


Coherence of jaw and neck muscle activity during sleep bruxism

Simone Gouw^{1,2}  | Angela Frowein¹ | Carlijn Braem^{3,4} | Anton de Wijer^{1,2} | Nico H. J. Creugers¹ | Jaco W. Pasman³ | Jonne Doorduyn³ | Stanimira I. Kalaykova¹

¹Department of Oral Function and Prosthetic Dentistry, College of Dental Sciences, Radboud University Medical Center, Nijmegen, The Netherlands

²Academic Institute, Utrecht, The Netherlands

³Department of Neurology, Radboud University Medical Center, Nijmegen, The Netherlands

⁴Technical Medicine, University of Twente, Enschede, The Netherlands

Correspondence

Simone Gouw, Radboud University Medical Center, College of Dental Sciences, in-house postal number 309, PO Box 9101, 6500 HB Nijmegen, The Netherlands.

Email: Simone.Gouw@radboudumc.nl

Abstract

Background: Studies have shown co-contraction of jaw and neck muscles in healthy subjects during (sub) maximum voluntary jaw clenching, indicating functional interrelation between these muscles during awake bruxism. So far, coherence of jaw and neck muscles has not been evaluated during either awake or sleep bruxism.

Objective: The objective of this study was to evaluate the coherence between jaw and neck muscle activity during sleep bruxism.

Methods: In a cross-sectional observational design, the electromyographic activity of jaw (masseter, temporalis) and neck (sternocleidomastoid, trapezius) muscles in individuals with “definite” sleep bruxism was measured using ambulatory polysomnography (PSG). Coherence for masseter-temporalis, masseter-sternocleidomastoid and masseter-trapezius was measured during phasic and mixed rhythmic masticatory muscle activity episodes using coherence-analysing software. Outcome measures were as follows: presence or absence of significant coherence per episode (in percentages), frequency of peak coherence (FPC) per episode and sleep stage.

Results: A total of 632 episodes within 16 PSGs of eight individuals were analysed. Significant coherence was found between the jaw and neck muscles in 84.9% of the episodes. FPCs of masseter-temporalis were significantly positively correlated with those of masseter-sternocleidomastoid or masseter-trapezius ($P < .001$). Sleep stages did not significantly influence coherence of these muscular couples.

Conclusion: During sleep bruxism, jaw and neck muscle activation is significantly coherent. Coherence occurs independently of sleep stage. These results support the hypothesis of bruxism being a centrally regulated phenomenon.

KEYWORDS

bruxism, central nervous system, electromyography, masticatory muscles, polysomnography

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1 | BACKGROUND

Sleep bruxism (SB), a masticatory muscle activity during sleep that is characterised as rhythmic (phasic) or non-rhythmic (tonic),¹ is a common condition in the general adult population, with an estimated prevalence of 5.5%-12.8%.^{2,3} It can lead to several symptoms, such as tooth wear and pain or dysfunction of the masticatory system.⁴

Sleep bruxism has been increasingly associated with central instead of peripheral mechanisms.^{5,6} Voluntary rhythmic masticatory muscle activity, like mastication, is controlled by a central pattern generator (CPG) in the brainstem.⁷⁻⁹ During mastication, this rhythmic opening and closing of the jaw is well coordinated by masticatory as well as neck muscles.¹⁰ During sleep, similar rhythmic masticatory muscle activity (RMMA) can be seen in healthy subjects as part of normal sleep microarousals,¹¹ but with higher prevalence in patients with SB.¹² RMMA can be divided into phasic activity (such as tooth grinding), tonic activity (such as clenching) and mixed activity (combination of phasic and tonic) and could be influenced in frequency, duration and intensity by multiple endogenous and exogenous factors, such as psychological and lifestyle factors or multimorbidity.¹¹ This is in line with the multifactorial aetiology of SB.^{1,5} The current hypothesis is that a central generator, or a common circuit, in the brainstem is responsible for the control of jaw and neck muscles.⁷ Taking into consideration this generator model, it can be expected that jaw and neck muscle activity during an RMMA episode in SB has a high level of intermuscular co-contraction.

For voluntary biting tasks, the co-contraction of masticatory and neck muscles has already been studied. Giannakopoulos et al^{13,14,16} and Häggman-Henrikson et al¹⁵ have found that there is low-to-moderate co-contraction of the masticatory and neck muscles during (sub) maximum voluntary clenching (MVC) in healthy subjects. This co-contraction is seen in different body positions,^{14,16} during different bite forces^{13,16} and during the chewing of test foods of different sizes and textures.¹⁵

Muscle co-contraction, a phenomenon in which a muscle is activated co-ordinately with another muscle, is purely observational and therefore does not imply a common generator per se.¹⁷ A more accurate analysis for detecting a common generator would be to perform coherence analysis of the electromyography (EMG) between different muscles.¹⁸ Coherence analysis examines the relationship of two signals in the frequency domain and is useful in oscillatory coupling of motor elements,¹⁹ such as muscle activities during phasic episodes and phasic parts of mixed episodes in SB. So far, neither co-contraction nor coherence of masticatory and neck muscles during SB events has been studied.

Against this background, the study reported on here aimed to evaluate the coherence between masticatory muscles and neck muscles during SB. We hypothesised that jaw and neck muscle activity during RMMA episodes in SB is significantly coherent. Coherence between these muscles could possibly support the concept of bruxism as a centrally regulated phenomenon.

2 | METHODS

2.1 | Study design

The study was designed as a cross-sectional observational study of bruxism episodes extracted from the polysomnography (PSG) recordings of individuals with "definite" SB as defined by Lobbezoo et al.¹

2.2 | Study population

The PSG recordings of eight individuals of at least 18 years of age without symptoms such as oro-facial pain were selected. PSG recordings that did not meet the SB criteria for "definite" bruxism^{1,20} were eliminated (ie "definite" SB is confirmed in the presence of more than four bruxism episodes per hour of sleep or more than 25 bruxism bursts per hour of sleep). Individuals with neurological, psychiatric or systemic disorders, participants using medication with a described influence on sleep structure or SB, and those receiving treatment for bruxism or its consequences, including occlusal splint therapy, were excluded. Participants were recruited through advertisements and announcements at the Universities and University Medical Centres of Utrecht and Amersfoort and in the waiting rooms of several general practitioners, dentists and physical therapists. All participants signed an informed consent. Data were collected during a one and a half year period. The study was conducted in accordance with the Helsinki guidelines and the STROBE guidelines and was independently reviewed and approved by the local ethics committee (NL46301.091.13).

2.3 | Polysomnography

In this study, polysomnography (PSG), which consists of electroencephalography (EEG), electrooculography (EOG), EMG and simultaneous audio-video recordings, was used. All PSG recordings were executed ambulatory without audio and video registration at the participants' homes. The participants were recorded for four nights.

EEG, EOG and EMG channels were used in accordance with the recommendations of the American Association of Sleep Medicine.²¹ EEG electrode position was determined in line with the International 10-20 System.²² EMG signals of the jaw and neck muscles were recorded using surface EMG electrodes (reusable gold cup electrodes, Embla). A total of 16 electrodes were positioned on the masseter, anterior temporal, sternocleidomastoid and superior trapezius muscles. On each muscle, two single electrodes were placed; one on the muscle belly and one on a random location, preferably a bone structure outside the muscle area, for reference. The four muscles on both left and right side were measured. The electrodes were connected to the Embla[®] titanium (Embla Systems), a wireless 34-channel amplifier. Each EMG signal was recorded at 256 Hz and was adequately filtered (hardware; 50 Hz notch; 3 Hz high pass; 100 Hz low pass).

2.4 | Data analysis

The PSG recordings were assessed in RemLogic-E™ (Embla) by an experienced independent sleep technician. First, the EEG, EOG and EMG recordings of the masticatory muscles were visually assessed for artefacts. If no accurate visual evaluation was possible due to artefacts or noise, a recording was excluded. In the recordings that were included, sleep stages were marked on the EEG and EOG traces.^{21,23,24} Subsequently, the SB bursts and episodes were marked on EMG traces of masseter and temporal muscles (Figure 1). This marking was based on established scoring criteria for SB²¹ (Table 1). Secondly, SB was labelled as “definite” SB when the diagnostic criteria^{19,25,26} (>four bruxism episodes per hour of sleep or >25 bruxism bursts per hour of sleep) were met.

Next, the EMG traces of the neck muscles were evaluated for artefacts. The registrations were excluded in the case of a corrupt file, in the case of early termination of the registration or where the registration contained a large amount of noise during visual assessment.

Subsequently, to the episodes of masticatory muscle activity, additional criteria were applied in order to detect the episodes that qualified for coherence analysis. First, tonic episodes were excluded because coherence can only be analysed for rhythmic muscle activity. Second, episodes that were longer than 25 seconds, which meant that they exceeded the coherence analysis window length, were excluded. A fixed window length was determined in order to include only windows of standardised length. The window length was set at 25 seconds as approximately 95% of the SB episodes were less than or equal to 25 seconds. If two episodes were positioned within the same window length of 25 seconds, the first episode was excluded.

For the final sample of episodes, coherence was analysed for six jaw-neck muscle couples: masseter-temporalis, masseter-sternocleidomastoid and masseter-trapezius for both left and right. The used coherence analysis estimates the power of a signal at different frequencies and is based on the concept of converting a signal from the time domain to the frequency domain.²⁷ The current programmes used to estimate coherence require long-term rhythmic activities, such as those present in tremors or chewing movements.^{10,17,28} However, bruxism involves short-term episodes that alternate uncontrollably in the form of tonic, phasic and/or mixed activation.²⁹ For this reason, a modified analysis programme for coherence analysis of phasic and mixed episodes during SB based in the widely used Welch's method²⁷ was prepared by the Department of Neurology of the Radboudumc and used in the present study. A description of the algorithm can be found in Appendix S1.

2.5 | Statistical analysis

The sample size is determined based on the number of RMMA episodes used in previous co-activation studies of the masticatory and neck muscles and set at 50 episodes.¹³⁻¹⁵

The significance threshold for the level of coherence was determined by our coherence-analysing programme with the following formula:

$$R = 1 - (1 - \alpha)^{1/(K - 1)} = R = 1 - (1 - 0.95)^{1/(5 - 1)} = 1 - (0.05)^{1/4} = 0.53.$$

with α displaying the detection threshold ($\alpha = 0.95$) and K the number of fragments used for the coherence estimation. K is set at 5 to divide each 25-second window into five fragments of 5 seconds.

Any coherence value of below 0.53 is considered not significant and is denoted as 0; significant coherence values are indicated as 1. The frequency of peak coherence (FPC) of coherent episodes was then calculated. This is the frequency where the coherence is at its peak. If several FPCs exceed the significance threshold, the highest FPC value is noted (Figure 2).

Pearson correlation coefficients were used to express the correlation between the FPCs of masseter-temporalis and the FPCs of masseter-sternocleidomastoid or masseter-trapezius. Analyses were performed using the IBM SPSS Statistics software (version 24.0).

When comparing the difference in coherence between sleeping phases, it must be considered that data are collected in clusters, that is eight people give data for one, two or three nights. This results in 16 clusters. Ignoring this would lead to an overestimate of the precision of the study, while comparing percentages. As a remedy, we applied 1000-fold bootstrapping, with those clusters as sampling unit. After that, 95% confidence intervals were created by looking at the 2.5 and 97.5 percentiles of the bootstrapped differences in percentages. The bootstrapping was achieved using R software, version 3.4.0.

3 | RESULTS

A total of 32 PSG recordings of eight participants (four male and four female, mean age (SD) 35.9 (7.4) years) with “definite” SB were obtained. Because of artefacts, 16 PSG recordings were excluded. A total of 632 bruxism episodes qualified for coherence analysis.

3.1 | Coherence rates per muscular couple

Significant coherence was found in 88.7% of the examined episodes of all included PSGs and all three muscular couples, that is masseter-temporalis, masseter-sternocleidomastoid and masseter-trapezius. Focussing on the episodes of the jaw-neck muscular couples, that is masseter-sternocleidomastoid and masseter-trapezius, a significant coherence of 84.9% was found. Table 2 shows the percentages of episodes with significant coherence, per participant, per night and per left and right muscular couple. The mean percentage for masseter-temporalis left and right was 95.8% (ranging from 74.2% to 100%), for masseter-sternocleidomastoid left and right 85.9% (ranging from 52.5% to 100%) and for masseter-trapezius left and right 81.8% (ranging from 39.6% to 100%).

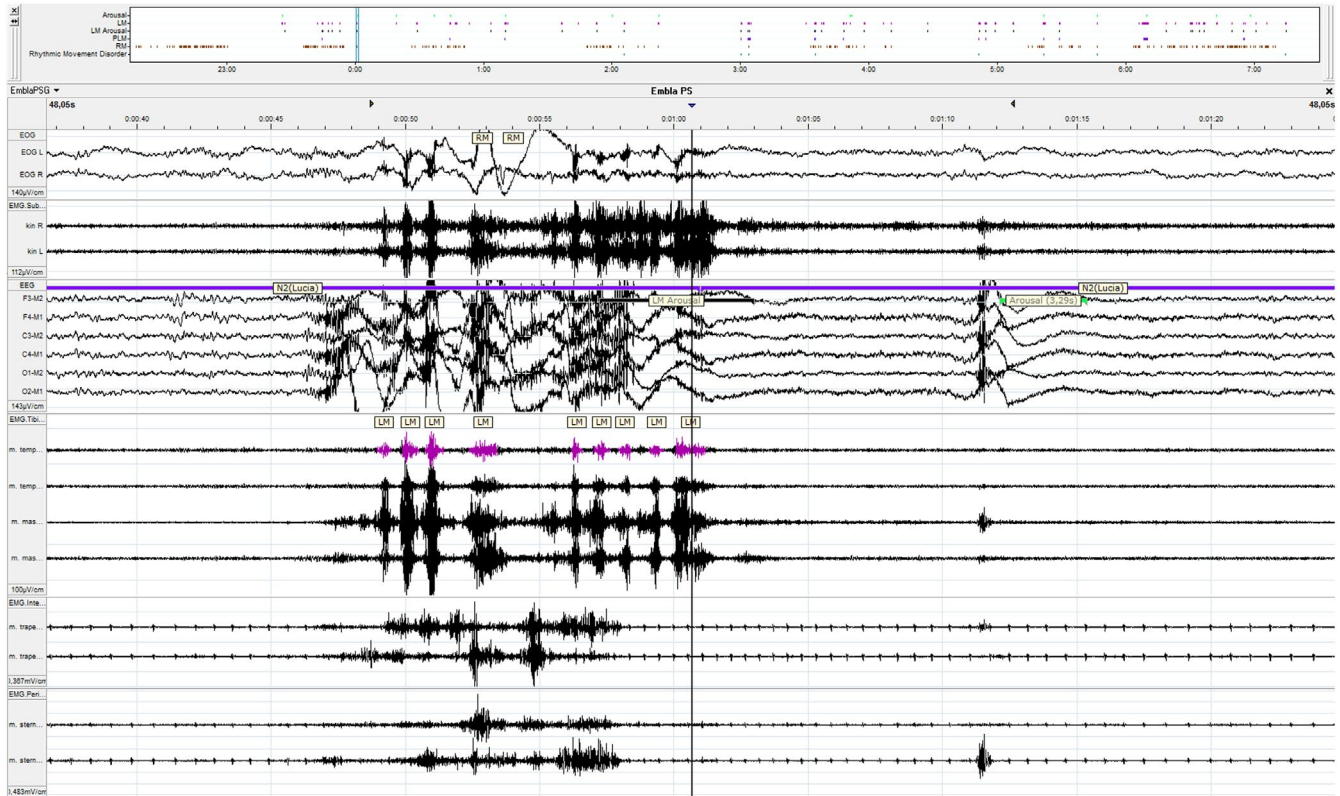


FIGURE 1 Example of the raw data covering the EOG, EEG and EMG traces with the marking of a bruxism episode on the EMG traces of the different muscles in the RemLogic-E software [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Scoring criteria for sleep bruxism according to American Academy of Sleep Medicine (AASM, 2001)²¹

The amplitude of the EMG activity must be at least twice the amplitude of the background muscle activity
Burst: Increase in muscle activity of masseter or temporalis muscle with a duration of 0.25-2 s
Episode: At least three consecutive bursts or one burst with a minimum duration of >2 s
A minimum of 3 s of stable muscle activity must be recorded before a new episode of bursts may be counted

3.2 | Frequency of peak coherence (FPC)

The FPC median of all muscular couples in total was 1.21 Hz, or 72.6 per minute. The FPC median per muscular couple is displayed in Table 3. A significant positive correlation ($r = .203, P < .001$) was found between the FPCs of masseter-temporalis and FPCs of masseter-sternocleidomastoid. Also, the correlation between the FPCs of masseter-temporalis and FPCs of masseter-trapezius was found to be significant ($r = .288, P < .001$).

3.3 | Coherence per sleep stage comparison

In Table 4, the means and 95% confidence interval (CI) of the differences in coherence per sleep stage are shown. For example, the

difference in coherence percentage between masseter and sternocleidomastoid muscle, when comparing REM sleep and sleep stage 1, is $-2.4 [-7.0, 2.2]$. In only 4 of the 42 comparisons, the 95% CI does not include the null value and were therefore statistically significant.

4 | DISCUSSION

To our knowledge, the present study is the first to evaluate coherence between the masticatory and neck muscles during SB. Our main finding is significant coherence between masticatory and neck muscle activity in 84.9% of all examined SB episodes. Furthermore, we showed that there was a significant correlation between the FPCs of masticatory and neck muscle couples. No significant correlation between sleep stage and coherence of the muscular couples was found.

In previous studies on the topic co-activation with jaw muscles, different neck muscles are measured, such as the trapezius, sternocleidomastoid, levator scapula and the deep dorsal neck muscles. In this study, we used the trapezius and the sternocleidomastoid for two reasons. First, we are interested in these muscles from a clinical perspective. In daily physical therapy, practice complaints such as muscle tension/stiffness of the jaw-closing muscles and the trapezius and sternocleidomastoid are often co-exist. Second, EMG of these muscles can be obtained by surface electrodes, while the deep dorsal neck muscles can only be measured by needle electrodes which are not possible for sleeping participants.

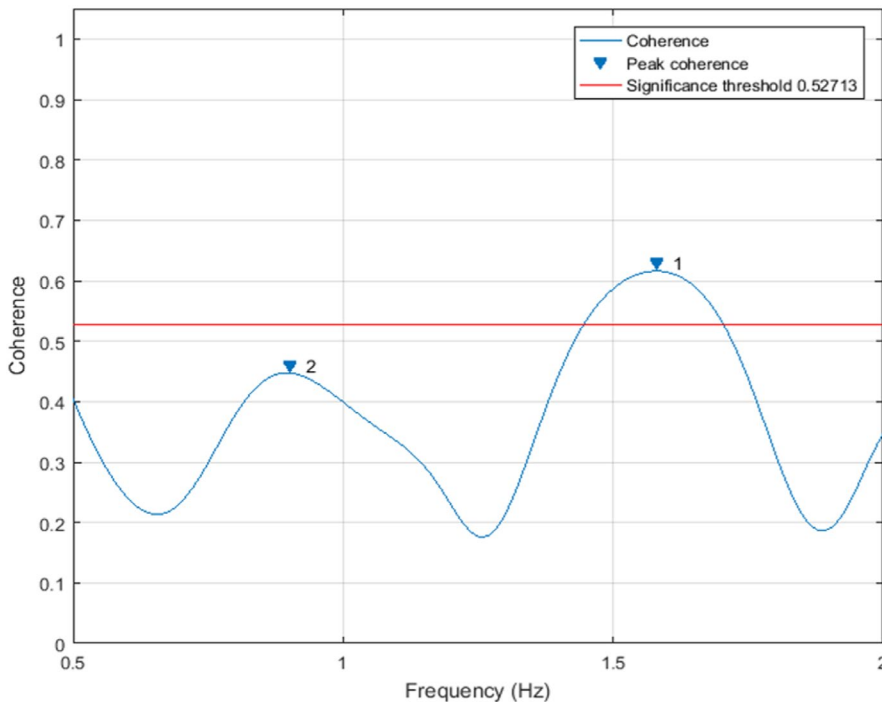


FIGURE 2 Example of a coherence chart of one episode of the jaw-neck muscle couple masseter-sternocleidomastoid left. The degree of coherence is plotted against the frequency in Hz. In this example, there is significant coherence with a frequency peak of 1.58 Hz [Colour figure can be viewed at wileyonlinelibrary.com]

4.1 | Coherence between masticatory muscles and neck muscles

As expected, the masseter-temporalis couple achieved a high degree of coherence (95.8%), because these muscles activate simultaneously during jaw activities such as mastication.³⁰ A noteworthy result was the difference in coherence between the muscular couples left and right, particularly for masseter-temporalis (left 100.0% and right 91.6%) and even more for masseter-sternocleidomastoid (left 94.5% and right 78.3%). So, for example for P1N1 in Table 2, in 95/100 of the left masseter activities, the left sternocleidomastoid also activated, while for the right side only 57/100 sternocleidomastoid activities were present. The authors could not explain this difference.

The FPC median of all muscular couples was 1.2 Hz. This means that the mean frequency of all episodes was at 1.2 Hz, which is consistent with the frequency of RMMA.³¹ Although weak, the degree of correlation of the FPC of masseter-temporalis with those of masseter-sternocleidomastoid and masseter-trapezius, respectively, was found to be significant. This means that an increase of the FPC of masseter-temporalis is related to a proportional increase of the FPCs of masseter-sternocleidomastoid and masseter-trapezius, and vice versa. The low correlation could mean that there are other influences. One aspect that should be considered as a confound is the somatosensory input associated with RMMA, for example input from periodontal mechanoreceptors. Research has shown that these receptors have a powerful influence on the central pattern generator.³² Therefore, also receptors of the somatosensory system could be involved in the coherence observed in this study.

This correlation corroborates the concept of a central regulation of SB. Bruxism is considered as an important phenomenon in physical therapy, but it might not be restricted to the masticatory system.

It could be that areas beyond the masticatory muscles, such as the neck muscles, are also influenced by the same CPG or have a common higher central regulatory circuit. Also, in line with RMMA as part of sleep-arousal activity,^{33,34} it is plausible that sleep arousals “excite” multiple systems, not solely the bruxism generator. This indicates that sleep bruxism is not a pathophysiological entity by itself, but rather one of the consequences of complex neurophysiological interactions within the central nervous system.

Although this present study used muscle coherence as outcome measure, studies using muscle co-activation as outcome measure support the current findings on masticatory and neck muscles.^{10,13-15} However, several methodological issues make the current findings not directly comparable with these co-activation studies. We evaluated SB, while in other studies only (sub) maximum voluntary clenching/biting tasks were examined. These tasks are performed mostly with tonic muscle activation, while in the present study rhythmic muscle activation was evaluated. To our knowledge, this study is the first to analyse coherence. In our study, coherence occurred independently of the sleep stage.

4.2 | Methodological considerations

A strong feature of this study was the large number of bruxism episodes analysed (in total 632 compared to the required minimum of 50, see Statistical analysis). This provided sufficient power for data analysis at the episode level, in line with our research aim. Furthermore, ambulatory PSG provided the opportunity to measure participants in their natural sleep environment. Because no audio or video data were collected, there might be a risk of overestimation of the number of SB events.¹ Nevertheless, the diagnostic accuracy of

TABLE 2 Percentages of significant occurrences of at least 0.53 coherence levels per participant, per night, per left and right muscular couple and in total

	Epi	MTP left (%)	MSCM left (%)	MTZ left (%)	MTP right (%)	MSCM right (%)	MTZ right (%)	Total (%)
P1N1	21	100.0	95.2	90.5	76.2	57.1	61.9	80.2
P1N2	31	100.0	87.1	80.6	74.2	64.5	67.7	79.0
P1N3	23	100.0	95.7	73.9	82.6	82.6	82.6	86.2
Total P1	75	100.0	92.0	81.3	77.3	68.0	70.7	81.6
P2N1	30	100.0	100.0	100.0	100.0	86.7	83.3	95.0
P2N2	38	100.0	97.4	84.2	97.4	86.8	71.1	89.5
P2N3	44	100.0	95.5	86.4	97.7	72.7	84.1	89.4
Total P2	112	100.0	97.3	89.3	98.2	81.3	79.5	90.9
P3N1	45	100.0	97.8	75.6	95.6	95.6	95.6	93.3
P4N1	53	100.0	96.2	54.7	90.6	88.7	88.7	86.5
P4N2	48	100.0	89.6	39.6	95.8	77.1	89.6	82.0
Total P4	101	100.0	93.1	47.5	93.1	83.2	89.1	84.3
P5N1	27	100.0	81.5	63.0	92.6	77.8	81.5	82.7
P5N2	21	100.0	66.7	61.9	85.7	61.9	81.0	76.2
Total P5	48	100.0	75.0	62.5	89.6	70.8	81.3	79.9
P6N1	53	100.0	96.2	100.0	96.2	94.3	92.5	96.5
P6N2	53	100.0	100.0	98.1	98.1	92.5	92.5	96.9
Total P6	106	100.0	98.1	99.1	97.2	92.5	92.5	96.5
P7N1	40	100.0	97.5	97.5	92.5	52.5	82.5	87.1
P7N2	54	100.0	100.0	96.3	90.7	74.1	83.3	90.7
Total P7	94	100.0	98.9	96.8	91.5	64.9	83.0	89.2
P8N1	51	100.0	100.0	84.3	100.0	88.2	92.2	94.1
Total	632	100	94.0	79.5	92.8	80.5	85.5	88.7
Total (excl. MTP)			94.0	79.5		80.5	85.5	84.9
SD		0.0	8.2	17.4	7.2	11.5	8.3	5.6

Abbreviations: Epi, number of episodes; MSCM, masseter-sternocleidomastoid couple; MTP, masseter-temporalis couple; MTZ, masseter-trapezius couple; N, recording night; P, participant.

TABLE 3 FPC median in Hz per muscular couple

	MTP left	MSCM left	MTZ left	MTP right	MSCM right	MTZ right	Total
Total	1.10	1.18	1.21	1.26	1.21	1.24	1.21
Total (excl. MTP)		1.18	1.21		1.21	1.24	1.21

Abbreviations: MSCM, masseter-sternocleidomastoid couple; MTP, masseter-temporalis couple; MTZ, masseter-trapezius couple.

ambulant PSG to detect “definite” SB without such input is considered good.^{25,26}

The use of a modified algorithm for coherence analysis of two signals leads to several technical restrictions. This algorithm uses a new application of an existing method in the time-frequency domain, Welch's method.²⁷ By changing the domain, the restrictions on the short episode length are solved. The correlation between signals is estimated on the basis of a time-frequency domain. In previous studies, the time-frequency domain was used for automatic detection of RMMA³⁵ and for evaluation of RMMA in natural chewing and during sleep.²⁸ With the modified algorithm, coherence can be estimated for the first time for phasic and mixed RMMA episodes during

SB. In order to use the algorithm for the present study, several additional selection criteria had to be considered. Especially, the window length is important for the significance threshold, and therefore, the FPC, the determination of this length, was crucial for the results of this study. A window length of 25 seconds was determined by the finding that about 95% of the SB episodes had a length of less than or equal to 25 seconds.

Some traces of the sternocleidomastoid and trapezius muscle in some PSG recordings showed noise that reflected electrocardiac activity. The inclusion of a heart rate frequency noise in a few of the sternocleidomastoid and trapezius EMG recordings might have influenced outcomes of coherence analysis, however most probably

TABLE 4 Mean and 95% confidence interval of the difference in coherence percentage per sleep stage

	Stage 0vs1 (%)	Stage 0vs2 (%)	Stage 0vs3 (%)	Stage 1vs2 (%)	Stage 1vs3 (%)	Stage 2vs3 (%)
MTP left	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)
MSCM left	-2.4 (-7.0, 2.2)	-1.0 (-4.7, 3.2)	1.2 (-2.8, 5.8)	1.4 (-2.9, 6.2)	3.6 (-1.9, 9.5)	2.1 (-1.4, 5.4)
MTZ left	-7.4 (-21.8, 5.0)	-4.7 (-10.7, 3.5)	6.6 (-0.2, 14.3)	2.7 (-9.9, 18.0)	14.0 (1.2, 29.4)	11.3 (2.5, 20.1)
MTP right	-6.6 (-12.5, -1.6)	-0.4 (-7.3, 7.2)	-4.2 (-10.1, 1.8)	6.2 (0.3, 12.9)	2.4 (-1.1, 6.1)	-3.8 (-9.7, 1.3)
MSCM right	6.3 (-6.6, 15.9)	-0.5 (-9.3, 9.2)	2.4 (-5.5, 9.3)	-6.8 (-18.7, 4.5)	-3.8 (-15.1, 9.7)	3.0 (-5.8, 10.9)
MTZ right	-1.4 (-10.6, 7.7)	-2.1 (-8.8, 3.5)	0.7 (-6.5, 6.8)	-0.7 (-11.5, 9.1)	2.1 (-7.4, 11.5)	2.8 (-2.5, 8.5)
MASL-MASR	-3.3 (-9.1, 2.2)	1.2 (-3.3, 6.1)	0.2 (-3.4, 3.8)	4.5 (-1.2, 9.8)	3.5 (-2.0, 8.4)	-1.0 (-4.4, 2.6)

Note: Bold data = significant, a positive difference means that the percentage is in favour of the lower sleep stage, that is "lower sleep stage" [x] percentage more coherence than "higher sleep stage".

Abbreviations: MASL, masseter left; MASR, masseter right; MSCM, masseter-sternocleidomastoid couple; MTP, masseter-temporalis couple; MTZ, masseter-trapezius couple; sleep stage 0, REM sleep; sleep stage 1, light sleep; sleep stage 2, light sleep; sleep stage 3, deep sleep.

by underestimating rather than overestimating the high coherence found in our study, because the noise was only seen on neck muscle EMG and not jaw muscle EMG.

The authors realise that in this study, no control measurements, that is EMG of a distant muscle, were performed in order to show the non-coherence between a remote muscle and the jaw and neck muscles. In sleep medicine, it is common to include EMG of the leg muscles as a control for extensive polysomnography.²⁴ However, SB and periodic limb movements commonly concur during sleep, especially in relation to the occurrence of EEG arousals.³⁶ Therefore, using the EMG of the leg muscles as a control would not suffice.

4.3 | Clinical relevance

There is a tendency in clinical practice involving oro-facial complaints to examine the upper body quadrant as a total neuromusculoskeletal system instead of examining single systems, such as the jaw or the neck. The anatomical, physiological and biomechanical association between the musculoskeletal system of the head, neck and shoulder region, or the craniocervical-mandibular system, has already been studied extensively in the awake state.^{37,38} The confirmed coherence between masticatory and neck muscles during SB corroborates the concept of a broader neuromuscular interaction. The high coherence rate might be related to the frequent observation of comorbid musculoskeletal jaw and neck complaints.³⁹ However, the relationship between bruxism and myofascial temporomandibular pain is still under debate.^{40,41} Moreover, EMG is a measure of muscle activity, not of muscle force. Since voluntary submaximal clenching performed in the contraction range, as may be expected during actual jaw clenching,^{12,42} leads only to very low-level co-activation (ca. 2%-14% MVC) of the neck muscles,⁴³ it is not plausible that masticatory muscle activity during SB alone will lead to painful overloading of the neck muscles. However, it is well established in occupational physiology that repetitive, long-lasting, low-intensity muscle loading, which selectively and continuously activates small type I motor units (Cinderella hypothesis), may lead to muscle pain

due to metabolic exhaustion and damage of single motor units.⁴⁴ It is conceivable that a similar mechanism may also occur within masticatory muscles of patients during repetitive motor activity, such as bruxism. Moreover, in the presence of pain, several other factors are involved with consequences for sensorimotor functions, such as increased muscle activity and altered coordination, of the masticatory and cervical region.^{41,45,46} Central pain mechanisms, such as central sensitisation, may also be involved in comorbid masticatory and craniocervical pain.⁴⁷ It is well known that pain can be generated and maintained or suppressed by changes in the central nervous system, creating a complete mismatch between peripheral nociceptive drive and perceived pain. For the upper body quadrant, the trigeminocervical nucleus is an important link for referred pain. Convergence between the trigeminal nerve and the C1, 2, 3 nerves can lead to pain perceived at a location other than the site of the painful stimulus. Therefore, pain in the neck region can actually be a representation of a pain source in the masticatory system.

For further research on coherence between masticatory and neck muscles during SB, two recommendations can be made. First, from a methodological perspective, additional audio and video registration as well as sleep position registration could improve the diagnostic accuracy of SB episodes. Possible influence of head or body movements, activation of other muscles and sleep position could be evaluated, and non-bruxism-related episodes (such as swallowing or coughing) could be excluded. Secondly, from a pathophysiological perspective, the coherence between masticatory and neck muscles during SB could be evaluated in a study population of pain patients. The presence of pain could influence the sensorimotor system and thereby affect coherence. Further investigation may give insight into the interaction between pain, bruxism and sleep in the craniocervical-mandibular system.

In conclusion, the present study confirms the hypothesis that during phasic and mixed SB episodes coherent muscle activation of jaw and neck muscles is present. Coherence occurs independently of sleep stage. This study emphasises the need to examine the upper body quadrant as a total neuromusculoskeletal system instead of examining single systems. Moreover, it supports the current concept of bruxism as a centrally regulated phenomenon.

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ORCID

Simone Gouw  <https://orcid.org/0000-0002-7873-7673>

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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