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METHODOLOGY REPORT

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A new test protocol and device for measuring the cranio-cervical flexion test in participants with bruxism

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ABSTRACT

Introduction: The craniocervical flexion test (CCFT) has been proposed to assess muscular stabilization using deep neck flexors. Reliability of the CCFT using a pressure biofeedback unit has been regarded as doubtful, and the level of evidence is reportedly low.

The aim of the current study is to pilot test an alternative measurement protocol by using a new digital device during the staged CCFT when compared to surface electromyography (sEMG) of neck flexor muscles in participants with bruxism.

Methods: Cross-sectional pilot study including five participants with bruxism and five controls. Measuring five incremental stages (20-100%), from a maximum force of 17 N for the CCFT and parallel to sEMG measurements of bilateral sternocleido-mastoideus (SCM) and masseter muscles. SEMG data were normalized to their activity during maximal voluntary contraction. Performance during the staged CCFT was fed back via a smartphone screen.

Results: A two-way repeated measures ANOVA found a significant stage ($F = 32.56$, $df = 4$, $p = 0.001$) but not group (0.30, $df = 1$, $p = 0.65$) main effect for SCM activity, with both groups demonstrating higher normalized sEMG activity for incremental stages of the CCFT. Neither group nor stage effects were found for normalized masseter activity during the staged CCFT.

Conclusion: A new measurement protocol and test device for the CCFT were examined in participants with and without bruxism. In parallel, sEMG used showed differences in SCM activity for incremental test stages. Group differences could not be found.

Keywords: Bruxism, Craniocervical flexion test, Measurement protocol, NOD device, Pilot study, Superficial EMG

Introduction

Muscular stabilization of the neck via the deep neck flexors (DNF) has been found important in everyday life (1). Impaired function is associated with problems such as neck pain (2), headaches (3-5), or craniomandibular dysfunction (CMD) (6). The craniocervical flexion test (CCFT) has been proposed for assessing the muscular stabilization by the DNF, which is provided predominantly by the longus capitis and longus colli muscles (7). The CCFT assesses three components: first, the ability to increase contractions of the DNF progressively and correctly to five inner range positions of craniocervical flexion. Second, to determine that stage or threshold someone can contract correctly without substitution by superficial muscles (sternocleidomastoideus, i.e. SCM and scalene muscles), for 10 seconds (i.e. activation score), and third to evaluate the holding capacity, which is the repeatedly correct activation of the DNF, usually up to ten times ten second holds (i.e. performance index) (8,9). The CCFT has commonly been investigated by using a pressure biofeedback unit (i.e. PBU) in clinical settings (2,10). In laboratory settings, additional measurements of superficial muscles by surface electromyography (sEMG) have also been performed (11,12). Intra- and interrater-reliability of the clinical CCFT using the PBU has, however, a conflicting level of evidence across some recent systematic reviews, as often only healthy participants had been examined, and measurement errors account for approximately 15 % of the whole range of the scale from 20 to 30 mmHg (2,10,13). Uthaikhup and Jull reported shortfalls in achieving incremental 2 mmHg values on the scale and during the CCFT by using the PBU in asymptomatic elderly of 5-30% (14). Studies reporting shortfalls or the opposite, overshooting during the CCFT in symptomatic populations and by using the PBU, are lacking. Further doubts regarding the PBU emerge from its scale with 2 mmHg interval units, making reported measurement errors

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below that one unit a theoretical value only (2). As reliability is necessary for validity, the latter is also restricted.

The NOD is a hand-held dynamometer (HDD) with three incorporated functions. The biofeedback function has been introduced to test the CCFT, but only one study by Lonati et al. has recently studied its concurrent validity in comparison to the PBU for examining the CCFT, and reported a strong correlation of r = 0.92 (15).

Lonati et al. have used a maximum value of 17 Newton (N) for the CCFT by using the NOD, which corresponds to 30 mmHg by using the PBU (15) (see also supplemental Material). In clinical settings, superficial muscle activity can be controlled for by palpation of the corresponding muscles (9). However, more accurate measurements are needed in laboratory setups, and especially when using a new test protocol and device. Alalawi et al. have measured maximal and submaximal cranio-cervical flexion strength by using the NOD parallel to sEMG of the SCM in healthy and two groups of neck pain patients (16). The maximum achievable value of 17 N, used by Lonati et al., corresponded to approximately 32% of the maximum strength for the healthy and 36-38% for the two symptomatic groups (16). Directly measuring DNF muscle activity with EMG techniques is difficult to perform, accordingly surface EMG measurements of the SCM were most frequently performed in parallel (12,17-19), as an inverse relationship between the activity of deep and superficial flexor muscles, for different populations like neck pain, whiplash and headache subjects has been demonstrated (5,12,18,20-22). Further significant differences for normalized root mean square values of superficial muscle activity between healthy controls and various patient groups, like neck pain, whiplash, cervicogenic headache, and migraine, have been reported (5,12,20,23-25).

Bruxism has been found to be associated with Temporomandibular disorders (TMD) (26). Co-contraction of neck muscles during teeth grinding has been shown in various studies (27-30), but not in association with the CCFT. Parafunctional bruxism with TMD has been found significantly associated with neck disability (26). However, authors reported that cervical impairments were unlikely to be associated with bruxism, but with a pain mechanism leading to increased sensitivity in the cranio-cervical region. Unfortunately, that study did not report results on the CCFT (26).

In order to examine the common notion of an impaired function of the DNF in participants with bruxism, a new measurement protocol using the NOD will be piloted in participants with and without bruxism.

The first aim of the current study is to examine the CCFT by introducing an alternative measurement protocol and device, the "NOD" (http://www.to-nod.com/) for measuring the CCFT in research settings and when compared to EMG of the superficial neck flexors, i.e., the SCM.

A further aim of this study was to examine whether participants with bruxism show a different performance of the CCFT together with higher activity of the superficial neck flexor or masseter muscles, as has already been found in other symptomatic groups. It was hypothesized that participants with bruxism showed an increased activation of the SCM and the masseter during the CCFT.

Methods

Study design

Pilot study using a cross-sectional design. The study was approved by the local ethics committee (ethics committee of the canton Zürich, Switzerland), identification number: 2023-01641, and registered at clinicaltrials.gov: NCT 06037798.

Recruitment and Inclusion

Participants were recruited via physiotherapy practices or at the university with flyers or direct references to the study. Those interested in participating were screened by an online questionnaire using REDCap (31) for eligibility. Persons with neurological conditions, primary headaches, mental or inflammatory diseases, known pregnancies, and current or ≥ three months TMD complaints during the last 12 months were excluded. Furthermore, subjects were excluded when reporting neck pain (32) with an intensity of >3 out of 10 on the numeric rating scale (NRS) at the start of the measurements.

Subjects with bruxism were further screened for complaints such as pain, aching, or stiffness within muscles of mastication, sensitized teeth, either self-reports or by partners of grinding or chattering with the teeth. On the day of measurement, further objective signs of bruxism like hypertrophy of the masseter muscle, cheek and/or tongue impressions, abraded tooth tips or exposed tooth necks were examined.

After inclusion, activation of DNF and sEMG of superficial neck flexors were examined in all participants, with and without bruxism, in a single session at the movement laboratory of the participating university.

Measurement protocol

After cleaning the skin of both cheeks and the region above both collar bones, with alcohol to decrease impedance and electrode skin interface noise, one pair of bipolar, oval, self-adhesive and wet sEMG electrodes (44.8 × 22 mm) with a centre-to centre distance of 2cms, each for the masseter and the sternal part of the SCM were attached on both sides (see Fig. 1) (33). EMG signals were recorded using the Cometa system with PICO EMG sensors. The amplification was set at 1000×. A band-pass filter integrated into the hardware was applied with cut-off frequencies set at 10 Hz (high-pass) and 500 Hz (low-pass) (34). The EMG sampling rate was 2000 Hz. EMG signals were transmitted to a receiver via Bluetooth.

For all tests, participants lay on their backs with their legs bent (crooked lying) (see Fig. 1).

In total, five tests were conducted:

1. Measuring the *resting tone of both the masseter and SCM muscles* for 30 seconds, once. Participants were asked to breathe normally but avoid swallowing.
2. Measuring the activation of the deep neck flexor muscles with the *staged CCFT*. The NOD device with a silicon pad attached was placed under the neck of the participant, enabling a nodding movement without lifting the head.

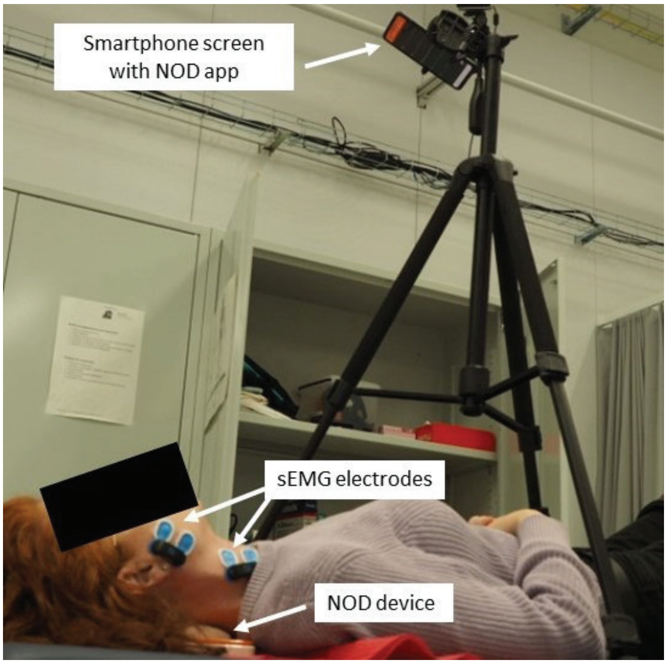

FIGURE 1 - Measurement setup.

A plastic foil was placed under the head to facilitate friction-free upper cervical flexion by sliding the head on the treatment table. If needed, persons with kyphosis were additionally supported with towels below the head or neck.

Measurements were recorded by using the "biofeedback mode" of the NOD. Minimum and maximum values were set manually at 0 and 17 N, respectively (15). The device was calibrated before every single test. An Android operating smartphone with the NOD app installed was fixed to a tripod, which was placed above the participant (Fig. 1). Participants were instructed and familiarized with the CCFT to nod without lifting the head, keeping their jaw muscles relaxed, and not to push their neck backwards. They were allowed to practice once or twice before measurements were recorded. Participants were given five seconds to adjust their contraction to each corresponding and incremental stage and to hold it for a further 10 seconds each, at 20, 40, 60, 80, and 100% of the maximum of a 17 N value. Accurate performance was fed back via the smartphone screen.

If the participants could hold steadily the requested %-line of force, and only occasionally had a "wobble" that did not reach or exceed the adjacent % lines, or repeatedly (three times within five seconds) crossed the requested centre line toward the adjacent %-lines, that stage was considered passed (see Figs 2 and 3).

For each stage, the activity in the SCM and masseter muscles was measured by sEMG.

3. *A "head lift-off" test* was used to measure the maximal voluntary contractions (MVC) of the neck flexor muscles.

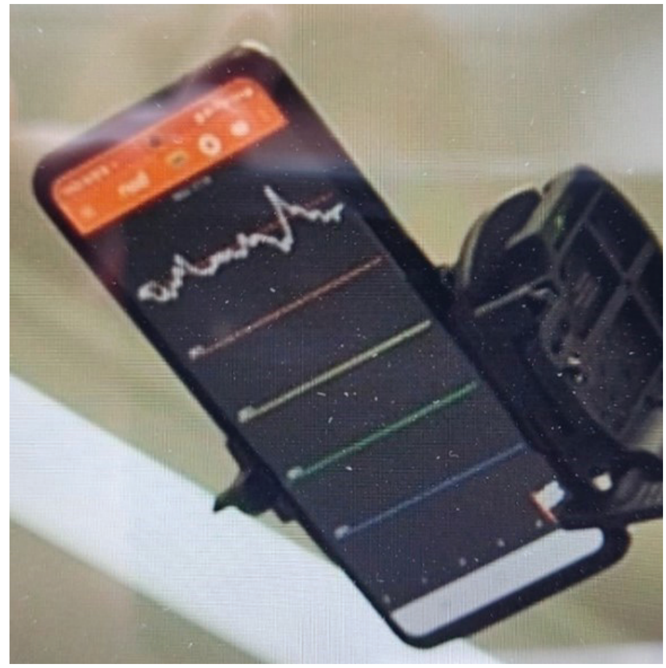

FIGURE 2 - Example of a participant who passed the final stage at 100%.

FIGURE 3 - Example of a participant who failed the 2nd (40%) stage.

Participants were fixed to the treatment table via a belt over their upper chest. The NOD was set to dynamometer mode. Participants had to lift their head for approximately 3 cm while maintaining upper cervical flexion (nodding). While doing so, they pressed their forehead against the NOD with maximum effort for five seconds in three runs with 30 seconds' rest in between (35-37). Surface EMG of the SCM muscles was recorded in parallel. The peak force was recorded by the App, and the mean of three trials was used for subsequent analysis. One familiarization and warm-up trial, asking participants to push with approximately half of their strength, was conducted prior to the recordings.

4. *Clenching the teeth*: The maximum force for bilateral masseter muscles by clenching the teeth on a wooden spatula and for five seconds in two runs was measured and used for further analysis (38-40). In addition, the activity of both SCMs was recorded. One familiarization and warm-up trial, asking participants to clench with approximately half of their strength, was conducted prior to the recordings.
5. *Nodding and clenching*: Participants were asked to perform a nod to the second stage (40%) of the CCFT while subsequently and maximally clenching their teeth on a wooden spatula. The capacity of holding the nod while clenching the teeth was evaluated. The same evaluation as for test 2 was applied here. If the 40%-line has been crossed three times within 5 seconds, the test is considered failed. One familiarization or warm-up trial was conducted prior to the recordings.

Data processing and analysis

Post-processing of all sEMG data was done with proEMG (version 2.1.3.12). The raw EMG signals were rectified and subsequently low-pass (450 Hz) and high-pass (20 Hz) filtered (Butterworth filter) to enable amplitude analysis. Maximum root mean square (RMS) values for the entire period of each test were calculated using a continuous smoothing RMS window of 1000 ms with 0.5 s overlap.

Data was examined for normal distribution by using the Shapiro-Wilk test. If the data were not normally distributed, non-parametric tests were applied subsequently.

All sEMG data of the SCM and masseter muscles during the *staged CCFT* and the *nodding and clenching test* were normalized to their activity during maximal voluntary contraction (MVC) and presented as a percentage.

Normalized values were examined for side differences first and averaged if no side differences were found (Wilcoxon signed-rank test).

Differences in sEMG activity for the SCM and masseter muscles between groups and for all tests but the *staged CCFT* were examined by using the Wilcoxon signed-rank test.

Frequencies of failed test performance during the *staged CCFT* and between groups were examined using Fisher's exact test.

For the *staged CCFT* group, differences in sEMG activity for the SCM and masseter muscles were examined using a two-way repeated measures ANOVA. Bootstrapping using 1000 iterations of subsamples was performed to provide confidence intervals and test statistics. For all statistical group comparisons, alpha was set at 0.05. For all statistical analyses, R Statistical Software (v4.4.1, R Core Team, 2024) (41) and the packages afex, epiR, epitools, ggplot2, gridExtra, plyr, and reshape were used (42-48).

Boxplots and interaction plots are provided for graphical illustrations.

Results

During enrollment, fifteen persons were assessed for eligibility using an online questionnaire on REDCap. Five people had to be excluded. Four did not meet the inclusion criteria, and one person did not complete the eligibility questionnaire. Finally, ten participants, five for each group, were included.

Both groups consisted of two men and three women, with a mean age ± SD of 35.8 ±11.0 years for the bruxism group and 39.4 ±16.5 for the control group, respectively.

In the bruxism group, two people each stated that they grind or clench during the day or at night, and one person during both time points.

Resting tone

There were no significant group differences in resting muscle activity for the SCM ($p = 0.69$) or the masseter muscle ($p = 0.55$) (see supplementary material)

Staged CCFT

During the staged CCFT, both groups showed an increased normalized sEMG activity of the SCM and masseter muscles. Whilst normalized sEMG values for the masseter muscle showed non-normal distribution across all stages of the CCFT, the opposite was true for normalized SCM values.

The two-way repeated measures ANOVA found a significant stage ($F = 32.56$, $df = 4$, $p = 0.001$) but no group (0.30, $df = 1$, $p = 0.65$) main effect (for mean values of SCM activity) with both groups demonstrating higher normalized sEMG activity with each stage of the CCFT (see Fig. 4).

The two-way repeated measures ANOVA for normalized masseter muscle activity during the staged CCFT found no stage (F 5.71, $df = 4$, $p = 0.28$) and no group effect (F: 0.54, df = 1, $p = 0.55$) (see Fig. 5).

From a total of 25 test stages performed among five participants per group, nine levels could not be controlled in the bruxism group, while three levels could not be controlled in the control group. The odds ratio of failing a test stage among participants with bruxism compared to controls was 4.01 (95% confidence interval: 0.883-26.71, $p = 0.10$)

Four participants of the bruxism group failed to control the highest stage (100%), whereas two participants of the control group could not pass this level.

Head lift-off

The control group showed larger strength values during the lift-off test, with a median value of 82.1 Newton and a range from 35.5 to 112.5 N, compared to the bruxism group with a median of 44.1 Newton and a range from 28.2 to 110.2 Newton. Differences were statistically not significant ($p = 0.42$). No statistically significant differences were found between groups for the sEMG activity for both SCM ($p = 0.42$) and masseter muscles ($p = 0.22$) during the lift-off test.

Clenching teeth

There were no significant group differences in the activity of SCM ($p = 0.42$) or masseter muscle ($p = 1$) during maximal teeth clenching.

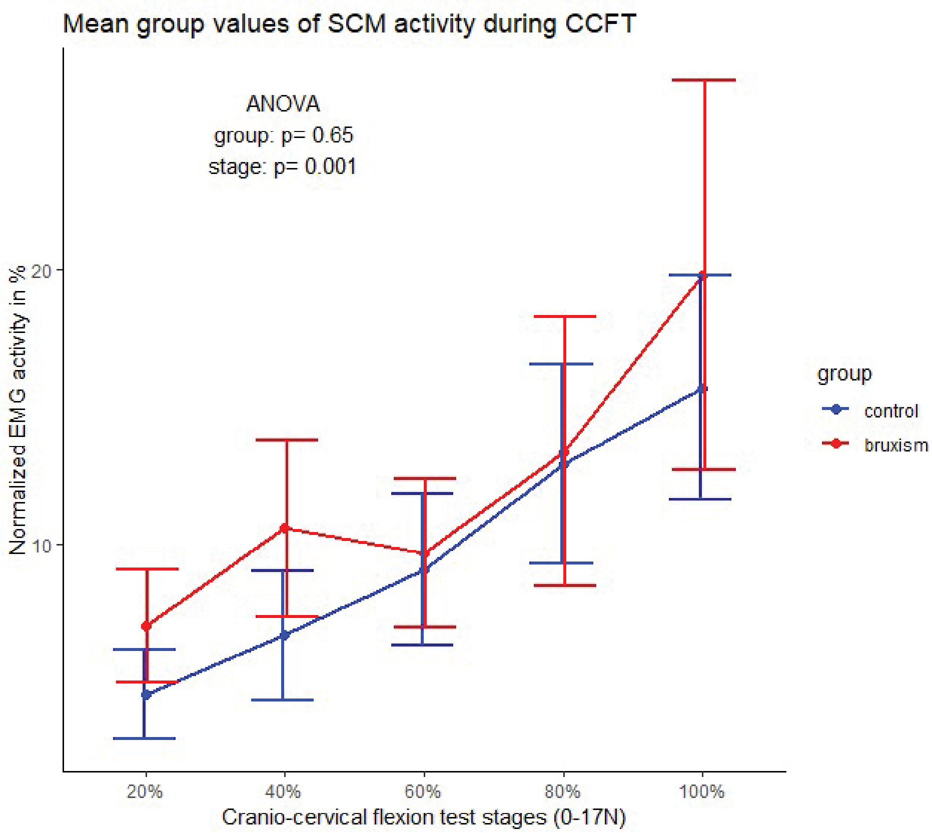

FIGURE 4 - Line plot with group means and standard errors of normalized sEMG activity of the SCM during the CCFT.

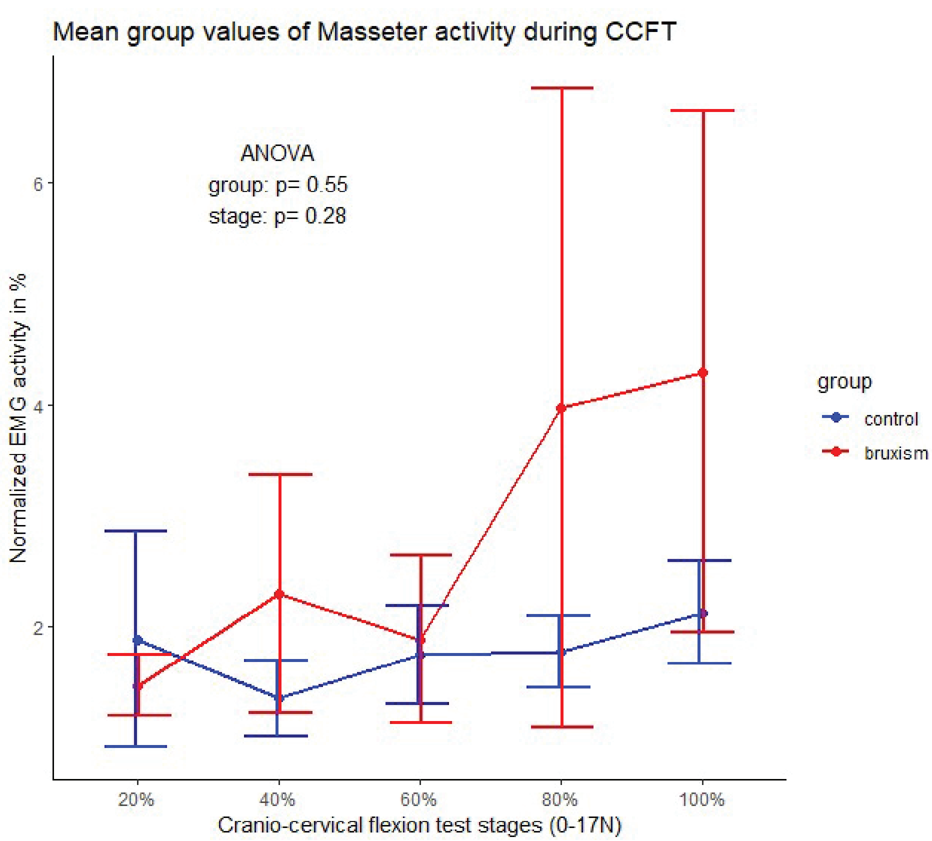

FIGURE 5 - Line plot with group means and standard errors of normalized sEMG activity of the masseter muscles during the CCFT.

Nodding and clenching

After cranio-cervical flexion to test stage 2 (40%), and subsequently maximal clenching of the teeth, the control group showed on average a lower activity of the normalized masseter muscle, which remained not significant with a median (interquartile range): bruxism: 48.86 (27.88) vs. control: 40.19 (9.34, p = 0.84) (Fig. 6).

The odds ratio of failing to perform the CCFT correctly while maximally clenching the teeth among participants with bruxism compared to controls was 3.61 (95% confidence interval: 0.230-224.19, p = 0.58).

Discussion

A new test protocol for the CCFT, by using the NOD, has been examined in the current pilot study. The NOD offers detailed feedback via an App on a smartphone or tablet screen for patients and therapists, which can help identify someone's impairment in correctly activating the deep neck flexor muscles during the CCFT. Five %-test-stages were manually set between 0 and 17 N and needed to be achieved by a cranio-cervical flexion action with the NOD device placed under the neck of the participant. Further criteria were defined, such as how correctly holding ten seconds of cranio-cervical flexion at these stages should be rated on the display, as described in the methods section.

By additionally using sEMG, we were able to provide preliminary evidence that both participants with bruxism and healthy controls may have an increased activity of superficial neck flexors during incremental stages of the CCFT, which has not been found for the masseter muscles.

The CCFT is designed to test the correct activation of the DNF during five incremental stages. Ideally, the activity of superficial muscles should not be pronounced, and associated movements, such as retraction or oral parafunctions, should not occur (9). Several studies have already shown increased activity of the superficial muscles while performing the CCFT for different patient groups, such as primary headaches (5,49,50), cervicogenic headache (25,51), whiplash-associated disorders (20) or neck pain (1,11,12).

Even if the current study has only found significant differences between incremental test stages of normalized activity for the SCMs (p = 0.001) during the staged CCFT, a tendency towards increased activity could also be recognized for the masseter muscles, but remained, for both groups, below that of the SCM muscles.

The amount of EMG activity in the SCM muscles and for the bruxism group is comparable to values found in other pathologies or disorders like migraine (5,23,25) or mild neck pain (24), though it tends to be lower than in whiplash-associated disorders (20), tension-type headache (25), and moderate (24) or chronic neck pain (1,12).

So far, most clinical and laboratory studies have used the PBU for measuring or treating patients with DNF exercises as a feedback tool (2,4,17,52,53), despite evidence that its reliability has been reported to be controversial, with large measurement errors (2,10). Reasons for the limitations are partially methodological ones, as many studies have examined only healthy participants (2,53). Another issue that affects reliability might be the PBU itself and its scale, with

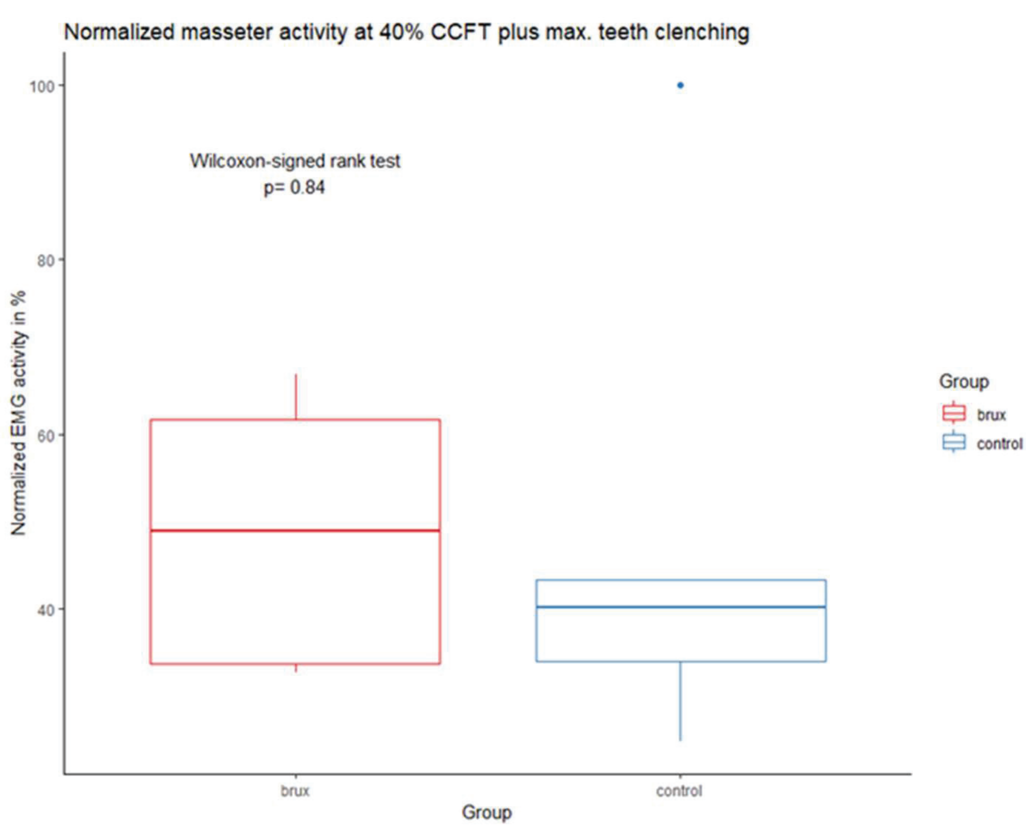

FIGURE 6 - Line plot with group mean values and standard errors of normalized sEMG activity of the masseter muscles during clenching teeth and at CCFT stage 2.

2 mmHg intervals between 20 and 30 mmHg, leaving only six values that can be achieved when including the starting value of 20 mmHg. To overcome these limitations, a "performance index" and "cumulative performance index" have additionally been established, but their use is time-consuming in clinical practice (8). Further, whether the manometer gauge of the PBU can exactly display the value someone can repeatedly and correctly hold in clinical settings is still doubtful. Uthaikhup and Jull have shown mean shortfalls of approximately 0.6 mmHg for the upper stage of 30 mmHg for elderly asymptomatic individuals (14). No study has examined potential shortfalls or the opposite overshooting, using the PBU in symptomatic populations. The NOD can overcome these shortcomings by offering a display with considerably more options for % values. Besides those percentages used in the current study, further interim values can be tested, too. By using additional settings via the NOD app, one can even add % thresholds in which a correct test needs to be performed, like a ±5% target error. At the end of the test, the App provides a "force score index," which might give an indication of the performance for that stage (see Fig. 7)

FIGURE 7 - further NOD settings and "force score index."

Unfortunately, these settings are currently not described in the NOD manual and were, at the time of the current study, also not known by the authors and accordingly not implemented in the current study. Furthermore, the scientific value of any "force score index", using a 5% or larger target error, needs to be first determined in future studies with symptomatic populations.

Despite these technical innovations, for examining the CCFT with the NOD, especially in clinical settings, without the use of EMG, therapists still need good observation and manual palpation skills to detect compensatory movements and/or superficial muscle activation, as it has been described before (1,54).

At the end of the testing procedure, a final report can be extracted from the App, making pre- to post-treatment comparisons possible, but this also needs to be scientifically evaluated first.

Clinically, bruxism participants showed a tendency for lower masseter muscle activation during maximal teeth clenching, while during other tests involving neck flexor muscle activity, the bruxism group had a tendency for more activity in the masseter muscles, which, however, also remained not significant. These results are in line with those described by Palinkas et al., who reported lower EMG activity for both masseter muscles during a maximal clenching task in cases with bruxism when compared to controls, which, similar to our results, remained not significant (39). Testa et al. used high-density sEMG in neck pain patients without TMD compared to controls and found significantly more masseter activity in the neck pain group during a maximal tooth clenching task and a changed activation pattern during submaximal clenching or chewing tasks (55). However, they did not specifically report on bruxism (55). Whether masseter activation in participants with dysfunctions in the neck and head region really differs when non-masticatory functions are tested needs to be examined in future cross-sectional or longitudinal studies.

Between-group results of the current study need to be regarded with caution, as this was not the primary objective. No specific a-priori hypothesis has been stated, and the rather small sample size may have introduced a beta error of not finding significant group differences. However, the findings of the current study can serve as preliminary evidence in planning future studies, including an appropriate sample size calculation.

Carrasco-Uribarren et al. developed another new device to measure the CCFT (56). In their study, the CCFT was measured by assessing gliding between two surfaces within their device and initiated by the occiput on the outer surface. Whether gliding might have also been initiated by neck extensors via retraction remains unknown, as no EMG measurements had been performed in parallel, and a fulcrum for cranio-cervical flexion, like it is present for the NOD or the PBU, is apparently not present in their device (56). Nevertheless, friction-free gliding of the occiput on the treatment table has also been established in the current study, though rather improvised using a plastic foil. This practical limitation has not been mentioned in clinical or laboratory studies so far, though obviously, cranio-cervical flexion might be impeded by friction between hair and the texture of various treatment tables. However, more elaborate material needs to be used in future studies.

Clinical implications

The current measurement protocol and using the NOD might be suitable for testing the CCFT in laboratory settings. In clinical settings, at least the same precautions to detect substitution strategies as have been described for using the PBU (1,20,54), need to be considered.

Limitations

Testing and data analysis were not blinded and could have introduced an observation bias. The sample size was low, as the study was primarily intended as a pilot study, exploring the feasibility of the NOD device to examine the CCFT in research studies.

Subjective examination by questionnaires was rather short and superficial. However, participants were further and objectively examined by the first author for typical signs of bruxism like hypertrophy of the masseter muscles, cheek and/or tongue impressions, abraded tooth tips or exposed tooth necks (57). Additional questioning regarding stress or depression leading to typical habits like grinding or clenching should be conducted in subsequent studies. Nevertheless, bruxism is, at least controversially discussed, for being a pain syndrome or a behavioural dysfunction only (58). Subsequent studies should screen all participants with a questionnaire about neck complaints, e.g., by using the neck disability index (NDI) to narrow down the probability of an impaired CCFT. An independent evaluation by dentists may also be performed in larger subsequent studies, but was disregarded for this pilot study.

Further evaluation of TMJ and upper cervical spine mobility, including pain responses to passive examination, can help to better identify bruxism patients who may suffer from comorbidities.

Even though none of the participants complained that the screen was too far away, a tripod is not ideal for use in future clinical and laboratory practice. A mobile stand that can be attached to a treatment plinth should be tested in future studies.

Conclusion

The staged CCFT, by using the current measurement protocol and the NOD device, might be a useful alternative to the currently used PBU in laboratory and clinical settings. The "force index score", provided by the NOD, might be a useful adaptation to the current protocol, but needs to be examined for its scientific value in future studies. Patients with subjective and objective signs of bruxism showed similar and increasing activity of the sternocleidomastoideus and masseter muscles, like bruxism-free control subjects.

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Author's contributor role

MJ conceived the study and designed the study protocol; was responsible for recruiting and examining participants in the movement laboratory, and writing the manuscript. AZ helped measure, process, and analyze the EMG data. MJE contributed to the design, helped during the measurements, analyzed the data, and wrote the manuscript. All authors read and approved the final manuscript. All authors agreed to be accountable for all aspects of the work, ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Data availability statement

Data is available by reasonable request.

Disclosures

Conflict of interest: The authors declare no conflict of interest.

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