertion | 0.43 (0.77) | 5.72 (3.39) | <0.001[c] |
| Posterior mandibular region | Right | 0.87 (1.89) | 6.63 (3.05) | <0.001[c] |
| | Left | 0.53 (1.28) | 6.65 (3.22) | <0.001[c] |
| Submandibular region | Right | 0.13 (0.43) | 3.04 (3.28) | <0.001[c] |
| | Left | 0.17 (0.46) | 3.13 (3.23) | <0.001[c] |
| Lateral pterygoid | Right | 2.07 (2.46) | 7.78 (2.29) | <0.001[c] |
| | Left | 1.93 (1.89) | 8.17 (1.98) | <0.001[c] |
| Tendon of the temporal | Right | 1.73 (2.12) | 8.02 (2.40) | <0.001[c] |
| | Left | 1.53 (1.98) | 8.24 (2.19) | <0.001[c] |
| TMJ/Lateral pole | Right | 0.77 (1.19) | 6.89 (2.95) | <0.001[c] |
| TMJ/Posterior attachement | Left | 0.23 (0.68) | 3.48 (3.74) | <0.001[c] |
| TMJ/Lateral pole | Right | 0.37 (0.76) | 7.15 (2.65) | <0.001[c] |
| TMJ/Posterior attachement | Left | 0.27 (0.87) | 3.87 (3.87) | <0.001[c] |

0–10 VAS scale (endpoints: 0 no pain and 10 extreme pain) TMJ: Temporomandibular Joint; $P$: probability in the statistical test. All $P < 0.05$ are significant.
[a] Student $t$-test.
[b] Mann–Withney test.
[c] Significant group difference in the two-way ANOVA (group × side). Neither differences between sides nor group × side interactions were observed.

**Table 2**
Orofacial myofunctional evaluation of the Control and TMD groups.

| Conditions | Maximum scores | Control ($n$ = 30) | | TMD ($n$ = 46) | | $P$ |
|---|---|---|---|---|---|---|
| Appearance/posture | | Mean | SD | Mean | SD | |
| Lips | 3 | 2.70 | 0.47 | 2.26 | 0.44 | 0.001 |
| Jaw | 3 | 2.80 | 0.41 | 2.20 | 0.40 | <0.001 |
| Checks | 3 | 2.80 | 0.41 | 2.41 | 0.65 | 0.020 |
| Facial symmetry | 3 | 2.30 | 0.47 | 1.93 | 0.49 | 0.019 |
| Tongue | 3 | 2.77 | 0.43 | 2.30 | 0.47 | 0.001 |
| Hard palate | 3 | 2.80 | 0.41 | 2.43 | 0.62 | 0.022 |
| *Mobility* | | | | | | |
| Lips | 12 | 11.70 | 0.70 | 10.74 | 1.53 | 0.011 |
| Tongue | 18 | 14.87 | 2.47 | 13.70 | 1.75 | 0.050 |
| Jaw | 15 | 13.83 | 1.02 | 12.43 | 1.44 | <0.001 |
| Checks | 12 | 11.83 | 0.38 | 11.07 | 1.22 | 0.01 |
| *Functions* | | | | | | |
| Breathing | 3 | 2.93 | 0.25 | 2.87 | 0.34 | NS |
| Deglutition | 15 | 14.30 | 0.99 | 13.39 | 1.27 | 0.001 |
| Mastication | 10 | 14.30 | 2.31 | 11.72 | 3.02 | <0.001 |
| SUM | 103 | 99.93 | 4.68 | 89.46 | 6.96 | <0.001 |

$P$: probability of Mann–Whitney test. NS. not significant. $P > 0.05$; Maximum scores (normal value) of the OMES protocol.

The TMD group had significantly lower OMES scores (De Felício et al., 2012a,b) and masticatory function clinically characterized by the perception of greater difficulty to chew, i.e., less ability, prevalence of the unilateral chewing type (Ratnasari et al., 2011) and more time spent during free mastication compared to the Control group.

During the EMG chewing test, the TMD group showed a less accurate combination of the four analyzed muscles (masseter and temporal muscles) on the working side (phase) and in the differential activations compared to the balancing side (location of the ellipses on the Cartesian coordinate system), with a reduced SMI and an increased standardized muscle activity employed to perform the function (IC and IC/cycle) compared to the Control group. These results differed from those found in subjects with short lasting and mild-moderate severity TMD (De Felício et al., 2013).

Patients with TMD more frequently showed variations (even not significant) in muscle recruitment at each chewing stroke (wider confidence ellipses) (Tartaglia et al., 2008), and larger mean amplitude values and variability (standard deviation) than healthy subjects (Sforza et al., 2010). The increased co-activation of the muscles on the balancing side might have contributed to a higher mean of IC, in contrast to the equilibrated and differential capacity of healthy subjects, who had a lower activity of balancing side (BS) than of working side (WS) masticatory muscles during unilateral chewing. The increase of the masseter WS/BS ratio due to decrease of BS activity represents a motor control feature to prevent BS dental contact and to limit loads acting on them in case they occur. A possible role for TMJ protection was suggested (Schubert et al., 2012; Morneburg et al., 2013).

Based on results, symmetry in the muscular coordination between right and left side mastication (SMI) matches with the condition of components and functions of the stomatognathic system and that established by TMD severity test. These confirm the relationship among indices of orofacial myofunction, ProDTMmulti

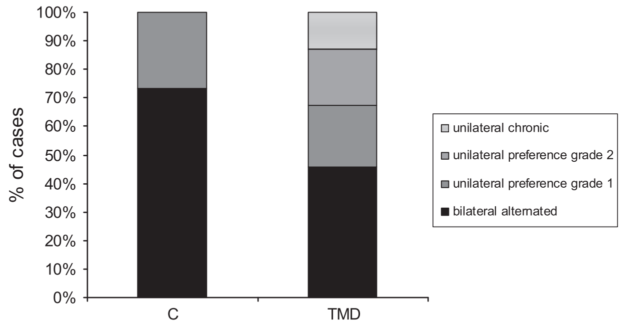


**Fig. 3.** Distribution of groups regarding the masticatory type in percentage (%).

**Table 3**
Electromyographic parameters of unilateral gum chewing.

| | Unit | Control | | TMD | | *P* |
|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | |
| Frequency | Hz | 1.22 | 0.26 | 1.27 | 0.24 | NS |
| Amplitude | % | 227.86 | 109.92 | 419.18 | 824.12 | NS |
| Phase | deg | 44.83 | 58.46 | 67.89 | 75.23 | 0.046 |
| Confidence ellipse | $\%^2$ | 3125.16 | 3061.34 | 11142.34 | 38301.08 | NS |
| Global activity | $\%^* s$ | 1212.31 | 598.24 | 1905.04 | 2091.39 | 0.014 |
| Activity/cycle | $\%^* s$ | 66.16 | 28.88 | 95.47 | 96.46 | 0.024 |
| SMI | % | 66.50 | 18.33 | 44.76 | 29.20 | <0.001 |

SMI: symmetric mastication index; *P*: probability of Student's *t*-tests. NS: not significant, $P > 0.05$.

scores and EMG symmetry, previously observed in static activity (De Felício et al., 2012a).

The present findings indicated poorly developed or poorly adapted orofacial motor control, that include but are not limited to the mastication, thus supporting our hypotheses: patients with moderate-severe chronic TMD have an altered orofacial motor control. This disability is correlated with TMD severity. A better understanding of these behaviors is important for the development of new therapeutic strategies.

Orofacial behaviors are determined by use and sensory experience, and pain is a potential factor for the adaptation of these behaviors, aiming at the maintenance of function and the protection of the system. However, orofacial functions may be maladapted, negative over time, and irreversible; even when their cause is eliminated (Avivi-Arber et al., 2011; Hellmann et al., 2011; Trulsson et al., 2012; van der Bilt, 2011). Additionally, there is growing evidence that primary somatosensory reorganization may occur in chronic pain conditions (Avivi-Arber et al., 2011), suggesting the need to incorporate other strategies for rehabilitation in addition to those traditionally employed.

Because exercise therapy is relevant for the rehabilitation of patients with musculoskeletal pain (Fuentes et al., 2011; Michelotti et al., 2012), TMJ with disc displacement (Haketa et al., 2010), and an oral-motor program optimizes the rehabilitation of swallowing and oral movements (Mangilli et al., 2012), these options should be better explored to potentiate the success of the treatment of patients with TMD.

A promising direction for new investigations about rehabilitation of TMD patients may be the translation of recent findings about the potential of orofacial motor training, skilled or precision tasks, in order to promote changes in muscle recruitment (Hellmann et al., 2011) and to facilitate the cortical neuroplastic changes (Avivi-Arber et al., 2011; Boudreau et al., 2013).

The present findings refer to a group of patients with chronic TMD, and moderate-severe signs and symptoms, diagnosed on the basis of physical examination and questionaries. However, the use of TMJ imaging to supplement clinical examination is recommended (Al-Saleh et al., 2012). Therefore, the current results should be interpreted with caution. Moreover, as previously explained, orofacial functions may be modified by several factors; therefore dental occlusion may be an adjunctive factor causing the differences found between TMD and Control groups, beside TMD and pain. Further studies are necessary to compare the orofacial motor control of subjects with and without TMD with similar occlusal characteristics, determined by specific examination.

Because in the current study examined men showed mild signs and symptoms of TMD, only women were selected. In fact, greater pain and muscle tenderness on palpation has been found in female than in male TMD patients (Schmid-Schwap et al., 2013).

## 5. Conclusion

Patients with chronic TMD, and moderate-severe signs and symptoms, showed impairment of the clinical and EMG parameters of masticatory function, with a less accurate recruitment of the temporal and masseter muscles on the working and balancing sides.

Impairment of swallowing and of other orofacial motor actions was also observed and should be considered in the elaboration of programs for TMD rehabilitation in order to relieve pain and to provide a lasting functional recovery.

## 6. Conflict of interest

The authors declare that they have no conflict of interest.

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