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Research Submission

Music Modulates Awake Bruxism in Chronic Painful Temporomandibular Disorders

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Objective.—In this experimental study, we aimed to determine whether guided music listening (GML) – a music intervention based on models of mood mediation and attention modulation – modulates masticatory muscle activity and awake bruxism in subjects with chronic painful muscular temporomandibular disorders (TMD myalgia, mTMD), a condition causing a significant burden to patients, their families, and healthcare systems.

Background.—Awake bruxism – a stress behavior characterized by clenching of the teeth – is a strong contributor to chronic mTMD. GML modulates psychological stress and motor responses and could thus reduce muscle activity in chronic musculoskeletal conditions, including mTMD.

Methods.—We recorded the electromyographic (EMG) activity in the right masseter of 14 women with chronic (>6 months) mTMD (median [IQR] = 39.5.3 [24.3] years) and 15 pain-free women (median [IQR] = 30.0 [3.5] years) during a GML session, including 3 music (stressful, relaxing, and participants' favorite music) and a no-music (pink noise) control blocks, each lasting 15 minutes. We measured the motor effort of the right masseter relative to the participants' maximum voluntary contraction (MVC), the muscular effort to maintain mandibular posture ($EMG_{posture}$), and to produce spontaneous awake bruxism episodes ($EMG_{bruxism}$), and the duration and frequency of spontaneous awake bruxism episodes. We tested between-group and within-group (between blocks) differences, as well as the effect of the interaction group by experimental block on these outcome measures.

Results.—In both groups, $EMG_{posture}$ was significantly affected by the interaction group by experimental block (P < .001). Compared to pink noise [mean (95% CI); *mTMD*: 2.2 (1.6-2.8) %MVC; *Controls*: 1.1 (0.5-1.7) %MVC], $EMG_{posture}$ increased during the stressful music block [contrast estimate (95% CI); *mTMD*: +0.8 (0.7-0.8) %MVC; *Controls*: +0.3 (0.3-0.4) %MVC; both P < .001], and decreased during the relaxing [*mTMD*: −0.4 (−0.5 to −0.4) %MVC; *Controls*: −0.3 (−0.4 to −0.3) %MVC; both P < .001] and favorite [*mTMD*: −0.5 (−0.6 to −0.5) %MVC; *Controls*: −0.5 (−0.5 to −0.4) %MVC; both P < .001] music blocks. $EMG_{posture}$ was greater in mTMD individuals than controls during the favorite music [contrast estimate (95% CI): +1.1 (0.2-1.9) %MVC; P = .019] and the pink noise [+1.1 (0.2-2.0) %MVC; P = .014] blocks. $EMG_{bruxism}$ was significantly affected by the interaction group by experimental block (P < .001). In mTMD participants, compared to the pink noise block [mean (95% CI); 23.8 (16.0-31.6) %MVC], $EMG_{bruxism}$ increased during the stressful music block [contrast estimate (95% CI); +10.2 (8.6-11.8) %MVC], and decreased during the relaxing [−6.2 (−8.1 to −4.3) %MVC; P < .001] and favorite [−10.2 (−12.2 to −9.1) %MVC; P < .001] music blocks. These effects were not observed in the control group [mean (95% CI); pink noise: 19.3 (10.9-27.6); stressful: 21.2 (12.9-29.4) %MVC; relaxing: 21.6 (13.3-29.9) %MVC; favorite: 24.2 (15.8-32.7) %MVC; all P > .05]. $EMG_{bruxism}$ was significantly greater in mTMD participants than controls during the stressful music block [contrast estimate (95% CI): +12.9 (1.6-24.2) %MVC; P = .026). GML did not affect the duration or the frequency of awake bruxism

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in either group (median [IQR], *mTMD*: 23.5 [96.7] s, range 1-1300 seconds; *Controls*: 5.5 [22.5], range 0-246 seconds; *P* = .108). The frequency of awake bruxism episodes was greater in the mTMD group compared to controls only during the pink noise block (median [IQR], *mTMD*: 5 [15.3] episodes, range 0-62 episodes; *Controls*: 1 [3] episode, range 0-27 episodes; *P* = .046). No significant between-group differences were found in either the overall time spent engaging in awake bruxism (median [IQR], *mTMD*: 23.5 [96.7] s, range 1-1300 seconds; *Controls*: 5.5 [22.5], range 0-246 seconds; *P* = .108), or during each block (all *P* > .05).

Conclusions.—In subjects with chronic mTMD, relaxing music and the individual's favorite music decreased the muscular effort during spontaneous awake bruxism episodes by 26% and 44% (relative changes), respectively. In contrast, stressful music increases it by about 43%. Because of its positive effects on awake bruxism, GML with selected music could be a promising and non-invasive component of a multimodal approach for the management of chronic mTMD.

Key words: facial pain, temporomandibular joint disorders, bruxism, masseter muscle, electromyography, music therapy

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INTRODUCTION

Temporomandibular disorders (TMD) comprise a set of pathological conditions affecting the temporomandibular joint and/or the muscles of mastication. Besides orofacial pain, headache is one of the primary features of TMD. TMD affects 5-12% of the general population, 15% of which develop chronic orofacial pain,[1] which has deleterious effects on quality of life.[2-4] The etiology of TMD is multifactorial.[5] Both laboratory and epidemiological studies have indicated that oral behaviors – for example, awake bruxism, gum chewing, and nail/lip/cheek biting – might harm the muscles of mastication and the temporomandibular joints by way of producing excessive forces to which these structures are exposed, potentially leading to or exacerbating symptoms of TMD.[6-10]

Awake bruxism, defined as masticatory muscle activity characterized by repetitive or sustained tooth clenching,[10] is highly prevalent in individuals with chronic TMD myalgia (mTMD).[9] Tooth clenching causes mTMD-like symptoms in healthy individuals,[11-14] and exacerbates pain in individuals with mTMD.[15-17] Therefore, reducing the force exerted during clenching and/or the frequency of awake bruxism has proven to be an effective approach towards mTMD management.[18-21]

There is a positive association between awake bruxism, psychological stress, and impaired mood.[16,22-26] For example, awake bruxism is highly prevalent in anxious individuals,[9,24] and experimental tooth clenching has been shown to reduce concentrations of cortisol in saliva.[23] Therefore, awake bruxism may represent a maladaptive coping mechanism developed for stress management.[22,27]

Guided music listening (GML) – a music intervention based on models of mood mediation and attention modulation – is used widely to reduce pain, stress, and to improve mood[28] in individuals with chronic pain conditions, including musculoskeletal disorders (eg, fibromyalgia).[29-32] Music promotes relaxation by increasing the activity of the parasympathetic nervous system.[33] It also modulates the contraction pattern of skeletal muscles by affecting cortical motor regions[34-36] and corticobulbar excitability.[37] These effects may be either inhibitory or excitatory depending on the music valence and rhythm.[29] In a related way, this underscores why music has been used effectively for motor rehabilitation.[38,39]

Although a first-line treatment approach for mTMD should orient patients toward avoidance of any potentially harmful oral behaviors,[18] awake bruxism is often difficult for patients to identify. Indeed, many individuals clench their teeth without realizing they are doing so.[16,40,41] Therefore, given the relationship between stress and awake bruxism, it is plausible that strategies that reduce an individual's stress might also reduce awake bruxism.

Here, we aim to determine whether GML modulates masticatory muscle activity in individuals with

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chronic mTMD. Specifically, we sought to determine the effects of GML on (1) postural masticatory muscle activity, that is, the muscular activity that maintains lower jaw posture at rest, and (2) the intensity, frequency, and the duration of spontaneous awake bruxism episodes. We hypothesized that music which is perceived as relaxing could reduce masseter muscle postural activity, and the intensity, frequency, and duration of awake bruxism episodes in subjects with chronic mTMD.

MATERIALS AND METHODS

All procedures were reviewed and approved by the Research Ethics Boards at the University of Toronto (#34188), and Mount Sinai Hospital (17-0081-E), Toronto, ON, Canada. Written informed consent was provided by all research participants.

Recruitment of Participants.—Using the *TMD Pain Screener*,[42] we screened females 18-65 years of age with a complaint of facial pain who were seeking consultation at the Faculty of Dentistry, University of Toronto, the Mount Sinai Hospital Department of Dentistry Craniofacial Pain Unit, as well as at a private orofacial pain clinic. The *TMD Pain Screener* is a 6-item questionnaire has a sensitivity of 0.99 and a specificity of 0.97 for correct classification of the presence or absence of TMD for scores ≥ 3.[42] Respondents with a score ≥ 3 were invited to the Centre for Multimodal and Sensorimotor Pain Research at the Faculty of Dentistry, University of Toronto, for a full clinical examination focused on identification and diagnosis of TMD by a trained examiner (TVI).[43] The TMD diagnosis was confirmed by a second examiner with expertise in TMD (IC). Subjects with a diagnosis of chronic (>6 months) mTMD according to the Diagnostic Criteria (DC) for TMD[43] were recruited for the study (mTMD group). Exclusion criteria included wearing extended dental fixed prostheses (3 teeth or more), ongoing orthodontic and/or dental treatment, neurological disorders, intake of drugs affecting the central nervous system, and muscle relaxants. Healthy women without facial pain serving as controls were recruited from the local community and through friend matching (ie, those with mTMD were asked to invite a friend to participate in the study). Participants comprising the control group were examined to exclude the presence of TMD. Other exclusion criteria were the same as those used for the mTMD group. Participants were asked to refrain from using analgesics for at least 24 hours before the experiment.

Pain Characteristics.—In the mTMD group, we computed the characteristic pain intensity (CPI score related to patients' pain characteristics) included in Graded Chronic Pain Scale (GCPS) v 2.0.[43] Briefly, the CPI ranges between 0 and 100, and is the average of the current facial pain, the worst pain intensity in the last 30 days, and the average pain in the last 30 days, multiplied by 100. Each of the measures is reported on 11-point numeric rating scales (0-10, anchors: "no pain" and "pain as bad as could be"). The GCPS grade is a categorical measure with 4 levels. It is computed using the CPI, and the impact of pain on daily, social and recreational, and family activities, and work.[43] The latter measures are each rated on 11-point numeric rating scales (0-10, anchors: "no interference" and "unable to carry on any activities"). GCPS categories are *Grade 0*: none; *Grade I*: low intensity pain without disability; *Grade II*: high intensity pain without disability; *Grade III*: moderately limiting; and *Grade IV*: severely limiting.

Baseline Psychophysical Measurements.— *Questionnaires*.—All participants completed questionnaires related to psychosocial domains and oral behaviors, including the Somatosensory Amplification Scale (SSAS),[44] the Oral Behavior Checklist (OBC),[40] the State-Trait Anxiety Inventory (STAI),[45] Beck's Depression Inventory (BDI),[46] and the Pain Catastrophizing Scale (PCS).[47]

The SSAS includes 10 statements investigating participants' sensitivity to bodily sensations on a 5-point scale (score range: 10-50). The OBC includes 21 items assessing awareness and the self-reported frequency of oral behaviors on a 5-point scale (range of scores: 0-84). The STAI includes 20 items to assess state anxiety (Y1) and 20 statements to assess trait anxiety (Y2) on a 4-point scale (range of scores for each subscale: 20-80). The BDI investigates 21 depressive symptoms, scored between 0 and 3 (range of scores: 0-63). Finally, the PCS provides a self-report measure of an individual's tendency to catastrophize about pain, and has 3 validated subscales:

rumination, magnification, and helplessness. The PCS uses a 5-point scale (range of scores: 0-52). Participants in the mTMD group were also asked to complete the DC/TMD symptom questionnaire,[43] which provides information about pain intensity, pain duration, presence of temporomandibular joint noises, and jaw locking.

Pressure Pain Thresholds.—Pressure pain thresholds (PPTs)[48] were measured with a real-time feedback electronic pressure algometer (Algomed, Medoc, Israel), with a rubber tip measuring 1 cm^2, at both trigeminal (bilateral superficial masseter muscles and bilateral anterior temporalis muscles) and extratrigeminal regions (bilateral thenar muscles in the palmar side of the hands).[9,49] PPTs were measured to determine whether participants with chronic mTMD had abnormal thresholds, which could indicate the presence of hyperalgesia and/or allodynia.

For the masseter muscle, PPTs were measured halfway between the origin and the insertion of the muscle and 1 cm posterior to its anterior boundary. For the temporalis muscle, PPTs were measured on the line from the top edge of the eyebrow to the highest point of the pinna of the ear and 2 cm behind the anterior margin of the muscle. For the thenar muscle, PPTs were measured on the thenar eminence located on the palmar side of the hand, as previously done.[9,49] For all measurements, the algometer was positioned perpendicular to the skin. A single trained operator (TVI) placed the algometer tip on the respective site and applied pressure at a constant rate of 20 kPa/seconds using visual feedback provided by software (Medoc Main Station, ver. 6.4, Medoc, Israel). Participants were asked to press a button the moment the pressure stimulus applied to their muscles changed from a pressure sensation to a painful sensation.[48] Each measurement was repeated serially at each muscle site 4 times, with a 1-minute interval between each measurement.

Study Design.—The overall design of this controlled experiment is shown in Figure 1. All procedures were performed in a single session. After the baseline psychophysical measurements, participants in both the mTMD and control groups underwent a music pretest, which served to select music pieces for the GML experiment, as done previously.[49] During the 60-minute GML experiment, participants were submitted to four 15-minute auditory blocks including pink noise (an auditory signal with a constant power spectral density), and 3 different music playlists including stressful, relaxing, and favorite music pieces, respectively. All auditory blocks were administered in random order. During the GML experiment, the electromyographic (EMG) activity of the right masseter was recorded.

Participants were asked to bring their own earphones to ensure a comfortable music experience. During the music pretest and the actual GML experiment, participants could adjust the audio volume to their desired comfort level (range of 40-60 dB) using a remote control connected to an open source multimedia player (VLC media player, VideoLAN, Paris, France) installed on a laptop computer (Acer Aspire V 15 V3-575T-57R3, Xizhi, New Taipei City, Taiwan).

The recruitment of participants and the experimental procedures were conducted between March 2017 and December 2018.

Music Pretest.—Participants were asked to bring their favorite music playlist to the study visit. First, they were asked to listen to 5 minutes of their favorite music playlist (shuffle mode), after which they rated their physical activation, pleasure intensity and

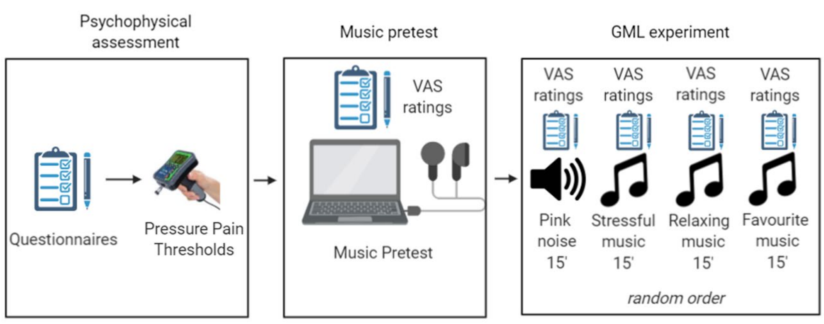


Fig. 1.—Experimental design. [Color figure can be viewed at wileyonlinelibrary.com]

associations triggered by the music using 3 separate 100-mm visual analog scales (VAS) on a paper form (*Physical Activation* – anchors: not activating at all/highly physically activating; *Pleasure* – not pleasurable at all/very pleasurable; *Associations and memories* – no memories at all/many memories are triggered). All participants received instructions on how to use the VAS prior to start the music pretest.

Next, participants listened to 2 preselected lists of 12 one-minute musical excerpts to select the musical pieces to be played during the relaxing and stressful experimental blocks of the GML experiment. An operator (TVI) preselected the playlists from a database developed by a musicologist (MT), which was stored on a computer in the research laboratory. The excerpts were separated by 30-second silent breaks, during which participants rated the excerpts on a 0-100 mm VAS with the anchors "*no relaxation*" and "*maximum relaxation*" for the relaxing excerpts and "*no stress*" and "*maximum stress*" for the stressful excerpts. The 12 relaxing preselected excerpts comprised music from 4 different genres (classic, new age, pop, and rock – 3 excerpts of each genre) with slow tempo ranges and harmonic tonality bases. The 12 stressful preselected excerpts comprised highly dissonant, atonal, and rhythmically unstable music from the same 4 genres (3 excerpts of each genre).

For each genre, a total score was computed by summing the score of each VAS for each excerpt. The genres with the highest scores were selected to compose the relaxing and stressful music playlists for the GML experiment. The style (tempo and tonality) of the relaxing or the stressful playlist was selected based on the characteristics of the music excerpt that had the highest score within the top-scored genre during the pretest.

The music selection for the actual experiment consisted of playlists of music pieces new to the participant, different from those played during the pretest, but with the same tempo range and tonality base, as determined during the pretest. Intensity (volume) levels for music were set within range of 40-60 dB. Preferred and relaxing music were highly tonal with conventional emphasis on tonic, subdominant, and dominant harmony progression. All music was played at a slow tempo range of 60-90 beats/minute in conventional 2/4, 3/4, or 4/4 meters. Instrumentation varied across pieces, but all consisted of strings, wind, brass, keyboard, percussion, and guitar orchestration. Once set, musical parameters did not change during the pieces in regard to tempo, loudness, tonality, and orchestration to avoid orienting responses to sudden changes musical structure.

GML Experiment.—All recordings were performed at the Centre for Multimodal Sensorimotor and Pain Research, Faculty of Dentistry, University of Toronto. Participants sat upright with their head unsupported in a temperature-controlled, silent room.

Participants went through 4 different auditory blocks including a pink noise block, serving as a non-music control block, and 3 different music blocks (including stressful, relaxing, and favorite music) in a randomized order, counterbalanced across participants. Each block lasted 15 minutes each for a total of 60 minutes. EMG activity of the right masseter was recorded throughout the entire GML experiment.

After each block, participants reported their perceived stress and relaxation levels using two 100 mm VAS, with the anchors "*no relaxation*" and "*maximum relaxation*" and "*no stress*" and "*maximum stress*." Participants also scored their music experience on 3 additional 100 mm VAS scales developed by a musicologist (MT),[49] to measure different dimensions of the perceptual music experience: (1) intensity of *physical activation* ("*Rate the intensity of your physical activation during the music task*"; left anchor: "*no physical activation*"; anchor: "*maximum physical activation*"); (2) *pleasure intensity* ("*Rate the pleasure intensity of this music task*"; left anchor: "*no pleasure at all*"; right anchor: "*maximum pleasure*"), and (3) whether *associations and memories* were triggered by the music task ("*Were associations, memories, pictures etc. triggered by this music task?*"; left anchor: "*no associations at all*"; right anchor: "*maximum amount of associations and memories*"). Participants were blinded to the relaxing and stressful music blocks, that is, they were not informed whether the music playlist they were listening to included stressful or relaxing music pieces.

To ensure consistency across participant, we recorded the EMG signal of the right masseter muscle using a wireless EMG device (BTS TMJoint, Milan, Italy) with disposable 24-mm bipolar self-adhesive electrodes (Covidien Kendall, Medtronic). Prior to start the recordings, the skin was cleaned with abrasive gel (Everi-Spes Medica, Genova, Italy) to allow for the conductive paste to adequately moisten the skin and decrease impedance. The signal was sampled at 1024 Hz and bandpass filtered between 10 and 500 Hz. The EMG electrodes were placed approximately 20 mm above the angle of the mandible along the line extending from the mandibular angle to the right outer canthus.[50] An operator (TVI) monitored the participants during the GML experiment and noted all possible head movements, which could have been source of EMG artifacts.

All participants received standardized information about the procedures and were informed that the study aimed to determine the effect of music listening on masticatory muscle activity. However, participants were not informed about the direction of the study hypothesis. Participants received financial compensation at the end of the experiment.

EMG Signal Preprocessing.—Before the GML experiment, the EMG activity of the right masseter was recorded during 3 maximum voluntary contractions (MVC) at maximum intercuspal position for 3 seconds each, separated by 5-second rests. Root mean square (RMS) measurements of EMG signals were computed. The average peak EMG activity produced during the 3 MVC tests was used to calculate relative EMG activity expressed as a percentage of MVC (%MVC), as done previously,[9,49,51] where MVC corresponded to 100%. Therefore, each transformed EMG signal expressed the level of motor effort of the right masseter relative to each participant's MVC during the 4 auditory blocks. Using the OTBiolab software (OT Bioelettronica, Torino, Italy), 2 operators (TVI and IC) visualized and processed all the EMG signals recorded during the GML experiment and removed EMG artifacts. During this procedure, the operators were blinded to group assignment of participants (data set masking).

Statistical Analysis.—The primary outcome measures of this study were:

1. EMG_{total} (%MVC): the motor effort of the right masseter during the experiment relative to each participant's MVC;
2. $EMG_{posture}$ (%MVC): the motor effort of the right masseter to maintain mandibular posture relative to each participant's MVC;
3. $EMG_{bruxism}$ (%MVC): the motor effort of the right masseter during awake bruxism episodes relative to each participant's MVC, and
4. Frequency and duration of awake bruxism episodes.

EMG_{total} was measured by including the entire transformed EMG signal (%MVC) of the right masseter recorded during the 4 blocks in the statistical model. $EMG_{posture}$ was determined posteriori, during signal post-processing, and included the transformed EMG signals with amplitude < 10% MVC, which were not identified as bruxism episodes.[9,49] $EMG_{bruxism}$ was also determined during post-processing, and included the transformed EMG signals of those muscle contractions (ie, awake bruxism) episodes with amplitude ≥ 10% MVC lasting at least 0.5 seconds, as done previously.[9,52] Awake bruxism episodes were identified and counted in each block to measure their frequency and their duration (seconds) using software (OT Bioelettronica, Torino, Italy).

Secondary outcome measures were psychophysical measures (SSAS, OBC, STAI, BDI, PCS scores and PPTs).

The Kolmogorov-Smirnov test was used to test whether data were normally distributed. Normally distributed data are reported as means ± standard deviations while non-normally distributed data are reported as medians and interquartile ranges (IQR).

The Mann-Whitney *U*-test was used to test between-group differences in masseter EMG activity during the MVC test (2-tailed). Mixed effect models with autoregressive covariance structure including the study group (mTMD vs control), the experimental block (pink noise, stressful, relaxing, and favorite music), and the interaction group by block as independent variables, were used to test (2-tailed) between-group and within-group (between blocks) differences in EMG_{total}, $EMG_{posture}$, $EMG_{bruxism}$, and frequency and duration of awake bruxism episodes.

The first trial of each PPT measurement was discarded, and the mean of the following 3 trials for each location was calculated. A paired 2-tailed *t*-test indicated that there was no significant difference between right and left sides at each muscle location in either group (all $P > .05$), so data from both sides were pooled. Student independent 2-tailed *t*-tests with unequal variance were used to test between-group differences in PPTs at each location, and in questionnaire scores (SSAS, OBC, STAI, and PCS). The Mann-Whitney *U*-test 2-tailed was used to test between-group differences in participants' age and BDI scores (2-tailed), which were not normally distributed.

A multivariate analysis of variance (MANOVA) was used to detect between-group and within-group (between blocks) differences in music VAS ratings (transformed data) as dependent variables, and the group, block, and group-by-block interaction as independent variables.

A minimum sample size of 12 participants per group was required to obtain 80% power with a large effect size (d = 0.8, α = 0.05) considering 2 groups (mTMD vs controls) and 4 experimental blocks (pink noise, stressful, relaxing, and favorite music), the interaction group-by-block, and assuming a correlation between levels of 0.6.[49] To account for potential drop-outs, we planned to recruit at least 14 participants per group.

Post hoc comparisons were adjusted using the Bonferroni's method. The level of statistical significance was set at P < .05. The statistical analysis was conducted with the operator (IC) blinded to group assignment of participants (data set masking) using SPSS (IBM Corp. Released 2018. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.).

RESULTS

A flow diagram of enrollment of mTMD participants is depicted in Figure 2. Fourteen women (*mTMD group*; median [IQR] age = 39.5 [24.3] years) with a diagnosis of chronic mTMD (>6 months) according to the Diagnostic Criteria for TMD (DC/TMD)[43] were recruited in the study. Fifteen healthy women without facial pain were also recruited (*control group*; median [IQR] age = 30.0 [3.5] years). There was no statistically significant age difference between groups (P = .227).

Pain Characteristics of the mTMD Group.—All mTMD participants had chronic (>6 months) mTMD. Seven of them had also TMD arthralgia. The mean ± SD CPI was 52.7 ± 15.9. The mean ± SD pain intensity (on a 0-10 numeric rating scale) in the last 30 days was 4.8 ± 1.7. The current pain intensity (ie, the pain participated reported to have just before the experimental session) was 3.8 ± 2.7. The median [IQR] pain duration was 7.5 [15.5] years. Four mTMD participants had GCPS grade I, 5 GCPS grade II, and 5 GCPS grade III.

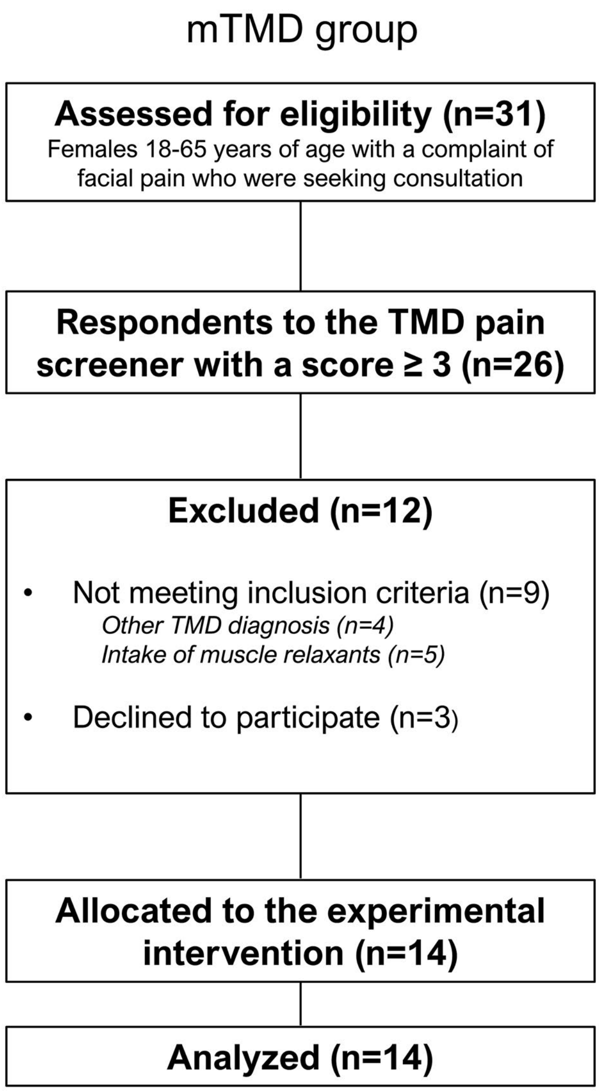


Fig. 2.—Flow diagram depicting the recruitment of participants with chronic temporomandibular disorders (TMD) myalgia (mTMD group).

Questionnaires and PPTs.—Two participants (1 in the mTMD group and 1 in the Control group) did not fill in the SSAS, STAI, BDI, and PCS. Results from the SSAS, OBC, STAI, BDI, and PCS questionnaires are reported in Table 1. Participants with mTMD scored higher on the OBC (P < .001), BDI (P = .008), and PCS (P = .041), compared to the

Table 1.—Descriptive Statistics of Self-Report Questionnaire Data

Questionnaire	Controls	mTMD	*P* Value
SSAS	24.3 ± 5.3	29.4 ± 7.3	.067
STAI-State	32.1 ± 10.3	36.8 ± 10.7	.268
STAI-Trait	38.6 ± 6.1	43.2 ± 15.6	.326
OBC	21 [6.5]	29 [12]	**<.001**
BDI	3 [5]	9 [11]	**.008**
PCS	10.6 ± 5.6	17.1 ± 9.6	**.041**

Normally distributed data are presented as mean ± SD, and non-normally distributed data are presented as median [interquartile range]. Bold type: statistically significant.
BDI = Beck's depression inventory; OBC = oral behavior checklist; PCS = pain catastrophizing scale; SSAS = somatosensory amplification scale; STAI = state-trait anxiety inventory.

Table 2.—Descriptive Statistics of Pressure Pain Thresholds (PPTs)

	Location	Controls (KPa)	mTMD (KPa)
Right side	Superficial masseter	121.1 ± 35.4	131.3 ± 61.9
	Anterior temporalis	138.3 ± 51.7	124.7 ± 49.5
	Thenar eminence	257.0 ± 96.1	263.8 ± 78.5
Left side	Superficial masseter	131.1 ± 53.3	139.4 ± 43.3
	Anterior temporalis	143.7 ± 54.3	133.6 ± 36.1
	Thenar eminence	266.6 ± 104.0	252.6 ± 77.4

Data are presented as mean ± SD.

control group. No differences were found between mTMD and control groups in SSAS (P = .050), state (Y1; P = .268) and trait anxiety (Y2; P = .326).

There were no statistically significant differences in PPT measures between groups at all sites (all P > .05). See Table 2 for specific muscle thresholds.

Music Selection.—Based on the music pretest, during the relaxing music block, 5 participants in the control group listened to classical music, 6 to new age music, 3 to pop and one to rock music. In the mTMD group, 4 participants listened to classical, 3 to new age, 3 to pop music and 4 to rock music. During the stressful music task, in the control group, 2 participants listened to classical music, one listened to new age, one to pop and 11 listened to rock. In the mTMD group, 3 listened to new age and 11 listened to rock music, and no participants selected classical or pop music.

VAS scores (relaxation, stress, physical activation, pleasure intensity, and associations and memories) and post hoc comparisons are reported in Figure 3. VAS ratings differed significantly across the experimental tasks ($F_{[15,279]}$ = 14.2, P < .001), but did not differ between groups ($F_{[5,101]}$ = 1.8, P = .120). There was no significant effect of the group-by-block interaction on VAS ratings ($F_{[15,279]}$ = 1.0, P = .421).

EMG Activity of the Right Masseter During the MVC Test.—The median and [IQR] EMG activity of the masseter during the MVC test in both the mTMD and control groups were 183 [191] µV and 223 [145] µV, respectively. There were no statistical differences between groups (P = .387).

Effect of GML on Masseter Activity.—*EMG_{total} is Modulated by GML.*—EMG_{total} was significantly affected by the interaction group by experimental block (P < .001, Fig. 4A). It was the highest during the stressful music block and the lowest during the favorite music block – in ascending order for the mTMD group [mean (95% CI) %MVC]: favorite [2.7 (0.8-4.5) %MVC], relaxing [3.5 (1.7-5.4) %MVC], pink noise [3.6 (1.8-5.5) %MVC], and stressful [5.2 (3.3-7.0) %MVC]; in ascending order for the control group: favorite [0.8 (0-2.6) %MVC], pink noise [1.2 (0-3.0) %MVC], relaxing [1.7 (0-3.5) %MVC], and stressful [2.0 (0.2-3.8) %MVC]. Contrast estimates and 95% CI for within-group pairwise comparisons are provided in Table S2.

EMG_{total} was greater in patients with mTMD than controls [contrast estimate (95% CI): +2.4 (0.6-5.7) %MVC; P = .016] during the stressful music block (Fig. 4A).

$EMG_{posture}$ is Modulated by GML.—$EMG_{posture}$ was significantly affected by the interaction group by experimental block (P < .001, Fig. 4B). It was the highest during the stressful music block and the lowest during the favorite music block – in ascending order for the mTMD group [mean (95% CI) %MVC]: favorite [1.7 (1.0-2.3) %MVC], relaxing [1.8(1.1-2.4) %MVC], pink noise [2.2 (1.6-2.8) %MVC], and stressful [2.5 (1.9-3.2) %MVC]; in ascending order for the control group: favorite [0.6 (0-1.2) %MVC], pink noise [1.1 (0.5-1.7) %MVC], relaxing [1.4 (0.8-2.0) %MVC], and stressful [1.9 (1.3-2.5) %MVC].

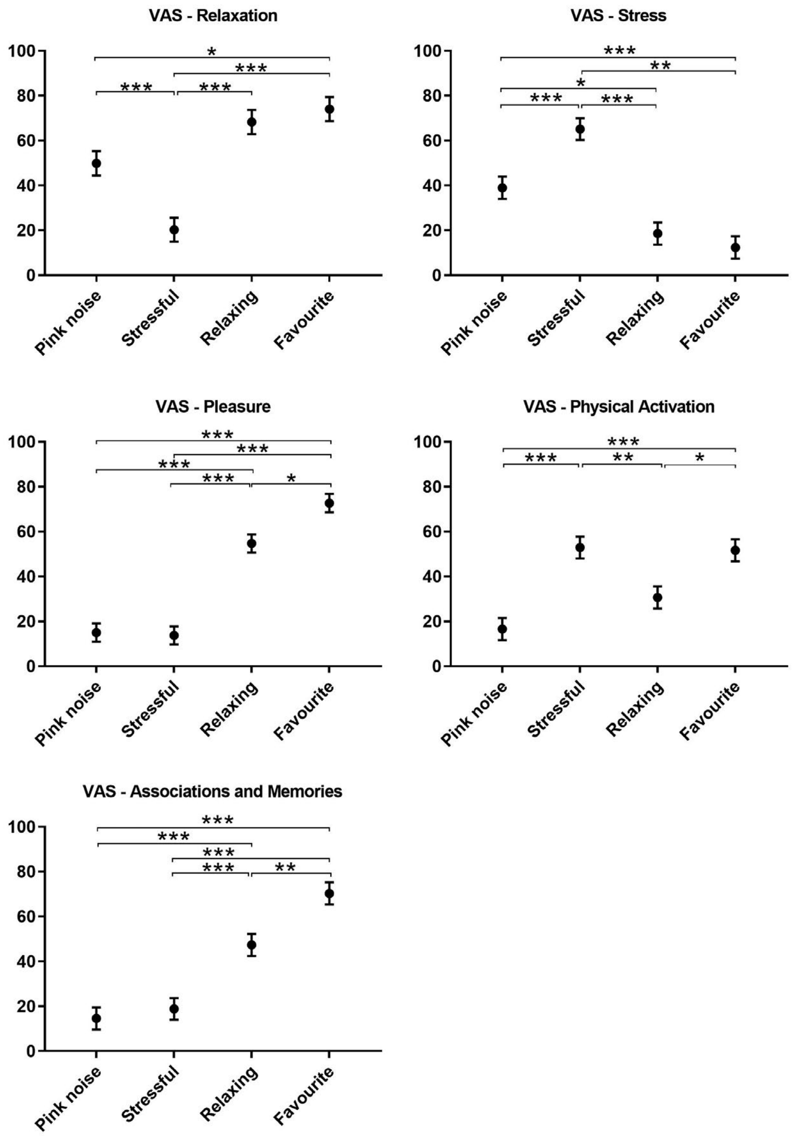


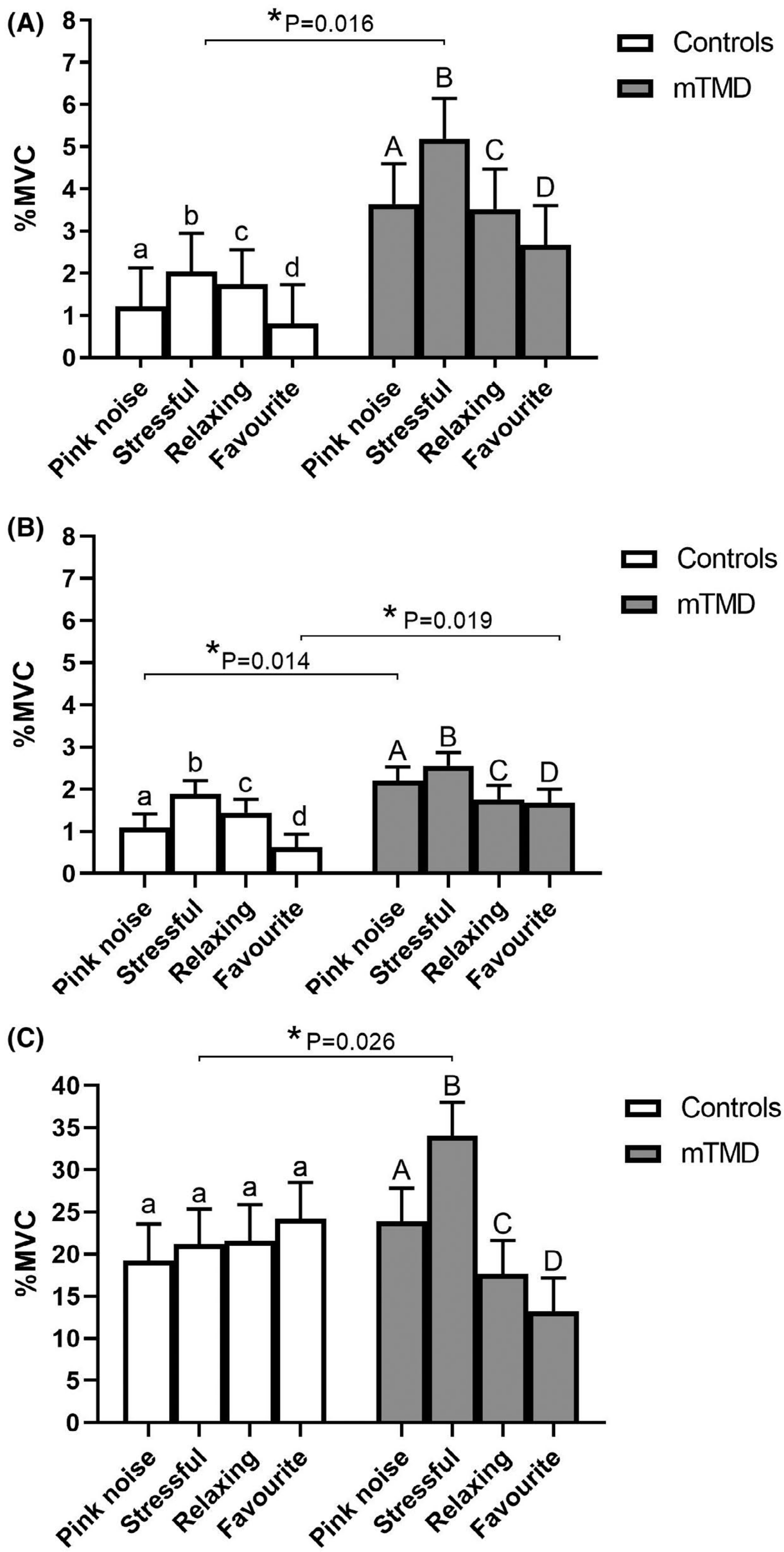
Fig. 3.—Mean visual analog scales (VAS; 0-100 mm) ratings during the 4 experimental blocks. Since no differences were found between the TMD myalgia (mTMD) and the control group, pooled data are reported. Significant pairwise comparisons are reported at *$P < .05$, **$P < .005$, and ***$P < .001$. Error bars indicate ± Standard errors of the mean.

Contrast estimates and 95% CI for within-group pairwise comparisons are provided in Table S3.

$EMG_{posture}$ was greater in mTMD patients than controls during the favorite music [contrast estimate (95% CI): +1.1 (0.2-1.9) %MVC; $P = .019$] and the pink noise [+1.1 (0.2-2.0) %MVC; = 0.014, Fig. 4B] blocks.

$EMG_{bruxism}$ is Modulated by GML.—$EMG_{bruxism}$ was significantly affected by the interaction group by experimental block ($P < .001$, Fig. 4C). GML did not affect $EMG_{bruxism}$ in the control group significantly [mean (95% CI) %MVC; favorite: 24.2 (15.8-32.7 %MVC; relaxing: 21.6 (13.3-29.9) %MVC; stressful: 21.2 (12.9-29.4) %MVC] when compared to pink noise [19.3 (10.9-27.6); all $P > .05$).

In mTMD participants, $EMG_{bruxism}$ was significantly smaller during the relaxing [17.6 (9.8-35.4) %MVC] and favorite [13.2 (5.4-21.0) %MVC] blocks than during the pink noise block [23.8 (16.0-31.6) %MVC], and significantly greater during the stressful block [34.0 (26.3-41.8) %MVC] compared to the pink noise block (all $P < .001$). $EMG_{bruxism}$ was



lower during the favorite than the relaxing music block ($P < .001$). Contrast estimates and 95% CI for within-group pairwise comparisons are provided in Table S4. Therefore, in the mTMD group, relaxing music and the individual's favorite music decreased $EMG_{bruxism}$ by 26% and 44% (relative changes),

Fig. 4.—Masseter muscle activity during guided music listening. Least square means of (A): the motor effort of the right masseter relative to each participant's maximum voluntary contraction (MVC) (EMG_{total} − %MVC); (B) the motor effort of the right masseter to maintain mandibular posture relative to each participant's ($EMG_{posture}$ − %MVC); and (C): the motor effort of the right masseter during awake bruxism episodes relative to each participant's MVC ($EMG_{bruxism}$ − %MVC) in both TMD myalgia (mTMD) (gray) and Control (white) groups during the 4 experimental blocks. Within-group (between blocks) significant differences at *P* < .05 are indicated by different small letters (control) or capital letters (mTMD). Error bars indicate ± Standard errors of the mean. *Between-group statistically significant difference at *P* < .05.

respectively. Differently, stressful music increased it by about 43%.

$EMG_{bruxism}$ was significantly greater in mTMD participants than controls during the stressful music block [contrast estimate (95% CI): +12.9 (1.6-24.2) %MVC; *P* = .026).

The Frequency and Duration of Awake Bruxism Episodes Are Not Modulated by GML.—GML did not affect the frequency of awake bruxism episodes in both groups (all *P* > .05). The frequency of awake bruxism episodes was greater in mTMD than controls only during the pink noise block (median [IQR], mTMD: 5 [15.3] episodes, range 0-62 episodes; controls: 1 [3] episode, range 0-27 episodes; *P* = .046). No significant group differences were found in either the overall time spent in engaging in awake bruxism (median [IQR], mTMD: 23.5 [96.7] s, range 1-1300 seconds; controls: 5.5 [22.5], range 0-246 seconds; *P* = .108), or during each block (all *P* > .05).

DISCUSSION

In this study, we sought to determine the effects of GML on masseter muscle activity and awake bruxism in individuals with chronic mTMD. To do so, we recorded the EMG activity of the right masseter during a GML session including 3 different music blocks (relaxing, stressful, and favorite) and a non-music control block (pink noise), and tested whether the motor effort of the right masseter relative to each participant's MVC was modulated by the auditory blocks.

We report 3 key findings. First, music valence modulated the self-reported state of the participants accordingly – that is, stressful music was associated with a statistically significant increase in self-reported stress, and relaxing and favorite music were associated with a statistically significant increase in participants' feeling of relaxation. These changes were also clinically significant (Fig. 3). Second, GML affected EMG_{total} (the muscular effort relative to the participant's MVC) and $EMG_{posture}$ (the muscular effort to maintain mandibular posture) in both women with mTMD and pain-free women. Specifically, relaxing music and participants' favorite music induced a statistically significant decrease in both EMG_{total} and $EMG_{posture}$. Conversely, stressful music was associated with a statistically significant increase in these parameters. However, whether these small changes may have clinical relevance should be investigated in future studies. Third, GML affected $EMG_{bruxism}$ (the muscular effort during awake bruxism episodes relative to the participant's MVC) only in individuals with chronic mTMD, but not in controls, and did not affect the frequency and duration of awake bruxism episodes in both groups. The decrease in $EMG_{bruxism}$ with favorite music and its increase with stressful music were both statistically and clinically significant, since both favorite and stressful music were associated with a >40% relative change in $EMG_{bruxism}$ compared to the pink noise block.

As shown in other studies, music reduces stress and improves mood in individuals with chronic pain.[30-32,53-58] There is substantial evidence that awake bruxism is related to stress and altered mood states.[22,24-26,59,60] It is possible that listening to relaxing and favorite music blocks – which were indeed perceived as relaxing by our study participants – reduced $EMG_{bruxism}$ in those with chronic mTMD. This effect was not observed in pain-free women, suggesting that individuals with mTMD may be more sensitive to music or have stress problems that are rooted in unique ways to the presence of chronic pain as compared to those who are pain-free. Indeed, chronic mTMD has been shown to be associated with increased activity in brain areas involved in emotional processing (medial prefrontal cortex, pregenual anterior cingulate cortex, and amygdala)[61] and increased somatic awareness.[62,63] Individuals with mTMD could, therefore, have been more emotionally labile/sensitive to GML than controls.

Interestingly, $EMG_{bruxism}$, in mTMD participants was lower during the favorite music block than the relaxing music block. Compared to relaxing music, favorite music corresponded to greater VAS scores for *association and memories and pleasure intensity*, indicating that participants related positively to favorite music. It is plausible that the neural mechanisms underlying the modulatory effect of favorite and relaxing music on masticatory muscle activity may be different. Differently from relaxing music, favorite music may have triggered a cognitively modulated response, likely based on deep encoding. Evidence shows that if individuals relate to music, the music can affect their emotional and psychological well-being.[64,65] There is evidence that the excitability of the corticomotoneuronal system is related to the emotion expressed by the listened piece.[37]

Music has long been used to change one's mood[37] but the precise mechanisms of this emotional modulation are not fully understood. Pleasurable music can change heart rate, respiration, and increase activity in brain regions related to both emotional processing,[66] and reward processing.[67,68] Some hypotheses on how music reduces stress have been proposed in the literature. Studies have suggested that music increases the perceived personal control that individuals have in stressful situations[69] and promotes distraction.[39] A study evaluating the effect of relaxing music on an experimental psychosocial stressor showed that relaxing music prior to the stressor led to a faster recovery to baseline cortisol levels after the stressor, compared to other types of auditory stimuli.[70] Also, music is thought to lower the adrenergic and neuromuscular arousal.[71]

There is evidence of a link between auditory and motor systems in the brain.[72] Notably, motor regions are activated even during passive music listening. Music allows for auditory feedback to reinforce the control and timing of movements as well as recruit motor units in a more regular pattern.[38] Studies have shown that metrically strong rhythms intensify corticospinal excitability.[36] Of importance, the motor response can be altered by the metrical strength, emotional valence, rhythmic complexity, tempo and groove.[37,72-74] Therefore, there is evidence that music can affect muscular activity.

Our findings corroborate a previous investigation conducted by our research team[49] using a similar GML experimental design and demonstrating that GML modulates awake bruxism in healthy individuals with highly frequent oral behaviors. In contrast to the previous study,[49] in the current study, GML did not affect the motor effort of the masseter during awake bruxism episodes in healthy individuals. Discrepancies in the findings between the 2 studies might be related to differences in the selection criteria of healthy research participants and to the shorter duration of the experimental blocks in this study. Indeed, in the previous study, we selected TMD-free individuals with extremely low vs extremely high self-reported frequencies of oral behaviors. In the current study, we recruited a group of healthy individuals regardless of their oral behaviors. Our findings are in line with previous investigations showing that mTMD is associated with increased masticatory muscle activity:[9,75,76] during the control no-music block (pink noise), the frequency of awake bruxism episodes and the average muscular effort of the masseter (EMG_{total}) were greater in women with mTMD compared to controls, and women with mTMD reported higher levels of oral behaviors than controls.

For this study, we collected psychophysical measures to characterize the study groups at baseline. Contrary to previous reports,[5,77] state and trait anxiety did not differ between mTMD and control groups. Patients participating in this study were already seen for their first appointment at Mount Sinai Hospital and by other dentists. Hence, the previous relationship with their health care providers could have reduced TMD-related anxiety.[78] Also, women with chronic mTMD had higher scores for pain catastrophizing and depression scores than pain-free women, consistent with previous reports.[77,79,80]

PPT data were within ranges reported in previous studies.[9,81-83] However, we expected that patients with mTMD would have lower PPTs than controls.[9,81-83] Nonetheless, we did not find significant differences in PPTs between groups. This contradicting finding may be explained by the fluctuating pain pattern in mTMD.[84,85] As we did not use pain intensity as an inclusion criterion, it is possible that those with low levels of pain were included in the study, and thus, PPTs were not significantly reduced. Therefore, previous reports of PPT differences between pain-free individuals vs those with mTMD may have been related to the cohort used for mTMD.

This study has some limitations that merit discussion. First, the assessment of relaxation and perceived stress after the music blocks were based on self-reports on VAS. More accurate measurements could have included the assessment of cortisol levels before and after each experimental block.[23] Second, awake bruxism is a broad term that includes several oral behaviors, including tooth clenching, bracing or thrusting of the mandible.[10] While we were able to identify tooth clenching by identifying the EMG activity periods greater than 10% MVC, as done previously,[9,49,86] bracing and thrusting of the mandible are difficult to isolate,[6] and were not assessed in our study. Therefore, we analyzed the frequency and duration of tooth clenching episodes and the motor effort of the masseter during these episodes as surrogate measures of awake bruxism. The latter measurement was based on transformed data (%MVC) and is an estimate of the masseter motor activity relative to the participant's MVC, and cannot be interpreted as an absolute measure of the electrical activity of the muscle.

Third, it might be argued that between-group differences in the frequency of swallowing may have affected the outcomes. It is known that the frequency of swallowing may be affected by systemic, including hormonal oral conditions, stress, and age.[87,88] In this study, both groups were not affected by medical conditions, were not using drugs affecting the salivary flow, were of similar age, and had similar levels of stress during the experimental blocks. Also, it has been shown that the number of functional tooth contacts (including swallowing) does not differ between individuals with mTMD and healthy individuals.[75,89] It could therefore be assumed that swallowing did not affect the differences found between the 2 groups. Moreover, the study focused on women and therefore no conclusions can be drawn about men with TMD. Finally, the current study was focused on the effects of GML on muscular function. Future studies should assess whether changes in masticatory muscle activity (including postural activity and the intensity of awake bruxism) affect spontaneous pain reported by patients with mTMD. Nonetheless, our findings clearly indicate that a participant's favorite music is beneficial to those with chronic mTMD, because of its positive effects on awake bruxism, which could contribute to reduce pain in individuals with mTMD.[18,21]

CONCLUSIONS

We demonstrate that GML modulates the activity of the masseter and targets awake bruxism in individuals with chronic mTMD: highly dissonant and stressful music increases the motor effort of the masseter during awake bruxism episodes, while relaxing and favorite music decrease it. Our findings suggest that GML may have positive effects in TMD patients and could be a promising, noninvasive component of a multimodal approach for the management of chronic orofacial pain due to this condition, if adequate music is selected. However, the mechanisms of masticatory muscle motor modulation with music are currently unknown and the impact of GML on TMD pain in the short and long terms should be addressed in future studies.

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