Temporal association between sleep apnea–hypopnea and sleep bruxism events

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SUMMARY

There is some evidence suggesting that obstructive sleep apnea–hypopnea syndrome is concomitant with sleep bruxism. The aim of this study was to investigate the temporal association between sleep apnea–hypopnea events and sleep bruxism events. In an open observational study, data were gathered from 10 male subjects with confirmed obstructive sleep apnea–hypopnea syndrome and concomitant sleep bruxism. Polysomnography and audio-video recordings were performed for 1 night in a sleep laboratory. Breathing, brain, heart and masticatory muscle activity signals were analysed to quantify sleep and sleep stage duration, and number and temporal distribution of apnea–hypopnea events and sleep bruxism events. Apnea–hypopnea events were collected within a 5-min time window before and after sleep bruxism events, with the sleep bruxism events as the pivotal reference point. Two temporal patterns were analysed: (i) the interval between apnea–hypopnea events termination and sleep bruxism events onset, called T1; and (ii) the interval between sleep bruxism events termination and apnea–hypopnea events onset, called T2. Of the intervals between sleep bruxism events and the nearest apnea–hypopnea event, 80.5% were scored within 5 min. Most intervals were distributed within a period of <30 s, with peak at 0–10 s. The T1 interval had a mean length of 33.4 s and was significantly shorter than the T2 interval (64.0 s; $P < 0.05$). Significantly more sleep bruxism events were scored in association with the T1 than the T2 pattern ($P < 0.05$). Thus, in patients with concomitant obstructive sleep apnea–hypopnea syndrome and sleep bruxism, most sleep bruxism events occurred after sleep apnea–hypopnea events, suggesting that sleep bruxism events occurring close to sleep apnea–hypopnea events is a secondary form of sleep bruxism.

INTRODUCTION

Sleep bruxism (SB) is a common sleep-related movement disorder characterized by clenching or grinding of the jaws or teeth (American Academy of Sleep Medicine, 2005). In a new, revisited definition, bruxism is a repetitive jaw-muscle activity characterized by clenching or grinding of the teeth and/or bracing or thrusting of the mandible. Bruxism has two distinct circadian manifestations: it can occur during sleep (SB) or during wakefulness (awake bruxism) (Lobbezoo *et al.*, 2013). Clinical consequences associated with SB include damage to the teeth and dental prostheses, possible temporomandibular disorder exacerbation, and headache (Camparis and Siqueira, 2006; Johansson *et al.*, 2011; Lobbezoo and Lavigne, 1997; Pergamalian *et al.*, 2003). Cumulative evidence supports that the genesis of some

SB-related motor activity is secondary to autonomic and central nervous system co-activation. However, because approximately 20% of SB motor event genesis has not yet been clearly explained, this explanation is not exclusive (Carra *et al.*, 2012b; Lavigne *et al.*, 2011). SB may also occur concomitantly or secondary to other sleep disorders (Carra *et al.*, 2012a,b; Kato *et al.*, 2013a). Obstructive sleep apnea–hypopnea syndrome (OSAHS) may be a sleep disorder that is concomitant with SB (Inoko *et al.*, 2004; Kato *et al.*, 2013b; Okeson *et al.*, 1991; Phillips *et al.*, 1986; Sjöholm *et al.*, 2000).

An epidemiological study suggested that patients with sleep-disordered breathing had higher risk for SB, with a 1.8 odds ratio (Ohayon *et al.*, 2001). However, despite a low but significant association between SB and OSAHS, the cross-sectional telephone survey design did not allow concluding causality between the two conditions. Based on polysomnographic (PSG) jaw muscle recordings in patients with OSAHS, masticatory muscle activity tended to occur around the termination of apnea or hypopnea events (AHEs) (Inoko *et al.*, 2004; Okeson *et al.*, 1991; Phillips *et al.*, 1986; Sjöholm *et al.*, 2000). However, these studies used electromyography (EMG) to measure masseter and temporalis muscle activity, a method that does not allow determining the specificity of jaw muscle activity to SB, which is typically identified by scoring rhythmic masticatory muscle activity (RMMA) (Lavigne *et al.*, 1996, 2011). Other types of non-specific EMG activity could occur in the masticatory muscles during sleep, including swallowing, coughing or face rubbing (Dutra *et al.*, 2009; Yamaguchi *et al.*, 2012). To assess SB events (SBEs) with higher specificity, PSG with audio-video (PSG-AV) recordings is the gold standard (American Academy of Sleep Medicine, 2005). In a recent study on patients with OSAHS without SB diagnosis, non-specific muscular activity, discriminated from SB using PSG-AV, tended to occur at OSAHS event termination (Kato *et al.*, 2013c). In the above-mentioned studies, except for the latter study on patients with OSAHS without SB diagnosis, simultaneous AV recording was not performed, and masticatory muscle activity around the termination of apnea or hypopnea events was not definitively identified as SBE.

A case report (Oksenberg and Arons, 2002) showed that most tooth grinding events appeared at the termination of AHEs. We presented an OSAHS case with severe SB that supported a potential temporal association between AHEs and SBEs (Saito *et al.*, 2011). However, these studies were case reports, with limited assessment of temporal and causal associations between OSAHS and SB.

It was further suggested that little or no solid temporal relationship is present between OSAHS and SB (Okeson *et al.*, 1991; Sjöholm *et al.*, 2000). Few differences were found in the number of SB-scored events in subjects with sleep-disordered breathing compared with controls (Okeson *et al.*, 1991). Masseter muscle events were associated with AHE termination for only 3.5–14.4% of scored events. Moreover, rhythmic jaw movement, a proxy for RMMA, was rarely directly associated with apnea events (Sjöholm *et al.*, 2000).

Given these contradictory findings, we performed PSG-AV analysis to investigate for the presence of a temporal association between SBEs and AHEs in patients with concomitant OSAHS and SB. If SBEs occur mainly after AHEs, this would support that SBEs in patients with OSAHS may be a secondary form of SB.

MATERIALS AND METHODS

Subject characteristics and study design

Patients with OSAHS with suspected SB were selected based on: (i) reports of tooth-grinding sounds or tooth clenching awareness during sleep; (ii) jaw muscle discomfort, fatigue, or pain and jaw lock upon awaking; and (iii) clinician-observed tooth wear. Subjects visited a sleep clinic for an examination and to confirm OSAHS diagnosis. Subjects were included if both OSAHS and SB were diagnosed. Subjects were excluded for major neurological, psychiatric or sleep disorders (e.g. rapid eye movement behaviour disorder, periodic leg movements during sleep); psychoactive medication intake, which may increase the risk of limb or orofacial activity; and absence of natural dentition. OSAHS and SB were definitively diagnosed from a 1-night sleep study, as described below, using a threshold apnea–hypopnea index (AHI) defined as >5 events h^{-1} for OSAHS and a threshold SB index (SBE h^{-1}) of >4 events h^{-1} for SB (American Academy of Sleep Medicine, 2005). The final patient sample comprised 10 male patients with OSAHS with SB with a mean age of 46.7 (SD: 11.5) years. The mean body mass index was 27.7 (3.9) kg m^{-2} and mean score on the Epworth Sleepiness Scale was 8 (5).

This study was approved by the ethical committee of Hokkaido University Hospital, and written informed consent was obtained from all subjects prior to participation in the study.

Polygraphic sleep recording

Subjects slept for 1 night in a sleep clinic. The recording variables included electroencephalograms (EEGs) at C3-M2, C4-M1, O1-M2 and O2-M1; right and left electrooculogram; EMGs of the submental and masseter muscle and anterior tibialis muscle (five channels); and an electrocardiogram (one channel). Body positions were detected using a body position sensor equipped with a 3D accelerometer. Sleep breathing variables included airflow (with a nasal/oral thermistor), chest and abdominal effort (two channels) and SpO_2 measured by pulse oximetry (one channel). Recordings were performed with an Alice 5 PSG system (Philips Electronics, Amsterdam, the Netherlands). For SB recognition, PSG recordings included masseter EMG with AV. Masseter recording side was randomized across subjects: masseter EMG electrodes were attached on the right side for seven subjects and on the

left side for three subjects. All recording signals were amplified and analogue-to-digital (A/D) converted at a 2-kHz sampling frequency. All scoring was performed offline using commercial software (Alice Sleepware, Philips Electronics). Chart5 (ADInstruments, Bella Vista, NSW, Australia) was also used for offline processing of masseter EMG waveforms. Masseter EMG data were high-pass filtered at 20 Hz and converted to absolute values using Chart5.

Sleep stage was scored according to standard criteria (Iber *et al.*, 2007). AHEs were scored according to AASM criteria (Iber *et al.*, 2007). Arousal events within 5 s of AHE termination were scored, and AHEs were classified into events with and without arousal.

Assessment of SBEs

Sleep bruxism events were assessed according to published criteria, and masseter events were identified as RMMA (American Academy of Sleep Medicine, 2005; Lavigne *et al.*, 1996). The amplitude threshold was set at twice the baseline activity (Yamaguchi *et al.*, 2012). Bursts with greater amplitude than the value with duration exceeding 0.25 s were selected. RMMA EMG events separated by 3-s intervals were recognized as SBEs if they corresponded to one of the three following patterns: phasic (three or more masseter EMG bursts, each lasting 0.25–2.0 s); tonic (at least one masseter EMG burst longer than 2.0 s); or mixed (both masseter burst types).

Events other than RMMA typical of SBEs (e.g. swallowing, coughing and face scratching), unidentified events with face hidden by blanket, and events during wake stage were excluded by AV scoring.

Classification of temporal associations between SBEs and AHEs

The nearest AHE before and after each SBE was selected, with the SBE as the pivotal reference point. Regardless of whether SBEs and/or AHEs occurred in clusters or in close sequence, only the nearest AHE was scored for each SBE. Two temporal patterns were analysed: (i) the interval between AHE termination and SBE onset, called T1 (AHE to SBE); and (ii) the interval between SBE termination and AHE onset, called T2 (AHE to SBE) (Fig. 1). Overlapping AHE

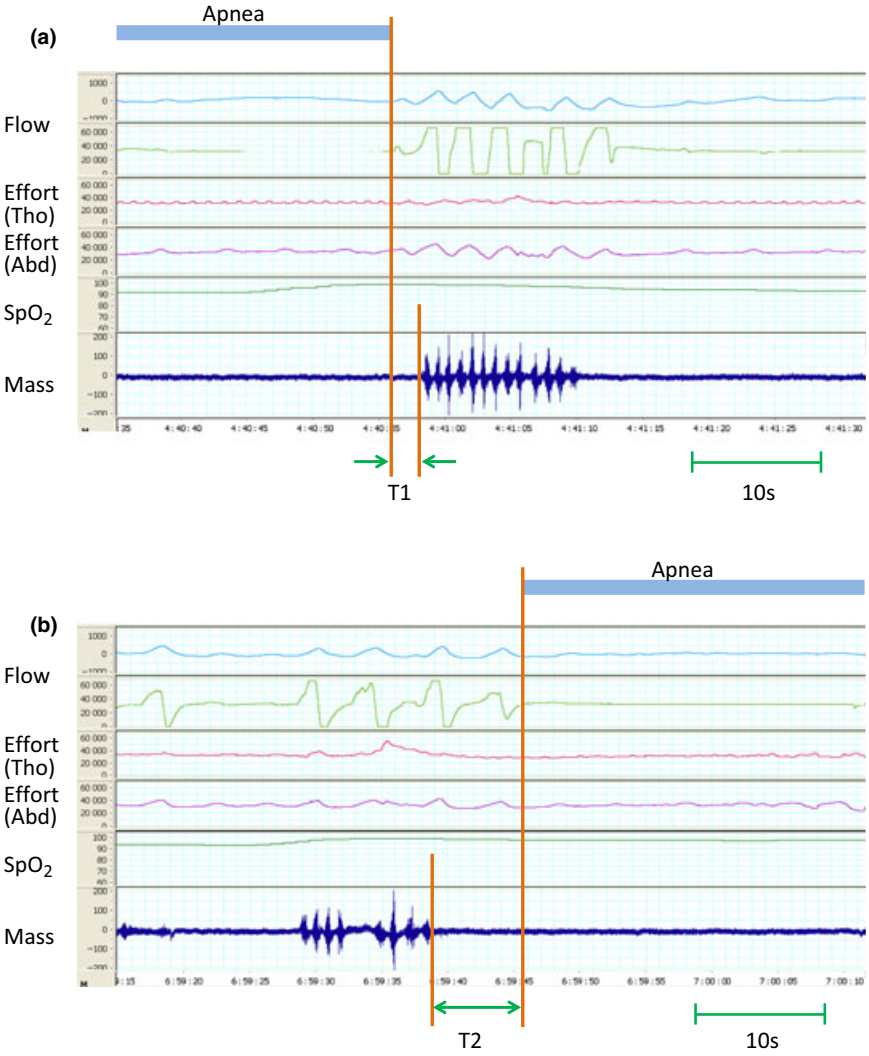

Figure 1. Temporal pattern of association between sleep apnoea–hypopnoea events (AHEs) and sleep bruxism events (SBEs) within a 5-min scoring window.
T1 = temporal interval between AHE termination and SBE onset (a).
T2 = temporal interval between SBE termination and AHE onset (b).
Flow = airflow (with a nasal/oral thermistor); Effort (Tho) = chest effort; Effort (Abd) = abdominal effort;
Mass = electromyogram (EMG) of the masseter muscle.

termination and SBE onset was considered T1, and overlapping SBE termination and AHE onset was considered T2. SBE temporal distribution was scored within a 5-min period after (T1) or before (T2) an AHE. Considering a possible sudden rise in autonomic sympathetic nerve activity at 4–8 min before SBE onset (Huynh *et al.*, 2006; Khoury *et al.*, 2008; Lavigne *et al.*, 2011), we examined a 5-min time window around AHEs and SBEs. Subjects were divided into two subgroups according to AHI. The moderate–severe OSAHS group included subjects with AHI more than 15, and the mild OSAHS group included subjects with AHI from 5 to 15.

Statistical analysis

Distributions of temporal intervals, or T1 and T2 within the 5-min windows, were expressed as a histogram. The mean distributions of the two intervals were calculated for all subjects. The numbers of SBEs associated with T1 and T2 were statistically compared. The intervals T1 and T2 were also statistically compared. All data are presented as means (SD).

The paired *t*-test was used for the statistical analysis. Statistical significance was set at $P < 0.05$. Microsoft Office Excel 2007 (Microsoft, Redmond, WA, USA) and Statcel 2 (OMS Publishing, Tokorozawa, Japan) were used for statistical analyses.

RESULTS

Subjects' sleep data are presented in Table 1. The mean AHI was 24.0 (17.1) (range: 7.4–60.0) and the mean number of SBEs h^{-1} was 13.5 (5.0) (range: 8.2–24.4). The most detected AHEs were obstructive apnea–hypopnea and mixed apnea (Table 1). Similarly, most AHEs nearest to SBEs were obstructive sleep apnea–hypopnea and mixed apnea. Very few central apnoeas were scored (Fig. 2).

For the total sample, the mean percentage of SBEs occurring within 5 min of AHEs was 80.5%, with 19.5% of SBEs occurring at more than 5 min from AHEs (Table 2). A significantly higher percentage of SBEs (54.9%) showed the T1 pattern (AHE to SBE) than the T2 pattern (SBE to AHE; $P < 0.05$), with the nearest AHE tending to occur before the SBE. This trend was also shown for the moderate–severe OSAHS group with significant difference between T1 and T2, while no significant difference in the percentage of SBEs between T1 and T2 was shown for the mild OSAHS group (Table 2).

Table 1 Sleep and AHE data of 10 subjects

	Mean	*SD*
Sleep data		
TST (min)	350.3	45.8
TIB (min)	399.6	30.1
Sleep efficiency TST/TIB (%)	87.5	7.8
Sleep stage distribution		
N1/TST (%)	30.3	17.1
N2/TST (%)	54.5	13.5
N3/TST (%)	4.1	5.2
R/TST (%)	10.7	4.5
Numbers of AHEs		
Obstructive		
Apnoea and hypopnoea	131.2 (95.5%)	96.8
Central apnoea	1.2 (1.8%)	1.5
Mixed apnoea	3.8 (2.4%)	9.8

AHE, apnoea–hypopnoea event; TIB, time in bed; TST, total sleep time.

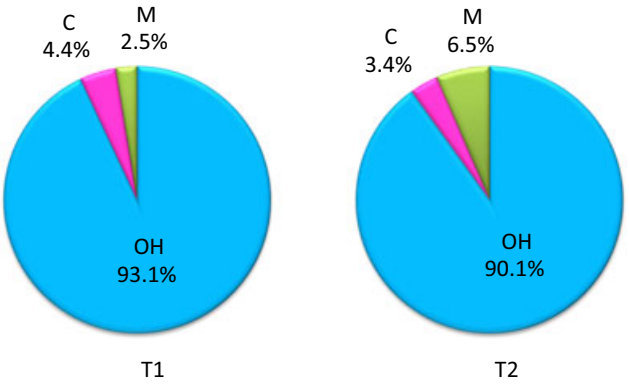

Figure 2. Classification of sleep bruxism events (SBEs) based on the nearest sleep apnoea–hypopnoea event (AHE) type ($n = 10$). Averages for the 10 subjects are shown. OH = SBE with the nearest AHE being obstructive apnoea–hypopnoea; M = SBE with the nearest AHE being mixed apnoea; C = SBE with the nearest AHE being central apnoea.

Within the 5-min windows, most T1 and T2 patterns were distributed within a period of less than 30 s, with 86.8% of T1 peaking at from 0 to 10 s and 65.8% of T2 peaking at from 0 to 10 s (Fig. 3; Table 3). Particularly strong convergence was found in the 0–10-s category for T1. The mean interval for T1 and T2 within 5 min was 33.4 s and 64.0 s, respectively, and T1 was significantly shorter than T2 ($P < 0.05$; Fig. 4).

The numbers of apnea–hypopnea events classified in relation to arousals and SBEs are presented in Table 4. For the total 10 subjects, the mean number of the nearest AHE before an SBE within 5 min [AHE(T1)] was 40.8 (30.0% of total AHEs), and the mean number of the nearest AHE after an SBE within 5 min [AHE(T2)] was 16.8 (12.3% of total AHEs). The ratio of AHE(T1) with arousal to total AHEs with arousal was significantly larger than the ratio for AHE(T2) ($P < 0.05$). Similarly, the ratio of AHE(T1) without arousal to total AHEs without arousal was significantly larger than the ratio for AHE(T2) ($P < 0.05$). In comparison between AHE (T1) with arousal and that without arousal, the mean ratio of AHE(T1) with arousal to total AHE with arousal was slightly larger than that without arousal, but no significant difference was shown.

DISCUSSION

A detailed investigation was performed to assess the temporal associations between SBEs and AHEs. In patients

Table 2 Number of SBEs classified by temporal interval from AHE according to OSAHS severity

	Moderate–severe OSAHS (n = 5)		*Mild OSAHS (n = 5)*		*Total (n = 10)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Total number of SBEs	94.6	37.8	79.4	23.9	87.0	30.9
SBE with T1						
N1	31.2	34.7	16.6	13.5	23.9	26.0
N2	35.6	15.8	9.6	11.8	22.6	19.0
N3	0.2	0.4	0	0.0	0.1	0.3
REM	1.2	2.7	1.2	1.8	1.2	2.1
Total	68.2*	27.6	27.4	20.4	47.8**	31.4
%	72.0		30.9		54.9	
SBE with T2						
N1	11.4	13.5	14.8	8.3	13.1	10.7
N2	8.8	6.8	7.6	7.8	8.2	6.9
N3	0.0	0.0	0.4	0.5	0.2	0.4
REM	1.2	2.7	0.2	0.4	0.7	1.9
Total	21.4*	12.9	23.0	10.8	22.2**	11.3
%	22.8		28.5		25.5	
SBE without AHE						
N1	4.8	9.7	18.2	8.7	11.5	11.2
N2	0.2	0.4	10.4	6.1	5.3	6.7
N3	0.0	0.0	0.4	0.9	0.2	0.6
REM	0.0	0.0	0.0	0.0	0.0	0.0
Total	5.0	9.6	29.0	9.4	17.0	15.5
%	5.2		40.7		19.5	

AHE, sleep apnoea–hypopnoea event; OSAHS, obstructive sleep apnoea–hypopnoea syndrome; REM, rapid eye movement; SBE, sleep bruxism event.
SBE without AHE = SBEs occurred at longer than 5-min intervals from AHEs.
T1 = temporal interval between cessation of an AHE and onset of a SBE.
T2 = temporal interval between end of a SBE and onset of an AHE.
Moderate–severe OSAHS = subjects with AHI more than 15.
Mild OSAHS = subjects with AHI from 5 to 15.
*,**$P < 0.05$ between SBE with T1 and SBE with T2.

Table 3 Cumulative number of SBE scored within 5 min from the nearest AHE ($n = 10$)

Temporal interval	*Cumulative number*	*%*
T1 (AHE to SBE)		
<10 s	35.5	74.3
<20 s	40	83.7
<30 s	41.5	86.8
<60 s	43.3	90.6
Total (<5 min)	47.8	100
T2 (SBE to AHE)		
<10 s	9.2	41.4
<20 s	12.7	57.2
<30 s	14.6	65.8
<60 s	16.7	75.2
Total (<5 min)	22.2	100

AHE, apnoea–hypopnoea event; SBE, sleep bruxism event.
The numbers are mean of the 10 subjects.
T1 = temporal interval between cessation of an AHE and onset of a SBE.
T2 = temporal interval between end of a SBE and onset of an AHE.

with concomitant OSAHS and SB, most SBEs occurred after AHEs. Such a finding suggests that SBE occurring close to AHE is a secondary form of SB.

Owing to our study limitation, we recognize that not all SBEs are secondary to AHEs, suggesting that other concomitant influences may be present in the temporal relationship between AHEs and SBEs.

Masseter EMG in SBE, AHE and other activities

Polysomnography with AV was used to confirm the presence of both OSAHS and SB, a major strength of the present study. When EMG bursts of masticatory muscle during sleep are scored, various types of bursts are observed, including myoclonic contraction, swallowing and sighing (Dutra *et al.*, 2009; Yamaguchi *et al.*, 2012). In wake periods during sleep,

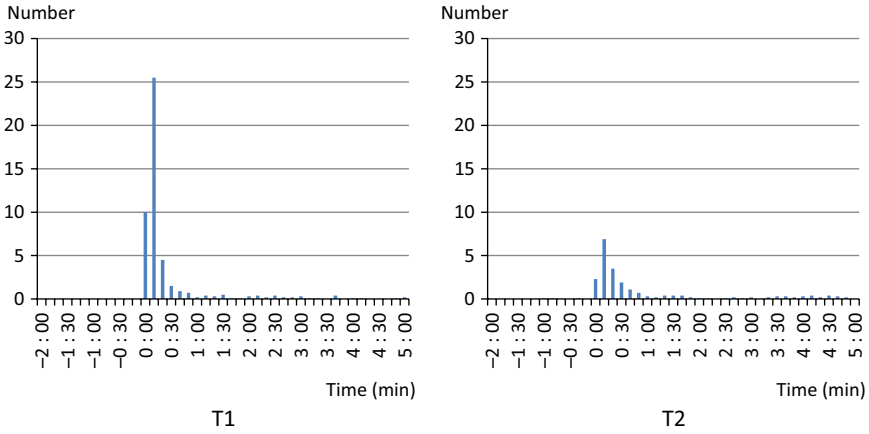

Figure 3. Distributions of temporal intervals from sleep bruxism events (SBEs) to the nearest sleep apnoea–hypopnoea event (AHE) within a 5-min scoring window ($n = 10$). The value of the vertical axis is the number of SBEs in each interval class. Averages for the 10 subjects are shown. T1 = temporal interval between AHE termination and SBE onset (25.5 events, peak at 0–10 s). T2 = temporal interval between SBE termination and AHE onset (6.9 events, peak at 0–10 s).

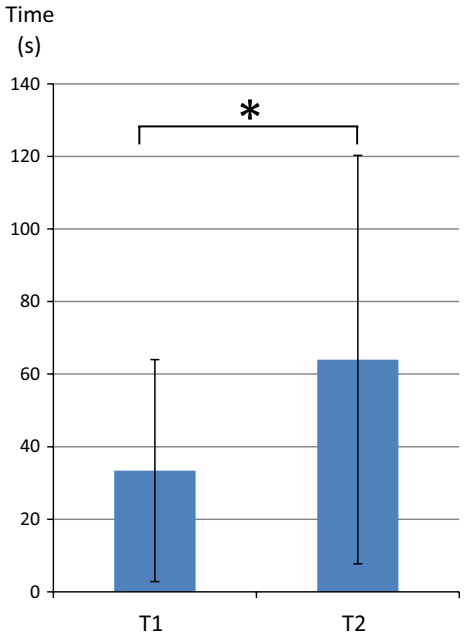

Figure 4. Mean intervals for T1 and T2 within 5 min (n = 10). Vertical lines on the bars indicate standard deviations. *P < 0.05. T1 = temporal interval between AHE termination and SBE onset. T2 = temporal interval between SBE termination and AHE onset.

various types of masticatory muscle activity are also observed. Accordingly, when analysing nocturnal EMG data, RMMA burst events typical of SB should be distinguished from other masseter activity. In the present study, other motor activity and bursts during wake periods were excluded, and more reliable data concerning SB were obtained with simultaneous AV recording.

Sleep arousal in relation to OSAHS and SB

The association between OSAHS and SB has been attributed to several potential causes: co-morbid sleep disorders, re-opening of upper airways, lubrication of the oropharynx and arousal reaction (Carra *et al.*, 2012a; Lavigne *et al.*, 2003).

Rhythmic masticatory muscle activity may be an oromotor activity that helps reinstate airway patency following a disrupted respiratory event during sleep, including airway resistance (Carra *et al.*, 2012a; Khoury *et al.*, 2008). RMMA may also act as a physiological motor event that is required to lubricate the oropharyngeal structures during sleep (Carra *et al.*, 2012a; Thie *et al.*, 2002). These hypotheses remain to be confirmed.

Masticatory muscle bursts may also arise from body movements as an arousal reaction to AHEs, or from saliva swallowing to lubricate a dry oropharynx due to AHEs. Previous studies have suggested that some masticatory EMG bursts occur at AHE termination (Inoko *et al.*, 2004; Okeson *et al.*, 1991; Phillips *et al.*, 1986). In addition, non-specific masseter contractions, which are distinct from RMMA, also tended to occur at AHE termination in patients with OSAHS without SB diagnosis (Kato *et al.*, 2013c). These results showed masseter muscle activity-SBEs at AHE termination as well as non-specific masseter muscle contractions.

It may also be suggested that both arousal reactions during sleep and autonomic sympathetic activation can be involved in the association between OSAHS and SB. Recently, it was found that SBE was accompanied by a specific ascending sequence of physiological activity: at 4 min before SBE onset (i.e. −4 min), a rise in autonomic sympathetic cardiac dominance with a withdrawal of cardiac parasympathetic dominance occurs; at −4 s a rise in rapid-frequency cortical activity (EEG activity) occurs; and at −1 s a change in heart rate, suprahyoid muscle tone and breathing occurs with a modest but significant rise in blood pressure (Huynh *et al.*, 2006; Khoury *et al.*, 2008; Lavigne *et al.*, 2011; Nashed *et al.*, 2012). Considering a potential sudden rise in autonomic sympathetic nerve activity and the results of the above-mentioned study (Huynh *et al.*, 2006), indicating a rise in the sympathetic nerve 4–8 min before SBE onset, we postulated that AHEs occurring within a few minutes of SBEs had some association with SBEs. To assess this association, we performed a 5-min time window analysis around AHEs and SBEs.

Due to the presence of arousals and hypoxia with AHEs and a concomitant rise in sympathetic activity (Bradley *et al.*, 2003), we also speculated that an arousal reaction to an AHE would acutely increase the probability of SBE occurrence. Because the sympathetic system in patients with OSAHS is considered to be chronically hypersensitized (Gilmartin *et al.*, 2010), SBEs in patients with OSAHS would tend to occur more frequently in conjunction with AHEs. In subgroup analyses, the nearest AHE tended to occur before the SBE for the moderate–severe OSAHS group, with a significant difference between T1 and T2, whereas no significant difference was found for the mild OSAHS group. Due to the small size of the subgroup samples, we cannot draw any firm conclusions at this time. Further studies are needed to confirm whether the association between AHE and SBE depends on the severity of OSAHS and chronic hypersensitization of the sympathetic system.

In the above-mentioned study by Kato (Kato *et al.*, 2013c), the non-specific contractions of masseter muscles after an AHE also depended on arousal duration. The data suggest that activation of the masseter muscle can be accelerated via an arousal reaction to an AHE. Similarly to this non-specific masticatory motor activity, we speculated that SBEs found in association with AHEs could be associated with sleep arousals. However, the AHE-arousal scoring in the present study showed no significant difference in the post-AHE occurrence of SBEs with and without arousal. Our hypothesis that OSAHS-related sleep instability may contribute to increase post-AHE occurrence of SBEs is therefore not supported. Further studies with larger sample sizes are needed to clarify the putative association with sleep arousal.

Table 4 Numbers of AHEs classified in relation to arousal and SBE

	Moderate–severe OSAHS (n = 5)		*Mild OSAHS (n = 5)*		*Total (n = 10)*	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*
Arousal						
Number of total arousal	105.2	67.9	35.2	26.5	70.2	61.0
Arousal index (number of total arousal h^{-1})	18.7	11.8	5.9	4.5	12.3	10.8
AHE						
AHI	37.8	13.0	10.2	3.0	24.0	17.1
Total AHE	210.6	51.2	61.8	21.5	136.2	86.7
AHE without arousal	140.0	68.6	51.8	23.0	95.9	67.0
AHE with arousal	70.6	60.6	10.0	11.8	40.3	52.1
AHE (T1) without arousal	31.0	15.5	12.4	6.4	21.7	14.8
AHE (T1) without arousal/total AHE without arousal (%)	23.5	6.2	30.7	26.8	27.1*	18.7
AHE (T1) with arousal	33.0	42.0	5.2	7.9	19.1	32.1
AHE (T1) with arousal/total AHE with arousal (%)	38.1	18.2	27.5	29.1	32.8**	23.6
AHE (T2) without arousal	11.2	5.8	10.4	3.7	10.8	4.6
AHE (T2) without arousal/total AHE without arousal (%)	10.9	8.2	25.6	17.7	18.2*	15.2
AHE (T2) with arousal	8.4	12.3	3.6	6.1	6.0	9.5
AHE (T2) with arousal/total AHE with arousal (%)	11.0	11.1	15.3	22.6	13.2**	16.9

AHE, sleep apnoea–hypopnoea event; AHI, apnoea–hypopnoea index; SBE, sleep bruxism event.
AHE (T1) = the nearest AHE before SBE within 5 min.
AHE (T2) = the nearest AHE after SBE within 5 min.
T1 = temporal interval between cessation of an AHE and onset of a SBE.
T2 = temporal interval between end of a SBE and onset of an AHE.
Moderate–severe OSAHS = subjects with AHI more than 15.
Mild OSAHS = subjects with AHI from 5 to 15.
*,**$P < 0.05$ between AHE (T1) and AHE (T2).

Cause and effect: not a unique temporal sequence pattern

Although there is no clear consensus on the temporal association between SBEs and AHEs, as described above, recent findings support our hypothesis (Inoko *et al.*, 2004; Okeson *et al.*, 1991; Phillips *et al.*, 1986; Sjöholm *et al.*, 2000; Saito *et al.*, 2011; Kato *et al.*, 2013c).

There are three possible cause-and-effect relationships between SB and OSAHS: OSAHS induces SB, SB induces OSAHS, or some other factors coincidently induce both SB and OSAHS. The present study focused on a potential temporal association, namely that a specific order of onset time between SBEs and AHEs would support a cause-and-effect relationship between the two events. One main finding was a greater number of T1 intervals (AHE to SBE), with peak occurrence within a 0–10-s period. This suggests that in patients with OSAHS, RMMA is frequently secondary to AHE. However, because 25% of SBEs preceded AHEs and 20% had no close temporal association with an AHE, we cannot exclude the possibility of other concurrent factors (e.g. SBE with airway resistance and SBE without arousal triggering AHE).

Changes in SBE occurrence in association with a reduction in AHEs through OSAHS treatments [e.g. continuous positive airway pressure (CPAP); mandibular advancement appliance] could provide further insight into the cause-and-effect issue. A case report using a CPAP demonstrated a reduction in the respiratory disturbance index from 47.6 to 4.1, and in the number of audible bruxism events from 73 to 0 after CPAP treatments, although SB was assessed by sound recording only (Oksenberg and Arons, 2002).

Both SBE and AHE in clusters or in single events were included in the analyses. In a cluster event, the presence of several AHEs might affect SBE occurrence. In the future, more detailed analyses of multiple associations among SBEs and AHEs are needed to clarify the associations between AHEs, SBEs and arousals.

Limitations

Whereas this study provided significant new information, several limitations should be noted. First, PSG-AV data were recorded for only 1 night. The PSG-AV equipment and unfamiliar circumstances might have affected the subjects' sleep state, known as first-night effects. Second, the results cannot be claimed as exclusive to general patients with OSAHS, because some patients with OSAHS may not exhibit SB (Sjöholm *et al.*, 2000), and the present study examined a small sample of patients with both OSAHS and SB. In addition, because the subjects were selected among patients with OSAHS, we could not determine the temporal association between SBEs and central AHEs. Third, we did not investigate the temporal association in relation to autonomic-cardiac activation. More detailed analyses in patients with OSAHS are needed, with larger samples, including patients suffering from central sleep apnea–hypopnea syndrome. Relationships

to arousal events as well as changes in sympathetic nerve activity should be examined in order to determine an intermediary factor between AHEs and SBEs. Fourth, only middle-aged OSAHS male subjects were examined. To improve the generalization of findings, this study should be replicated in larger samples of mixed OSAHS and SB populations.

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CONFLICTS OF INTEREST

No conflicts of interest declared.

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