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ORIGINAL ARTICLE

The intensity of awake bruxism episodes is increased in individuals with high trait anxiety

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Abstract

Objectives Trait anxiety is associated with an increased occurrence of awake bruxism episodes, a behavior characterized by clenching of the teeth contributing to temporomandibular disorders in some individuals. Here we measured the activity of the masseter and the intensity and duration of spontaneous wake-time tooth clenching episodes in healthy individuals with different levels of trait anxiety (TA).

Materials and methods Two hundred fifty-five individuals completed a web survey. Using their TA scores, we allocated them in low (< 20th percentile of the TA score distribution), intermediate (between 20th and 80th), and high (> 80th) TA groups. We analyzed the electromyographic (EMG) activity of the right masseter during a 15-min silent reading task in forty-three individuals with low (n = 12), intermediate (n = 17), and high TA (n = 14). We tested between-group differences in EMG activity of the masseter, as well as postural activity—the muscular activity that maintains mandibular posture, and amplitude and duration of spontaneous tooth clenching episodes.

Results The activity of the masseter (mean ± SEM %maximum voluntary contraction/MVC) was greater in the high TA (10.23 ± 0.16%MVC) than the intermediate (8.49 ± 0.16%MVC) and low (7.97 ± 0.22%MVC) TA groups (all p < 0.001). Postural activity did not differ between groups (all p > 0.05). The EMG amplitude of tooth clenching episodes was greater in the high TA (19.97 ± 0.21 %MVC) than the intermediate (16.40 ± 0.24%MVC) and low (15.48 ± 0.38 %MVC) TA groups (all p < 0.05). The cumulative duration of clenching episodes was not different between groups (p = 0.390).

Conclusions Increased TA is associated with both increased masseter muscle activity and intensity of wake-time tooth clenching episodes.

Clinical relevance TA may contribute significantly to masticatory muscle overload.

Keywords Masseter · Trait anxiety · Awake bruxism · Tooth clenching · Surface electromyography · Temporomandibular joint disorders

Introduction

Awake bruxism—an oral behavior characterized by repetitive or sustained tooth contact (i.e., tooth clenching) and/or by bracing or thrusting of the mandible [1]—is important to identify clinically as it could contribute to the onset of painful temporomandibular disorders (TMD) and dental wear [1–3] in some individuals.

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There is substantial evidence indicating that oral behaviors and awake bruxism are affected by mood states, such as anxiety [1, 4–8]. Anxiety is a temporary state characterized by feelings of unease, worry, tension, and stress in face of events (state anxiety), or a general personality predisposition to react anxiously to events (trait anxiety) [9]. While state anxiety is situation-dependent, trait anxiety is stable over time [10]. One plausible physiological explanation to account for the association between anxiety and awake bruxism is that individuals may engage in this oral behavior to cope with stress [2, 6, 8]. In fact, experimental tooth clenching reduces cortisol concentrations after stressful tasks [11].

Most of the previous studies demonstrating an association between psychological factors and oral behaviors used self-reports (via questionnaires or ecological momentary

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assessment) and portable electromyographic (EMG) devices [3, 5–7, 12]. Self-reports provide qualitative information about oral behaviors (presence/absence), which could be used to estimate frequencies. Differently, surface electromyography provides detailed information about jaw motor activity. Surface electromyography is an objective and reliable method to evaluate the intensity of muscle contraction and duration of contraction episodes [12–15], and can be used to measure electrophysiological characteristics of spontaneous wake-time tooth clenching episodes, which could help yield a more precise understanding regarding the effects of anxiety on jaw motor activity and awake bruxism.

In this cross-sectional study, we aimed to determine whether trait anxiety affects the activity of the masseter and the intensity and duration of spontaneous wake-time tooth clenching episodes in healthy individuals. We hypothesized that the EMG activity of the masseter, and the intensity and duration of spontaneous wake-time tooth clenching episodes were greater in individuals with high versus low levels of trait anxiety.

Materials and methods

Participants

Participants were recruited from a pool of 255 university students (161 females, 94 males; mean age ± SD = 25.8 ± 4.7 years) who participated in a web survey for a previous research study [16]. As part of the web survey, participants filled in a demographic questionnaire, the TMD pain screener [17], the State-Trait Anxiety Inventory (STAI) [9], and the Oral Behaviour Checklist [18].

The TMD pain screener is a 6-item questionnaire. This questionnaire investigates about the presence of facial pain in the last 30 days and whether such pain is affected by jaw activities. A score from 0 to 2 is available for the first question, and 0–1 for the remaining questions. The TMD pain screener has a sensitivity of 0.99 and a specificity of 0.97 for correct classification of the presence or absence of painful TMD for scores ≥ 3 [17]. The total score range for this questionnaire is 0 to 7.

The STAI is a questionnaire including 20 items for assessing state anxiety (Y1) and 20 items for assessing trait anxiety (Y2). Y2 includes constructs such as "I feel pleasant," "I feel nervous and restless," "I feel like a failure," and "I am calm, cool, and collected." Participants indicated how they generally feel by choosing among the following options: "almost never," "sometimes," "often," or "almost always." Each answer is ranked on a 4-point scale (from 1 to 4). For this study, only Y2 was used. The total score range for Y2 is 0 to 80 [9].

The OBC includes 21 items assessing self-reported frequency of oral behaviors (e.g., clench teeth together during waking hours, press, touch, or hold teeth together other than while eating). Participants reported the daily frequency for each oral behavior listed in the checklist by choosing among the following options: "none of the time," "a little of the time," "some of the time," "most of the time," or "all of the time." Each answer is ranked as a score from 0 to 4.

The total score range for OBC is 0 to 48 [18].

We used the Y2 total scores to construct three study groups as follows: low trait anxiety (< 20th percentile of STAIY2 score distribution), intermediate trait anxiety (between 20th and 80th percentile), and high trait anxiety (> 80th percentile). The composition of these groups, with two extreme categories (< 20th and > 80th percentile of STAIY2) and an intermediate group (between 20th and 80th percentile), allows to contrast the potential effect of increased and clinically relevant trait anxiety (STAIY2 score > 50) [19] on the EMG outcome measures.

Participants with TMD pain screener score ≥ 3 [17] were excluded from the dataset (n = 47) as TMD could affect masticatory muscle activity [20]. Participants to the survey were contacted to screen for the following exclusion criteria: current orthodontic treatment, active psychiatric disorders, use of medication acting on the Central Nervous System, habitual analgesic consumption, pain in the orofacial district, any systemic disease that could affect motor activity, presence of fixed extended (equal or more than three teeth) or complete/partial removable dentures, and chronic use of alcohol and/or drugs. Those who confirmed their interest in participating in the study and were not excluded were invited for a TMD clinical assessment according to the Diagnostic Criteria for TMD (DC/TMD) [21] at our research lab to confirm that they did not have TMD. Exclusion criteria were further verified.

A flow diagram of participants' recruitment is depicted in Fig. 1. Forty-five healthy volunteers were enrolled. Based on the selected percentiles, the resultant trait anxiety groups were as follows: low (STAIY2 ≤ 32; n = 14, 8 F and 6 M), intermediate (33 ≤ STAIY2 ≤ 50; n = 17; 14 F and 3 M), and high (STAIY2 ≥ 51; n = 14; 9 F and 5 M) trait anxiety. Two participants in the low anxiety group had to be excluded for technical reasons. Therefore, the final study sample included forty-three individuals (29F, 14 M; mean age ± SD = 26.0 ± 3.4 years) divided in three groups as follows: low trait anxiety (n = 12, 8 F and 4 M), intermediate trait anxiety (n = 17, 14 F and 3 M), and high trait anxiety (n = 14, 9 F and 5 M).

Experimental design

To test our hypotheses, we measured the EMG activity in the right masseter of our research participants. The right side was chosen as a convenience side. Prior to the experimental session, male participants were asked to shave, and all make-up

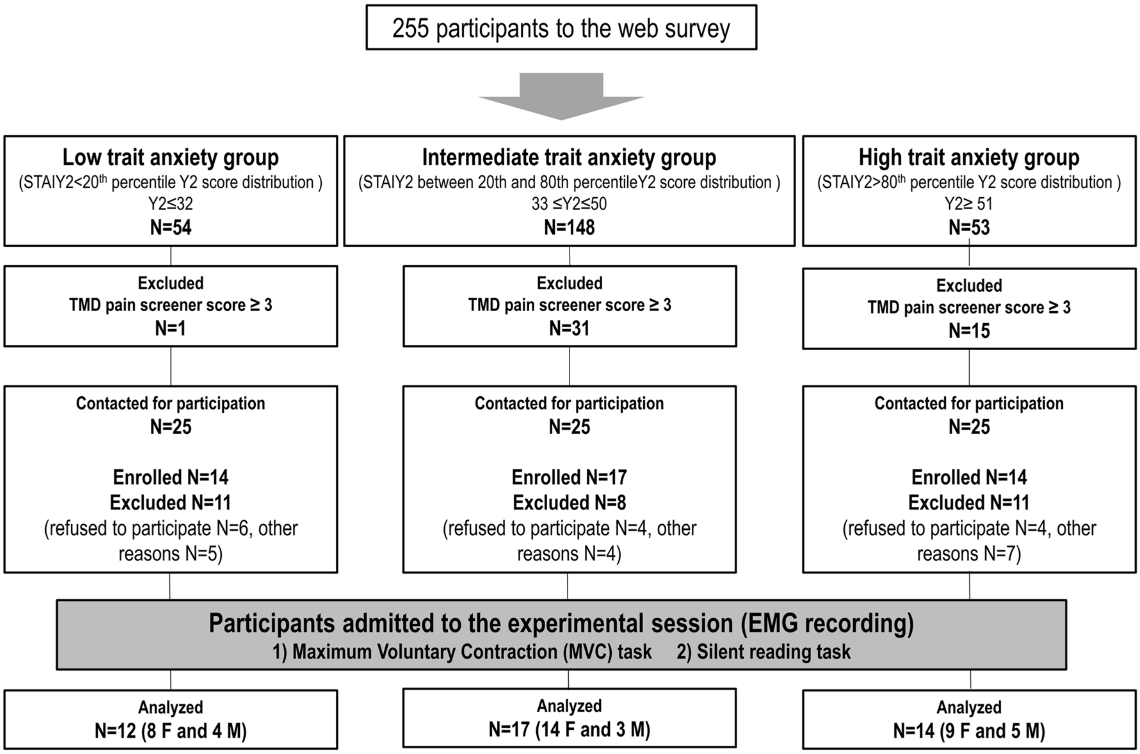

Fig. 1 Recruitment of research participants

was removed. The experimental session was conducted in a private silent room with controlled temperature in the research lab.

All participants were asked to sit on a chair, with their head unsupported. Chewing gums, food, and drinks were not allowed. Participants were asked to abstain from energy drinks or caffeinated drinks within the 12 h preceding the experimental procedure. Before positioning the EMG electrodes, 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. For bipolar EMG measurements, two 24-mm Ag/AgCI self-adhesive pre-gelled EMG electrodes (Covidien-Kendal) were placed approximately 20 mm above the right angle of the mandible on the right masseter muscle along the line extending from the right mandibular angle to the outer canthus of the right eye [22].

The EMG activity of the right masseter muscle was recorded using a Wi-Fi EMG device (BTS TMJoint, Milan, Italy) during the following two tasks:

1) Maximum voluntary contraction (MVC) task. Participants were invited to clench at their MVC in maximum intercuspal position, for three times, with each lasting 3 s, separated by two 5-s intervals, during which participants were invited to relax their jaw muscles as much as possible. Verbal encouragement was provided during the MVC task. The determination of the average EMG amplitude of the three MVC tests served to transform and standardize the EMG signals recorded during the following reading task of a magazine (see EMG postprocessing paragraph). During the MVC task, participants were asked to keep their head still.
2) Silent reading task. Participants were invited to read silently a magazine for 15 min and keep their head still. The magazine covered celebrity and human-interest stories. The content of the magazine used for the experimental tasks was deemed to be suitable for the experiment, as pages which could have triggered an exaggerated stress or emotional response were removed prior to the experiment.

Prior to the experimental tasks, the EMG devices weretested, and participants were invited to perform some activities such as swallowing, touching electrodes, and shaking their head. Participants were asked not to talk during the EMG recordings. The procedure was monitored by a single operator (JC) who recorded activities that could have led to movement artifacts (e.g., touching electrodes, coughing, and head movements). The operator was blinded to group assignment of participants.

The EMG signals were sampled at 1024 Hz, amplified, and bandpass filtered between 10–500 Hz. The Wi-Fi frequency of the EMG system was 2.4 GHz (standard IEEE802.15.4); the input impedance was > 10 GOhm. The acquisition frequency was 1 KhZ, with a sensitivity of 1 μV and accuracy of ± 2%. The common mode rejection ratio (CMRR) was > 110 dB at 50–60 Hz.

Data analysis

EMG postprocessing

The EMG signals of each participant were processed using the OTBiolab software (OT Bioelettronica, Torino, Italy) to identify spontaneous wake-time tooth clenching episodes during the experiment and to determine whether their amplitude and duration was different between trait anxiety groups. We further compared overall EMG activity of the masseter and postural muscular activity.

To ensure that the EMG signals were not affected by the participants' transition to the experimental task, the first minute of the EMG recording was removed. Root mean square (RMS) was computed via software. A diagram of the method used to process EMG signals is depicted in Fig. 2. First, for each participant, an offset was computed using the average EMG activity during the two 5-s breaks (maximum relaxation) of the MVC task. This value was subtracted from the entire EMG signal. Thereafter, the average RMS (expressed in μV) of the three clenching tests during the MVC tasks was calculated and set to 100%MVC. A scaling factor was computed to convert the entire EMG signal from μV into %MVC.

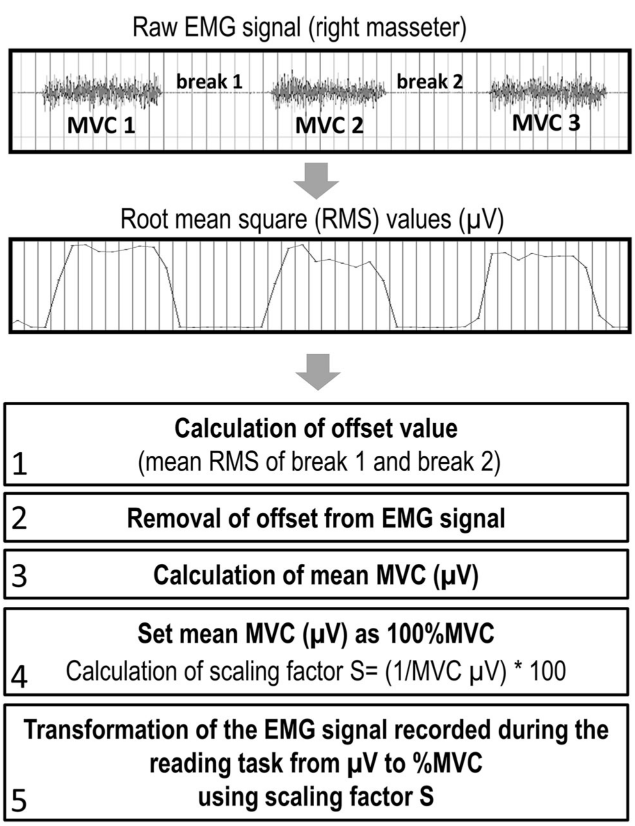

Fig. 2 Diagram describing the method used to post-process EMG signals

This procedure served to standardize the EMG signals recorded during the reading task and reduce the effect of noise on the EMG recording. Therefore, each transformed EMG signal (%MVC) expressed the level of motor effort of the right masseter relative to each participant's MVC during the silent reading task.

The EMG signals were examined by two operators (MR and IC) who were blinded to group assignment of participants (dataset masking). Artifacts were manually removed.

The primary outcome measures of this study were as follows:

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 spontaneous tooth clenching episodes relative to each participant's MVC, and
4) Frequency and duration of spontaneous tooth clenching episodes.

EMG_{total} was measured by including the entire transformed EMG signal (%MVC) of the right masseter recorded during the silent reading task in the statistical model. $EMG_{posture}$ included the transformed EMG signals with amplitude < 10% MVC, which were not identified as tooth clenching episodes, as done previously [12, 14]. $EMG_{bruxism}$ included the transformed EMG signals of those muscle contractions (i.e., tooth clenching episodes) with EMG amplitude ≥ 10% MVC lasting at least 0.5 s, as done previously (Fig. 3) [12, 14]. These episodes were identified and counted. Their duration and their cumulative duration were measured (s) in each participant using software (OT Bioelettronica, Torino, Italy).

All participants signed an informed consent and were compensated for taking part in the study. The recruitment of participants and the experimental procedures were completed between June 2016 and December 2017. The procedures were approved by the Research Ethics Board at the University of Toronto (#32797).

Statistical analysis

A mixed effect model was used to test between-group differences in EMG_{total}, $EMG_{posture}$, and $EMG_{bruxism}$. The sex of participants was included in the model as a covariate, as sex has been reported to affect masticatory muscle activity and bite force [23]. Between-group differences in frequency, duration, and cumulative duration of spontaneous wake-time tooth clenching episodes, and MVC were tested using the Kruskal-Wallis *H* test. ANOVA was used to test between-

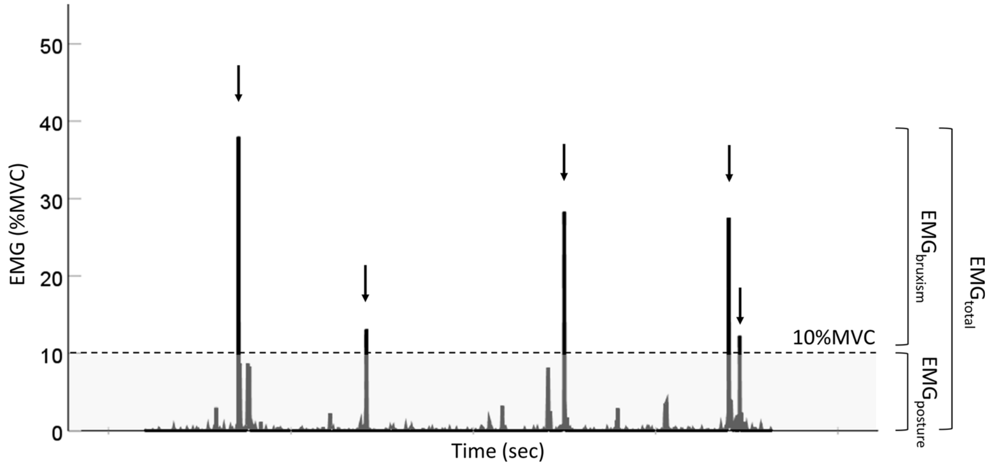

Fig. 3 Electromyographic activity of the right masseter of a research participant during the reading task (EMG_{total}). Spontaneous tooth clenching episodes were identified as activity periods with amplitude ≥ 10% MVC lasting at least 0.5 s (black arrows). The amplitude of each of these activity periods was used to compute $EMG_{bruxism}$ (average EMG amplitude of all spontaneous clenching episodes during the reading task). The remainder of the EMG activity (< 10%MVC, gray) was used to compute the average postural activity of the masseter ($EMG_{posture}$)

group differences in OBC scores. Post hoc comparisons were adjusted using the Bonferroni method.

A minimum sample size of 12 participants per group was required to obtain 80% power with a medium to large effect size ($d = 0.6$, $\alpha = 0.05$). The SPSS software (version 24, IBM, Armonk, New York) was used for all statistical analyses. Statistical significance was set as a $p < 0.05$. The statistical analysis was conducted with the operator (IC) blinded (dataset masking) to group assignment of participants.

Results

The mean ± SD STAI Y2 score of the low, intermediate, and high trait anxiety groups was 28.3 ± 2.8, 38.9 ± 4.7, and 57.3 ± 6.5, respectively. The OBC scores of the low, intermediate, and high trait anxiety groups were not different between groups ($p = 0.150$) and were (mean ± SD) 22.5 ± 10.7, 18.6 ± 6.2, and 23.9 ± 6.0, respectively. The median [IQR] EMG amplitude of MVC in the low, intermediate, and high trait anxiety groups was 142 [136] µV, 115 [240] µV, and 160 [169] µV, respectively. The MVC did not differ significantly between groups ($p = 0.520$).

The activity of the right masseter was significantly affected by trait anxiety ($p < 0.001$) but not by sex ($p = 0.800$). EMG_{total} was greater in the high (mean ± SEM: 10.23 ± 0.16 %MVC) than both the intermediate (8.49 ± 0.16 %MVC; $p < 0.001$) and low (7.97 ± 0.22%MVC; $p < 0.001$) trait anxiety groups. No significant difference was found between the intermediate and low trait anxiety groups ($p = 0.057$; Fig. 4a).

$EMG_{posture}$ did not significantly differ between groups (all $p > 0.05$; Fig. 4b) and was (mean ± SEM) 0.45 ± 0.14 %MVC, 0.57 ± 0.12 %MVC, and 0.50 ± 0.13 %MVC in the low, intermediate, and high trait anxiety groups respectively.

$EMG_{bruxism}$ was greater in the high (mean ± SEM: 19.97 ± 0.21 %MVC) than both the intermediate (16.40 ± 0.24 %MVC; $p < 0.001$) and low (15.48 ± 0.38 %MVC; $p < 0.001$) trait anxiety groups. It was also greater in the intermediate than the low trait anxiety group ($p = 0.040$; Fig. 4c).

The mean frequency of spontaneous wake-time tooth clenching episodes was (mean ± SD) 0.6 ± 0.8 (range 0–2), 2.0 ± 4.5 (range 0–18), and 2.1 ± 3.6 (range 0–11) in the low, intermediate, and high trait anxiety groups, and did not differ significantly across groups ($p = 0.805$).

The mean duration of spontaneous wake-time tooth clenching episodes was 1.2 ± 1.1 s (range 0.5–3.0 s), 0.6 ± 0.1 s (range 0.5–0.8 s), and 0.6 ± 0.2 (range 0.5–0.9 s) in the low, intermediate, and trait anxiety groups, respectively. The mean duration of spontaneous tooth clenching episodes did not differ significantly across groups ($p = 0.765$).

The mean cumulative duration of tooth clenching episodes did not differ between the low (1.6 ± 1.3 s; range 0.5–3.0 s), intermediate (3.8 ± 3.1 s; range 1.5–9.0 s), and high (3.6 ± 3.2 s; range 0.5–8.5 s) trait anxiety groups ($p = 0.390$).

Discussion

In this study, we demonstrated that the activity of the masseter (relative to the individual's MVC) was greater in individuals with high and clinically relevant trait anxiety compared to those with intermediate and low trait anxiety. Contrarily, the postural activity of the masseter was not affected by trait anxiety levels. Finally, the intensity of spontaneous wake-time tooth clenching episodes was significantly greater in

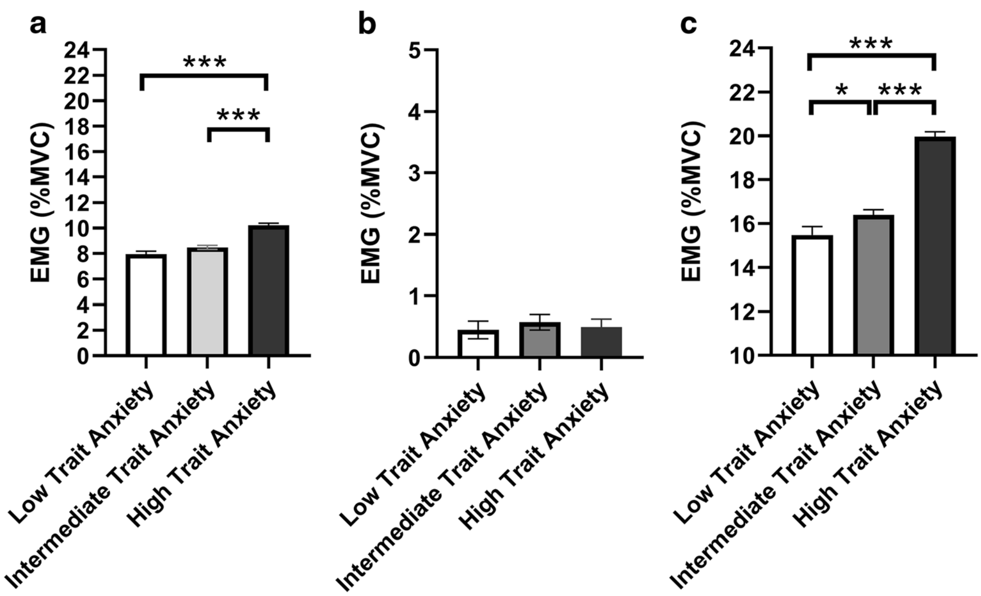

Fig. 4 Mean EMG amplitude of **a**) entire right masseter muscle activity (EMG_{total}), **b**) postural EMG activity ($EMG_{posture}$), and **c**) spontaneous tooth clenching episodes ($EMG_{bruxism}$). The error bars indicate standard errors of the mean. *$p < 0.05$;***$p < 0.001$

individuals with high trait anxiety compared to those with intermediate and low trait anxiety.

For this study, we decided to compute the mean postural activity ($EMG_{posture}$) of the masseter by selecting EMG signals < 10%MVC, as done in previous studies [12, 14], instead of recording the activity of the masseter when the mandible is postured in the clinical rest position with the help of an operator. Indeed, we wanted to record the activity of the masseter during a real-life situation (magazine reading task) and it might have been challenging for our participants to maintain the clinical rest position during such task. Nonetheless, the average postural activity of the masseter, after artifact removal, was found to be < 1%MVC in our study, which is consistent with a previous study [24]. As in previous investigations [12, 14, 25], we used 10% MVC as an EMG threshold to detect spontaneous wake-time tooth clenching episodes, as a contraction of 5% MVC is sufficient to bring teeth in contact [26].

Effects of trait anxiety on masticatory muscle activity and frequency, intensity, and duration of tooth clenching episodes

We found that trait anxiety affected both EMG_{total} and $EMG_{bruxism}$, but not $EMG_{posture}$, which indicates that trait anxiety did not significantly affect muscle tone in our investigation. This result contrasts with a previous study showing that masseter muscle tone of 113 young adults correlated positively with anxiety scores measured using the Hospital Anxiety and Depression Scale (HADS) [27]. However, the authors recorded the EMG activity of the masseter only for 20 s with the mandible in resting position, and it is unclear how the resting position of the mandible was determined. Furthermore, respondents to the HADS are asked to rate items according to how they have felt during the previous week [28]. In contrast, the STAIY2 investigates how one generally feels and is not related to a specific time frame [9].

Both epidemiological studies and studies using ambulatory recordings demonstrated that oral behaviors (including wake-time tooth clenching) occur more frequently in individuals with greater anxiety [4, 5, 8, 16]. In a previous investigation [16], we showed that trait anxiety correlated positively with the frequency of oral behaviors, as assessed using the Oral Behaviour Checklist (OBC scores) [18], and specifically to those activities involving tooth-to-tooth contact and tooth clenching [16]. Endo et al. found that individuals with highly frequent wake-time tooth clenching episodes (identified as EMG epochs with amplitude ≥ 20%MVC and lasting at least 3 s) had moderate to severe anxiety [5]. Michelotti et al. found that individuals reporting highly frequent oral behaviors had greater trait anxiety compared to those reporting less frequent oral behaviors [29]. Recently, Gonzalez et al. demonstrated that subjects with increased anxiety scores had more frequent masseter muscle contractions (i.e., duty time) during wake-time than those with lower scores [30]. In contrast to the abovementioned studies, in this investigation, we did not find differences in the frequency of tooth clenching episodes and OBC scores between trait anxiety groups. However, our study was not designed to test differences in frequencies of spontaneous tooth clenching episodes, which may have required a more extended experimental task. Besides, the high variability of OBC scores and the limited sample size of our study groups suggest that our study did not have sufficient power to detect differences in OBC scores, yet these were not objectives of the current investigation.

Our results indicate that increased and clinically relevant trait anxiety is associated with increased muscle load during spontaneous wake-time tooth clenching episodes. To the best of our knowledge, this is the first study which attempted to determine whether the intensity of spontaneous wake-time tooth clenching episodes is affected by trait anxiety levels in healthy individuals. Because of the lack of similar studies, it is not possible to make comparisons.

Whether trait anxiety affects the duration of tooth clenching episodes is still matter of debate. Manfredini et al. reported an increased duration of masseter and temporalis muscle contraction episodes during sleep in individuals with high trait anxiety [31]. Differently, we did not find a significant effect of trait anxiety on the duration of wake-time tooth clenching episodes. Discrepancies in these results may possibly be attributed to the fact that awake and sleep bruxism are two different disorders with different aetiologies [7, 8]. Of note, in a previous study, we demonstrated that the duration of spontaneous wake-time tooth clenching episodes was found to be significantly longer in healthy subjects when playing a videogame compared to reading a magazine or completing a questionnaire [12]. Therefore, the context individuals are placed in can likely influence the duration of tooth clenching episodes. In addition, in line with previous studies [12, 32], the frequency of clenching episodes in the participants recruited in our study was relatively small, amounting only to a few episodes during the experimental reading task.

Mechanisms underlying the relationship between trait anxiety, awake bruxism, and TMD pain

Wake-time tooth clenching favors the onset of TMD pain in healthy individuals [30] and is highly prevalent in subjects with TMD [12, 33–35]. The mechanism by which sustained masticatory muscle contraction can lead to pain is likely due to impairment of blood flow to the muscle and peripheral sensitization [35, 36]. Of note, muscle symptoms depend on the magnitude of muscle contraction [33], and the relationship between trait anxiety and frequency of oral behaviors is stronger in individuals with TMD pain [16], i.e., the same levels of trait anxiety are associated with more frequent oral behaviors in subjects with TMD pain than individuals without TMD pain. Therefore, it is possible that increased levels of trait anxiety contribute to increasing both the frequency and the intensity of tooth clenching episodes in individuals with TMD, as reported in a previous study [12].

Although it is well known that frequent and sustained tooth clenching contributes to the onset and maintenance of TMD, it is still unknown what frequency, duration, or intensity of wake-time tooth clenching episodes is detrimental to the muscles of mastication. Clinical evidence indicates that many people who keep their teeth in contact during wake-time develop TMD-like symptoms, but others do not. It is possible that the difference between these two subtypes is related to different compensatory mechanisms. There is evidence that reduced oxygenation of the muscles of mastication may play a role in the onset and maintenance of muscular TMD [36–38]. In a recent study, we measured tissue oxygen saturation (StO_2) in the masseter of individuals with frequent oral behaviors (HP) and those with sporadic oral behaviors (LP), as assessed using the OBC) [36]. We demonstrated that StO_2 was lower in HP than LP individuals during maximum voluntary contraction, while it did not differ between groups after the MVC exercise. These findings suggest that individuals with frequent oral behaviors use more oxygen during maximum voluntary contraction than LP ones. Still, they cannot compensate as quickly as LP individuals, i.e., post-exercise hyperemia may not be sufficient. We also demonstrated that HP individuals had reduced blood flow to the masseter after a sustained clenching session at 10-20%MVC [36]. It can be hypothesized that those individuals who develop TMD symptoms have reduced blood flow to their muscles of mastication, and engage more frequently in tooth clenching and/or engage in more sustained/intense behaviors. Notably, based on these findings and the available literature, it is not possible to provide a threshold for tooth contact duration which could be considered harmful to the muscles of mastication. Such information may be also misleading, as the duration of tooth contact is not the only factor involved in the pathogenesis of TMD.

Neurobiological mechanisms underlying the relationship between trait anxiety and increased masticatory muscle activity

The neurobiological mechanisms underlying the relationship between trait anxiety and increased masticatory muscle activity are difficult to pinpoint, due to the absence of studies investigating the effect of this personality trait on masticatory muscle contraction patterns. It is known that anxiety is associated with a state of arousal and increased activation of the sympathetic system, which, in turn, can affect motor responses, in line with the fight-or-flight response. Anxious states, exposure to stressors, or stress anticipation and could contribute to make skeletal muscles more tense, and accelerate reaction times to specific tasks [39]. There is some evidence suggesting that changes in muscle spindle sensitivity may provide a putative mechanism through which anxiety may influence motor control [40]. Of note, muscle spindles play a fundamental role in jaw motor behaviors and are highly present in the masseter muscle [41]. Finally, it has been shown that the increase in sympathetic activity during mental stress tasks coincides with an increase of the activity of the temporalis and masseter muscles [42]. All of these mechanisms could explain why the masseter of individuals with high trait anxiety is more active than those of individuals with low trait anxiety.

Spontaneous wake-time tooth clenching episodes could be an acquired behavior to reduce stress [11, 43]. Animal studies show that chewing behaviors in response to stressors are associated with an increase in the activation of the medial prefrontal cortex and the central amygdala [44]. Notably, trait anxiety predicted individual differences in the structural integrity of the amygdala prefrontal pathway in a human investigation [45]. Our study indicates that the intensity of spontaneous tooth-clenching episodes is greater in individuals with high trait anxiety compared to those with low trait anxiety, which supports a putative relationship between those brain areas and jaw motor function, yet whether more intense spontaneous wake-time tooth clenching episodes in anxious individuals may help coping better with stress should be investigated in future studies.

Data from the Orofacial Pain Prospective Evaluation and Risk Assessment (OPPERA) study suggests that TMD pain is associated with dysregulation of autonomic function at rest and in response to stressors [46]. Indeed, at rest, individuals with TMD pain had increased diastolic blood pressure and heart rate than controls. Increased heart rates were also recorded during physical and psychological tasks. Individuals with TMD had also reduced baroreceptor sensitivity. Altogether these findings characterized by a greater cardiosympathetic than cardioparasympathetic tone in individuals with TMD pain compared to controls [46] may justify an increased masticatory muscle activity in patients with TMD pain. Similarly, Carlson et al. found higher heart rates and systolic blood pressure in patients with masticatory muscle pain than controls during a stressful task. However, they did not found differences in the electromyogram of the masseter [47], yet many other factors other than tooth clenching and altered psychological states have been shown to contribute to the onset of TMD, which include, but are not limited to, frequency of somatic symptoms, genetic variability, comorbid conditions, and sex [48].

Study limitations

There are some limitations to this study. First, the study sample included university students, which may not be representative of the general population. Second, the study sample included a proportionately greater number of females compared to males. However, we included sex as a covariate in our statistical analysis, and sex did not significantly affect our outcome measures. Third, the EMG recording period was relatively short. Therefore, only a limited number of spontaneous tooth clenching episodes could be detected and analyzed, and our study was probably underpowered to test the effect of trait anxiety on the frequency of spontaneous wake-time tooth clenching episodes. However, this was not an aim of the present investigation. In addition, it may be argued that the analysis of tooth clenching episodes may have been confounded by between-group differences in the frequency of swallowing. It is known that the frequency of swallowing can be affected by systemic, hormonal, and oral conditions, and by age [49, 50]. Our participants were all healthy and of similar age. Also, swallowing leads to an activation of the masseter ranging between 3 and 7% MVC [24], which is below the threshold we set to identify spontaneous tooth clenching episodes (≥ 10%MVC). Therefore, between-group differences in swallowing frequency, if any, likely did not affect our results. During the silent reading task, all participants had their head unsupported and they were asked to keep their head still. Any major head movement was noted by the operator in the room to detect potential movement artifacts during EMG signal postprocessing. However, minor head movements could have occurred, as participants' head was not restrained using a craniostat. Nevertheless, it is unlikely that these movements had significant effects on the masseter EMG readings. Finally, for this study, we have used %MVC (a relative measure) instead of microvolts (absolute measure) as a measure of muscle contraction, in line with other studies [12, 14, 15], as there is evidence that the EMG activity recorded from the muscles of mastication is dependent on several factors, such as dentofacial morphology [51], dental malocclusions [52], and even minor occlusal discrepancies [53]. By computing standardized %MVC for each participant, it is possible to reduce the potential impact of all these interindividual variations on the overall EMG analysis. However, %MVC 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.

Conclusions

We demonstrate that healthy individuals with high and clinically relevant trait anxiety have greater masseter activity and more intense spontaneous wake-time tooth clenching episodes than individuals with lower trait anxiety. It would therefore be prudent to identify anxious patients early on to provide them with specific information and education to prevent the onset of masticatory muscle fatigue and pain. From a clinical perspective, the STAI [9] can be employed as a screening tool chairside to identify individuals with increased trait anxiety.

Authors' contributions MR contributed to data collection and analysis, interpretation of data, and drafting of the paper; JC contributed to the research design, data collection, interpretation of data, and revision of the manuscript. IC contributed to conception and design, analysis and interpretation of data, and draft of the paper. All authors approved the final version of the manuscript.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the Institutional Research Ethics Board (protocol #32797) and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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