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Characterization of the relationships between rhythmic masticatory muscle activities and limb movements in patients with sleep bruxism

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Running head: Jaw and limb movements in sleep bruxism patients

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Abstract:

Background: Most rhythmic masticatory muscle activities (RMMAs) have been shown to be accompanied with limb movements (LMs) in sleep bruxism (SB) patients during sleep.

Objectives: To compare the relationships between RMMAs and LMs in SB patients and normal subjects.

Methods: Polysomnographic recordings were performed on eight SB patients and nine normal subjects and the frequencies and durations of RMMAs as well as LMs were determined. Linear regression and correlation analysis was performed to study the relationship between durations of RMMAs and LMs when RMMAs occurred with LMs.

Results: Most LMs in SB patients, but not in normal subjects, were accompanied with RMMAs. RMMAs in SB patients were more likely to be isolated, phasic or mixed, while RMMAs in normal subjects were more likely to be tonic. The frequencies of LMs, isolated RMMAs and RMMAs accompanied with LMs in SB patients were significantly higher than those in normal subjects. Furthermore, linear regression and correlation analysis showed that duration of RMMAs was significantly associated with that of LMs when RMMAs occurred with LMs. The duration of RMMAs, when accompanied with LMs, in SB patients was significantly longer than that in normal subjects.

Conclusions: Close relationships between LMs and RMMAs exist in SB patients and normal subjects, and SB episodes may be part of cortical arousal responses and the increased cortical activities associated with SB episodes may not just be localized to the central nervous system (CNS) that controls jaw movements but may also include other parts of CNS that controls LMs.

Keywords: Jaw movements; sleep bruxism; rhythmic masticatory muscle activities; limb movements.

Introduction

Sleep bruxism (SB) is a masticatory muscle activity during sleep which is rhythmic (phasic) or non-rhythmic (tonic) and is not a movement disorder or a sleep disorder for healthy individuals [1]. It affects about 8% of general population with a higher prevalence in children and youths [2,3]. Sleep bruxism might not only cause destruction to teeth but also induce temporal and masseter muscle pain, temporomandibular disorders, and headache although SB in some conditions (e.g. gastro-oesophageal reflex) might have protective effects which attribute to a decrease in the chance of a negative health outcome [1,4–8].

Although some studies suggest that genetic polymorphisms, stress, anxiety, smoking, alcohol intake, drug abuse, sleep apnea, sleep position, and gastroesophageal reflux may be associated with SB [9–15], the exact pathophysiologic mechanisms underlying SB are still largely elusive [16–18]. The current treatments for SB include occlusal splints, biofeedback, kinesiotherapy, and repetitive transcranial magnetic stimulation, electrical stimulation as well as drug intake such as clonidine [19–25]. However, most of the therapies could be only used to protect teeth and their associated structures and none of them can effectively prevent the occurrence of SB without severe side effects.

Sleep bruxism is considered to be generated in brainstem due to the imbalance of neurotransmitters (e.g. dopamine and GABA) and mostly happens within cortical arousal, which highlights changes in cortical activities around the occurrence of SB episodes [18,26–31]. Relevant studies showed a series of physiological changes before the onset of SB episodes i.e. an increase in sympathetic tone starting about 4-8 min before the onset of SB episodes, and then an increase in power of alpha waves of the cortical electroencephalographic activities starting about 4 s before, followed by changes in heart rate, respiration and suprahyoid muscle activity [32]. There is a possibility that the changes in cortical activities around the occurrence of SB episodes may not just be localized to the part of the central nerve system that controls jaw

movements (e.g. cortical masticatory area) but may also include the part of central nervous system that controls limb movements (LMs). Indeed, it has been showed that a majority of SB episodes (85.05%) were accompanied with LMs [33,34]. In line with this, it has also previously been shown that SB patients had a higher periodic leg movements index (PLMI) than normal subjects, and in SB patients, the number of SB episodes accompanied with periodic leg movements was significantly higher than that of the isolated SB episodes [35]. Moreover, it has previously been shown that about 15% of patients with restless leg syndrome (RLS) also reported tooth grinding; conversely, about 10% of the SB patients also reported RLS-related symptoms [36]. Furthermore, most of SB episodes (70.52%) occurred with a companion of movements in both upper and lower limbs and most of LMs (70.54%) initiated prior to the onset of SB episodes [33].

All of these highlight the existence of a close relationship between LMs and SB episodes. However, so far, analyses of the relationships between RMMAs and LMs were limited to the difference between their onsets. Many aspects of their relationships (e.g. relationship between durations of RMMAs and LMs) are still unknown. It is likely that durations of RMMAs and LMs are closely related in the SB patients since cortical arousals often occur around the occurrence of SB episodes [33,35]. Furthermore, RMMAs without tooth-grinding events can also be observed in about 60% of normal subjects during sleep [37]. It is also likely a similar relationship also exists between RMMAs and LMs in normal subjects given similar cortical arousals also often occur. Therefore, we hypothesized that the durations of RMMAs and LMs were closely related in both SB patients and normal subjects. The aims of the study were to test the hypothesis by characterizing the relationships between RMMAs and LMs in SB patients and normal subjects.

Materials and methods

Participants:

As shown in Table 1, 8 SB patients (3 males and 5 females with ages of 19-24 years and 9 normal subjects (2 males and 7 females with ages of 19-25 years) were recruited. All subjects have no psychiatric, medical or sleep disorders such as sleep insomnia, sleep apnea, and periodic leg movement. No one used any alcohol, cigarettes, coffee, medications or psychostimulants during the past six months. All SB patients were first selected based on the following criteria: a) recent history reports from patient himself/herself, sleep partner, or roommates about tooth-grinding sounds at least three nights per week in the last six months; b) masseter hypertrophy; c) presence of tooth wear; d) a report of fatigue, pain, and other discomfort including transient jaw-muscle pain and headache in the morning. Then, diagnosis of SB was confirmed in the polysomnographic recordings together with audio and video monitoring according to the criteria established by American Association of Sleep Medicine (AASM) [38] by presentation of at least two SB episodes with tooth grinding sounds as well as the RMMA/SB index (number of RMMAs per hour of sleep) ≥ 4 and the burst index (the number of EMG bursts per hour of sleep) ≥ 25. The normal subjects didn't report any history of tooth grinding or recent experience of sleep disorders and didn't meet any diagnosis criteria above, which was also verified with two full night polysomnographic recordings at the sleep laboratory.

Polysomnographic recordings

Two consecutive nights of polysomnographic recordings were performed on all subjects in the sleep laboratory of the Jiangxi Mental Hospital. During the first night, all subjects were habituated to the experimental environment. The data recorded at the first night were only used to detect whether there were any sleep or sleep related disorders such as sleep apnea, restless legs syndrome, and periodic limb movements. The data recorded during the second night were used for analysis and presentation. Polysomnographic recordings of EEG (F3-A2, F4-A1,C3-A2, C4-A1, O1-A2, O2-A1), electrocardiographic (ECG), electrooculographic (EOG), and

electromyographic (EMG) activities as well as recordings of respiration and peripheral capillary oxygen saturation were exactly the same as that described in the previous study [33]. Briefly, in addition to recordings from masseter muscle as in the routine sleep monitoring, EMG activities from myohyoid and limb muscles (bilateral flexor and extensor carpi radialis, gastrocnemius and tibialis anterior muscles) were recorded by use of cup surface electrodes. The high and low cut-off filters in the EMG recordings were set at 0.3 and 100 Hz, respectively, to eliminate electrical frequencies from cardiac, respiratory, and neural activities. Nasal airflow pressure and thermal sensors as well as abdominal and thoracic belts were used to record the subjects' respiration. A finger pulse oximeter and a position sensor were used to monitor peripheral capillary oxygen saturation and body position during sleep, respectively. Jaw movements and LMs were confirmed and nonspecific orofacial movements (talking, coughing, grimacing) were excluded by both audio and video recordings during sleep.

All electrical signals were recorded and amplified at a sampling rate of 256 Hz, then stored for off-line analysis by use of the Compumedics Net Beacon Application (Pro Fusion PSG 3 Software, Compumedics Limited, Abbotsford, Australia) and Spike 2 (CED, Cambridge, UK).

Data analyses and statistics:

The sleep-related parameters shown in Table 1 were determined based on the criteria published by AASM [38]. According to the AASM criteria, RMMA episodes were classified as phasic (at least three consecutive masseter EMG bursts and each burst lasting for at least 0.25 s), tonic (one EMG burst lasting for longer than 2 s), and mixed (a mixture of phasic and tonic masseter EMG activities). The onset of RMMA episodes was determined when the EMG amplitude of masseter muscle exceeded two times the level of baseline [38]. If there was an interval of 3 s or longer between two RMMA bursts, they were considered as two separated RMMA episodes. The onset of

LMs was defined when the amplitude of limb EMG was 8 μV higher than the baseline [38]. Besides, occurrence of LMs was considered when the duration of limb muscle EMG burst was longer than 0.5 s and the interval between adjacent EMG bursts was shorter than 5 s [38]. When there was a time overlap between masseter muscle EMG activity and limb muscle EMG activity, RMMA episodes and LMs were considered to be associated with each other.

The statistical analyses were performed by use of GraphPad prism 7 (GraphPad Software, Inc., USA) and SigmaPlot 12.5 (Systat Software, Inc., USA). The independent sample two-tailed t-test or Mann-Whitney U test was used to analyze whether there were any significant differences in sleep efficiency, percentage of each sleep stage, RMMA/SB index, arousal index, apnea-hypopnea index, PLMI, and frequencies of different types of movements between SB patients and normal subjects wherever appropriate. The Pearson χ^2 tests were used to analyze whether there were any significant differences in distribution of types of movements (isolated RMMAs, isolated LMs, and RMMAs accompanied with LMs) between SB patients and normal subjects. The partition of χ^2 tests were used to test differences between any two different types of movements. The χ^2 goodness-of-fit tests were used to analyze the distribution of types of movements in SB patients and normal subjects. Two way analysis of variance (ANOVA) was used to test whether there were any significant differences in the durations of RMMAs and LMs between SB patients and normal subjects. Linear regression and correlation analyses were used to examine the relationship between duration of RMMA episode and its associated limb movement and covariance analysis was performed to compare the slopes of regression lines between SB patients and normal subjects. $P < 0.05$ was considered to be statistically significant.

Ethical approval:

This study was approved by the Regional Ethical Review Board at Jiangxi Mental

Hospital (2017007) and in accordance with the ethical standards of the Declaration of Helsinki. Informed consent was obtained from each subject prior to participation.

Results

3.1 Association of RMMAs with LMs in SB patients and normal subjects.

Three types of movements, i.e. RMMAs accompanied with LMs (movements of upper and/or lower limbs) (Fig.1A), isolated RMMAs (Fig.1B), and isolated LMs (Fig.1C) occurred in both SB patients and normal subjects. However, as shown in Table 2, proportions of the three types of movements in SB patients and normal subjects were significantly different. Moreover, χ^2 goodness-of-fit tests showed RMMAs accompanied with LMs accounted for the majority among the three types of movements in SB patients ($P < 0.001$) while isolated LMs constituted most of the movements in normal subjects ($P < 0.001$). In addition, χ^2 test showed there were significant differences in proportion of LMs with and without a companion of RMMAs ($P < 0.001$) and in proportion of RMMAs with and without a companion of LMs ($P < 0.001$) between SB patients and normal subjects (Table 2).

3.2 Different types of RMMAs in SB patients and normal subjects

The three types of RMMAs were not equally distributed in SB patients and normal subjects (Table 2). Pearson χ^2 test showed there was a significant difference in proportion of three types of RMMA between SB patients and normal subjects ($P = 0.002$). Further partitions of χ^2 tests showed that there were significant differences in both the proportions of phasic and tonic, and the proportions of tonic and mixed types of RMMA between SB patients and normal subjects ($P = 0.006$ and $P < 0.001$, respectively; $\alpha = 0.017$).

3.3 Association of three types of RMMAs with LMs

In SB patients, 64.21% phasic, 69.62% tonic, and 85.95% mixed RMMAs were accompanied with LMs. In contrast, in normal subjects, 86.30% phasic, 78.57% tonic, and 98.33% mixed RMMAs were accompanied with LMs. χ^2 tests showed there were significant differences in the proportions of phasic and mixed RMMAs accompanied with LMs between SB patients and normal subjects ($P < 0.001$ and $P = 0.008$, respectively). The proportions of phasic and mixed RMMAs accompanied with LMs in normal subjects were significantly higher than that in SB patients.

3.4 Frequencies of LMs and RMMAs in SB patients and normal subjects

The unpaired t-test showed there was a significant difference between SB patients and normal subjects in the frequency of RMMAs (RMMA events per hour) ($P < 0.001$, Table 1) and LMs (LM events per hour) ($P = 0.019$, Fig. 2A). In addition, there were also significant differences in the frequencies of RMMAs accompanied with LMs (unpaired t-test, $P < 0.001$, Fig.2B) and isolated RMMAs ($P=0.038$, Fig. 2C) between SB patients and normal subjects.

3.5 Durations of RMMAs and LMs in SB patients and normal subjects

Two way ANOVA analysis showed significant differences in durations of isolated RMMAs and RMMAs which were accompanied with LMs [$F(1, 634) = 33.704$, $P < 0.001$] and between SB patients and normal subjects [$F(1, 634) = 8.983$, $P = 0.003$]. However, there was no significant interaction between type of subjects and duration of RMMAs with or without a companion of LMs [$F(1, 634) = 0.270$, $P = 0.603$]. As shown in Fig. 3A, post hoc Holm-Sidak tests showed that the duration of RMMAs which were accompanied with LMs was significantly longer than that of isolated RMMAs in both SB patients ($P < 0.001$) and normal subjects ($P = 0.003$). In addition, the duration of RMMAs which were accompanied with LMs in SB patients was

significantly longer than that in normal subjects ($P < 0.001$).

Similarly, two way ANOVA analysis showed significant difference in the durations of isolated LMs and LMs which were accompanied with RMMAs [$F (1, 1014) = 384.148$, $P < 0.001$] but no significant difference between SB patients and normal subjects [$F (1, 1014) = 0.018$, $P = 0.892$] and no significant interactions between type of subjects and duration of LMs with or without a companion of RMMAs [$F (1, 1014) = 0.120$, $P = 0.729$]. As shown in Fig. 3B, post hoc Holm-Sidak tests showed that the duration of LMs which were accompanied with RMMAs was significantly longer than those of isolated LMs in both SB patients ($P < 0.001$) and normal subjects ($P < 0.001$).

3.6 Relationship between duration of RMMA and duration of LMs when RMMA were accompanied with LMs

There were significant correlations between the durations of RMMAs and LMs in both SB patients and normal subjects when RMMAs were accompanied with LMs (Fig. 4). As shown in Fig. 4, when the duration of LMs was considered as an independent variable and the duration of RMMAs as a dependent one, their relationship could be expressed as $y = 0.84*x+4.45$ ($R^2 = 0.35$, $P < 0.001$) in SB patients and $y = 0.65*x+2.87$ ($R^2 = 0.42$, $P < 0.001$) in normal subjects. The covariance analysis showed that the slopes of these two regression lines were not significantly different ($P = 0.094$).

Discussion:

Sleep bruxism is characterized by a rhythmic (phasic) or non-rhythmic (tonic) masticatory muscle activity during sleep [1]. Without effective treatment, SB might cause secondary destruction to teeth and might induce temporal and masseter muscle pain, temporomandibular disorders, and headache [4–7]. In the current study, we have

found when RMMAs and LMs concurred, the durations of RMMAs and LMs were significantly longer than those of isolated RMMAs and LMs, respectively (Fig. 3) and significant correlations existed between the durations of RMMAs and LMs in both SB patients and controls (Fig. 4). These findings clearly indicate existence of close relationships between RMMAs and LMs and might help us to understand the pathophysiological mechanisms underlying SB.

Sleep bruxism was once thought to be caused mainly by morphological abnormalities of the oromotor system and occlusal discrepancies. However, more recent studies have suggested that the central and autonomic nervous systems play an essential role in the genesis of a masticatory muscle activity during sleep that is rhythmic (phasic) or non-rhythmic (tonic) [1,18]. It has been shown that the generation of RMMAs is involved in co-activation of jaw-opening and jaw-closing motor neurones in the central pattern generator (CPG) for mastication, which are mostly inhibited during sleep, by excitatory inputs from the cortex through the cortico-bulbar projection and putative mechanisms that contribute to the increase in excitatory input to the CPG and the occurrence of SB may be related to transient cortical arousals and increase in sympathetic tone, which might be associated with changes in the influence from neurochemicals [34]. Indeed, previous studies have found an increase in sympathetic tone indicated by an increase in low frequency of heart rate variance about 4-8 minutes before the start of SB episodes, followed by an increase in cortical alpha and theta wave EMG activities about 4 sec before the onset of SB episodes and a change in respiration pattern and frequency, an increase in heart rate and blood pressure and jaw opening muscle activities before the onset of SB episodes [32,39–41]. This highlights the importance of the central and autonomic nervous systems in the pathophysiology of SB. Furthermore, previous studies have shown that a majority of episodes of SB/RMMAs were associated with cortical arousals and LMs and episodes of SB/RMMAs were more likely to be accompanied with LMs when cortical arousals occurred [33,35,42]. In the current study, we further showed that a positive correlation between duration of episodes of SB/RMMAs and

LMs. These studies suggest that SB is part of an cortical arousal response and the increased cortical activities before and during SB episodes may not just be localized to the central nervous system (CNS) that controls jaw movements (eg, cortical masticatory area) but may also include other parts of CNS that controls LMs.

The occurrence of SB episodes might be related to the changes in brain neurochemicals such as in the dopaminergic, GABAergic, serotonergic and adrenergic system and inhibition of the central and autonomic nervous systems by influencing of these neurochemicals might affect the occurrence of SB [24,31,43]. Some previous studies have linked dopaminergic mechanisms in the CNS to occurrence of SB and a possible dysfunction of central dopaminergic system has been postulated [18,40,44]. However, there is some inconsistence regarding the role of dopamine in the occurrence of SB. For example, the short-term use of L-dopa, a dopamine precursor, showed a decrease in frequency and duration of SB episodes in controlled polysomnographical studies while dopamine receptor agonists such as pramipexole did not show any attenuation of occurrence of SB [45–47]. Further studies are needed to clarify the role of dopamine in occurrence of SB. Nevertheless, the role of GABA in the occurrence of SB is more clear. GABA-related drugs such as diazepam, gabapentin, tiagabine, and gamma-hydroxybutyrate have been shown to decrease the occurrence of SB and these effects might be related to improvements of sleep and reduction of cortical arousals during sleep [48–52]. This suggests that GABA may be critically important to the occurrence of SB. In addition, serotonergic system might also be involved in the occurrence of SB. Clinical use of selective 5-HT re-uptake inhibitors (SSRIs), such as paroxetine, fluoxetine, fluvoxamine, and sertraline, has been associated with SB, which may be related to a disruption of sleep [43,53–56]. Indeed, other antidepressants with sedative properties like trazodone rapidly improve sleep and have been shown to decrease the occurrence of SB [57,58]. Moreover, clonidine, a selective α2 receptor agonist, has been showed to cause a significant decrease in the occurrence of SB [24]. This might be related to its inhibition of sympathetic tone preceding the onset of SB episodes, not due to inhibition of overall

sympathetic tone since propranolol, a β adrenergic receptor antagonist does not affect the occurrence of SB although propranolol decreases the overall sympathetic tone during sleep [59]. All of these suggest increases in sympathetic activity and cortical arousals play an important role in the pathophysiology of SB, and inhibition of sympathetic or cortical activity preceding the onset of SB and cortical arousals might reduce the occurrence of SB.

It is worth mentioning that there were some common features of RMMAs in SB patients and normal subjects. First, the increase in sympathetic activity and cortical arousals associated with RMMAs accompanied with LMs may last longer than that for generation of isolated RMMAs or isolated LMs since the durations of both LMs and RMMAs when they occurred together were significantly longer than that of isolated LMs and isolated RMMAs, respectively. Second, there were positive correlations between durations of RMMAs and LMs when they occurred together in both SB patients and normal subjects. These findings suggest genesis of RMMAs in both SB patients and normal controls might involve some common mechanisms.

There were some distinct differences in the occurrence of RMMAs between SB patients and normal subjects, however, although the occurrence of RMMAs in normal subjects followed the similar pattern as in SB patients. First, RMMAs which were accompanied with LMs in SB patients lasted longer than those in normal subjects (Fig. 3), which may indicate the increases in sympathetic activity associated with RMMAs and LMs last longer in SB patients. Second, there might exist some differences in frequency involved excitation of different parts of the CNS between SB patients and normal subjects during sleep as we have found most of the movements were RMMAs accompanied with LMs in SB patients while most of the movements in normal subjects were isolated LMs, and lower frequency of RMMAs in normal subjects as in the previous report [37]. Third, the occurrence of RMMAs in normal subjects might be more frequently accompanied with excitation of the CNS that controls LMs in normal subjects and occurrence of LMs in SB patients might be more frequently accompanied with excitation of the CNS that controls jaw movements. This was

supported by our findings that RMMAs in normal subjects were more likely to be accompanied with LMs and LMs in SB patients were more likely to be accompanied with RMMAs (Table 2). Fourth, the frequency of LMs, especially accompanied with RMMAs, was significantly higher in SB patients than in normal subjects (Fig. 2), which is consistent with previous findings that SB patients had more periodic leg movements than normal subjects and further suggests occurrence of LMs in SB patients might be more frequently accompanied with excitation of the CNS that controls jaw movements, which often involved cortical arousals [33,35]. Last, the percentages of phasic and mixed RMMAs in SB patients were significantly higher than those in normal subjects. The findings may partially, at least, explain why RMMAs cause damages to the tooth in some SB patients, but no damage in normal subjects since previous studies showed that the frequency and amplitude of RMMAs in SB patients were significantly higher than in normal subjects and the severity of tooth damage was positively related to the number and duration of phasic RMMAs [60].

Conclusion:

There are close relationships between LMs and RMMAs in SB patients and normal subjects. SB episodes may be part of cortical arousal responses and the increased cortical activities before and during SB episodes may not just be localized to the CNS that controls jaw movements (eg, cortical masticatory area) but may also include other parts of the CNS that controls LMs.

Limitation of the study:

The age range of the subjects was narrow and sample size of the study was relatively small. Moreover, no SB patients with severe symptoms were recruited. Further study with more polysomnographic recordings on large number of subjects is

required. In addition, the data used for presentation in the current study were collected only from one night recordings and polysomnographic recordings from more nights might be needed as RMMAs/SB in SB patients /normal subjects might vary from night to night.

Conflict of interest:

The authors have stated explicitly that there are no conflicts of interest in connection with this article.

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Table 1. Comparisons of age and general sleep variables between SB patients and normal subjects.

Variable	Normal subjects	SB patients
Age	21.44 (1.88)	21.75 (1.75)
Total sleep time (min)	405.56 (29.67)	415.13 (72.21)
Sleep efficiency (%)	93.15 (4.06)	95.77 (1.81)
Sleep stage (%)		
N1	11.78 (5.05)	8.53 (2.65)
N2	42.78 (7.30)	39.84 (4.52)
N3	22.54 (5.93)	29.26 (7.30)
REM	22.90 (3.77)	22.38 (5.63)
RMMA/SB index (events/h)	2.94 (1.73-4.99)	7.50 (6.19-13.26) ***
Arousal index (events/h)	3.30 (2.46-8.96)	7.25 (6.00-10.84) **
Apnea-Hypopnea index (events/h)	0.20 (0.00-0.70)	0.30 (0.00-1.00)
PLMI (events/h)	0.52 (0.00-3.05)	0.93 (0.00-5.42)

Mean (standard deviation) for variables with normal distribution.

Median (min-max) for variables with non-normal distribution. PLMI: periodic leg movement index.

**$P < 0.01$; ***$P < 0.001$

Table 2. The comparisons of RMMAs and LMs in SB patients and normal subjects.

	SB patients	Normal subjects	*P* value of χ^2 tests	P value of partition of χ^2 tests
Movements (n)	710	455		
A: RMMAs with LMs	47.32%	36.48%		< 0.001 (A : B)
B: Isolated RMMAs	16.62%	5.06%	< 0.001	< 0.001 (B : C)
C: Isolated LMs	36.06%	58.46%		< 0.001 (A : C)
LMs (n)	592	432		
A: Isolated	43.24%	61.57%	< 0.001	
B: With RMMAs	56.76%	38.43%		
RMMAs (n)	454	189		
A: Isolated	25.99%	12.17%	< 0.001	
B: With LMs	74.01%	87.83%		
RMMAs (n)	454	189		
A: Phasic	41.85%	38.62%	0.002	0.006 (A : B)
B: Tonic	17.40%	29.63%		< 0.001 (B : C)
C: Mixed	40.75%	31.75%		

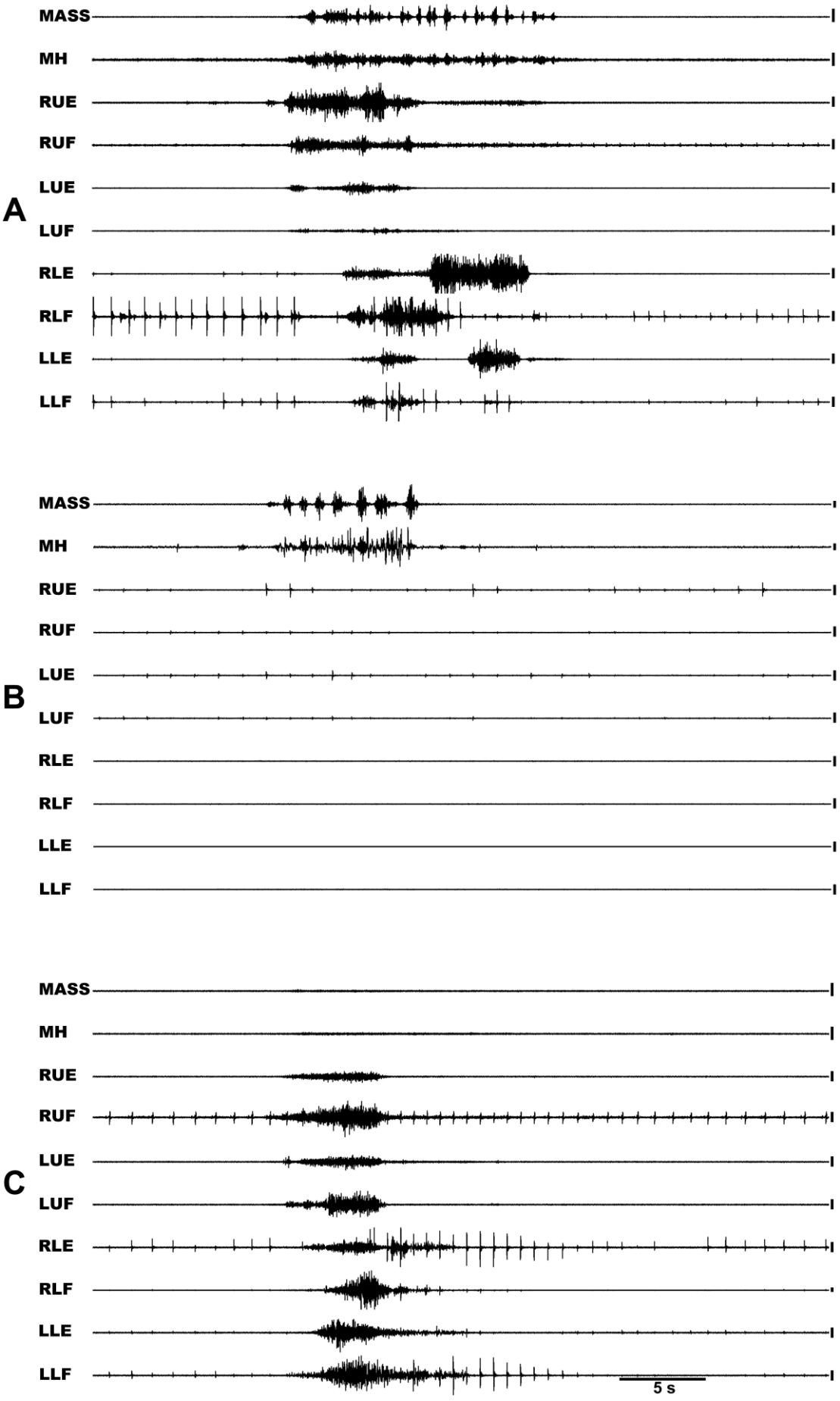
Figure legends:

Fig. 1. An example of RMMA accompanied with LM (**A**), isolated RMMA (**B**), and isolated LM (**C**) during sleep. MASS: masseter muscle; MH: myohyoid muscle; RUE: right extensor carpi radialis; RUF: right flexor carpi radialis; LUE: left extensor carpi radialis; LUF: left flexor carpi radialis; RLE: right tibialis anterior muscle; RLF: right gastrocnemius; LLE: left tibialis anterior muscle; LLF: left gastrocnemius. Horizontal bar: 5 s; Vertical bar:100 μV.

Fig. 2. Comparisons of the frequencies of LMs (A) and RMMAs accompanied with LMs (B), and isolated RMMAs (C) in SB patients and normal subjects. Error bars represent one standard deviation. *$P < 0.05$; ***$P < 0.001$.

Fig. 3. Comparisons of the durations of RMMAs (A) and LMs (B) in SB patients and normal subjects. Error bars represent one standard deviation. **$P < 0.01$; ***$P < 0.001$.

Fig. 4. Relationships between durations of RMMAs and LMs in SB patients and normal subjects when RMMAs were accompanied with LMs.


A
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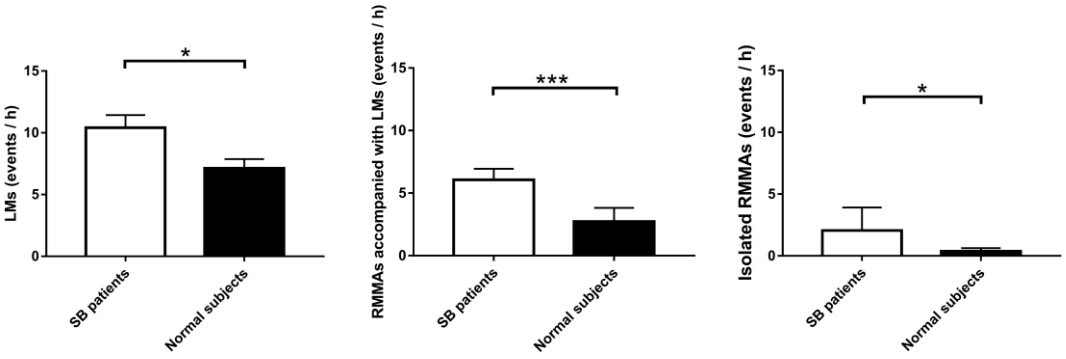
LMs (events / h)
15
10
5
0
*
SB patients
Normal subjects
RMMAs accompanied with LMs (events / h)
15
10
5
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***
SB patients
Normal subjects
Isolated RMMAs (events / h)
15
10
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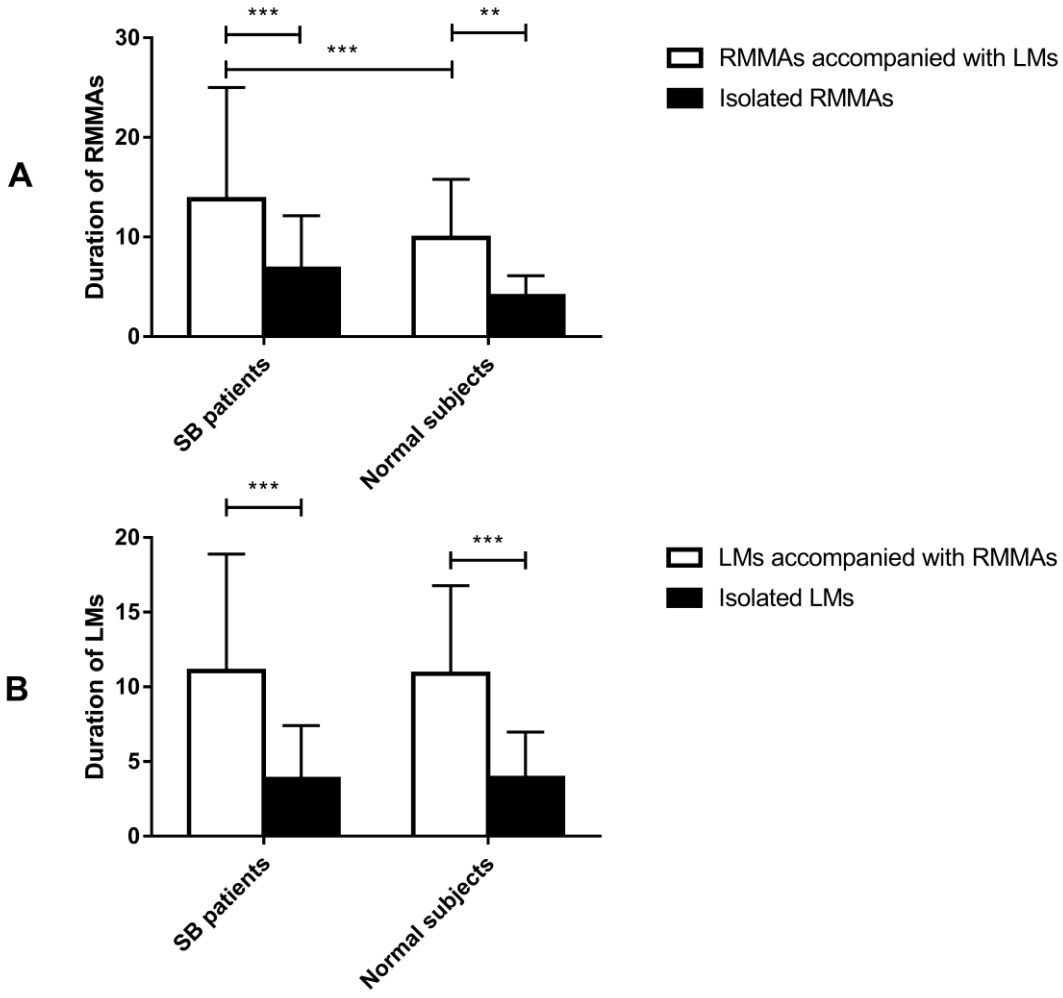
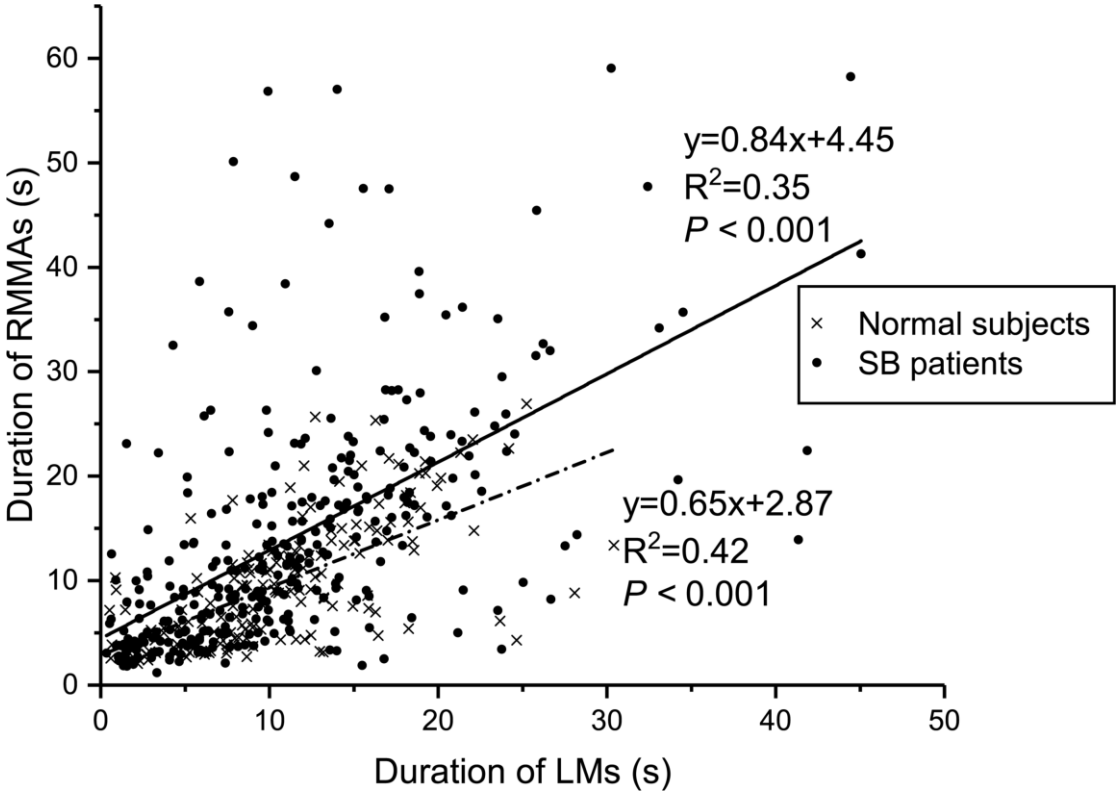
*
SB patients
Normal subjects


A
Duration of RMMAs
30
20
10
0
***
***
**
SB patients
Normal subjects
RMMAs accompanied with LMs
Isolated RMMAs
B
Duration of LMs
20
15
10
5
0
***
***
SB patients
Normal subjects
LMs accompanied with RMMAs
Isolated LMs


Duration of RMMAs (s)
Duration of LMs (s)
y=0.84x+4.45
R2=0.35
P < 0.001
y=0.65x+2.87
R2=0.42
P < 0.001
Normal subjects
SB patients
0
10
20
30
40
50
60