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RESEARCH ARTICLE

Influence of periodontal afferent inputs for human cerebral blood oxygenation during jaw movements

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Abstract Using functional magnetic resonance imaging (fMRI) and near-infrared spectroscopy (NIRS), we examined the role of periodontal afferent inputs on cerebral activation pattern evoked by masticatory muscle activity in twenty-two subjects. Statistical comparisons were used to identify brain regions with significant activation after subtraction of baseline activity from sham teeth-tapping (no periodontal input) and teeth-tapping (periodontal input) activity in an fMRI (N = 14) and NIRS study (N = 8). Both sham teeth-tapping and teeth-tapping significantly activated bilateral sensorimotor cortex and supplementary motor area in the fMRI study. NIRS revealed that oxygenated hemoglobin concentrations increased in sensorimotor cortex; however, there was no significant difference in degree of oxygenated hemoglobin changes between sham teeth-tapping and teeth-tapping. A control study (N = 8) characterized the jaw muscle activity and amplitude of the two motor tasks and demonstrated significantly higher electromyogram (EMG) activity in the jaw closing muscles during teeth contact in the teeth-tapping session. Since the cerebral activation during sham teeth-tapping and teeth-tapping was similar, we suggest that the influence of periodontal afferent inputs and associated jaw muscle activity is relatively minor compared to the rhythmic jaw movements. Although the clinical significance of the present findings remains unknown, they may have implications for the understanding of awake or sleep-related bruxism characterized by subconscious and rhythmic teeth-grinding or teeth-clenching.

Keywords Functional magnetic resonance imaging · Near-infrared spectroscopy · Periodontal afferent inputs · Masticatory muscle · Cerebral activity · Trigeminal physiology

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Introduction

The cortical networks related to various types of jaw movements have been examined with different neuroimaging techniques using fMRI (Onozuka et al. 2002; Tamura et al. 2003) or positron-emission tomography (PET) (Momose et al. 1997). Onozuka et al. and Momose et al. demonstrated that a rhythmic gum-chewing task evoked significantly greater cerebral activity than a rest condition using fMRI and PET (Momose et al. 1997; Onozuka et al. 2002). In an fMRI study, Tamura et al. found differences in

cerebral activity between voluntary jaw movements and mastication (Tamura et al. 2003). In addition, some groups have suggested that there are differences in cerebral activity associated with jaw movements between patients with complete dentures and those with implant-supported dentures (Yan et al. 2008; Kimoto et al. 2011). Thus, these fMRI and PET studies have provided evidence that rhythmic jaw movements or mastication increases cerebral activity in various regions of the human brain. However, the examined jaw movements included both masticatory muscle activity and teeth contact, and these studies did not describe the potential contribution from the periodontal membrane receptors evoked by tooth contact. The importance of sensory-motor integration for oral function has, for example, been demonstrated in a study by Teismann et al. who showed that a short-term decrease in oropharyngeal sensory input impedes the cortical control of swallowing (Teismann et al. 2007). However, there may be differences in the sensory-motor integration between rhythmic jaw movement and swallowing. Thus, to clarify the cerebral activity during rhythmic jaw movements, it is essential to investigate the role of periodontal membrane receptors in cerebral activation during jaw movement using neuroimaging studies. Additionally, in order to understand the cerebral activation patterns in clinical conditions such as awake or sleep-related bruxism, it may be important to investigate the impact of periodontal afferent inputs to the cerebral activity.

In a recent fMRI study, we demonstrated that there are significant differences in cerebral activity between a teeth-clenching task and a bilateral hand motor task and suggested that teeth-clenching induces more complex cerebral activity than performance of a hand motor task (Iida et al. 2010a). Byrd et al. also reported in an fMRI study that activation in supplementary motor area (SMA) during teeth-clenching in participants with normal function was significantly higher than in participants with self-reported bruxism (Byrd et al. 2009). In addition, near-infrared spectroscopy (NIRS) studies have shown that the intensity of teeth-clenching influences the activation level of cerebral activity (Shibusawa et al. 2009; Takeda et al. 2010). Furthermore, magnetoencephalography studies have reported increased activity in sensorimotor cortex (SMC), pre-motor cortex, somatosensory cortex, and cerebellum, with each of these areas involved in the signal pathway immediately preceding teeth-clenching (Iida et al. 2007; Iida et al. 2010b). However, the mechanisms of awake or sleep-related bruxism have not been described in detail using neuroimaging techniques.

In contrast to fMRI and PET studies, NIRS analysis focuses only on a small region of interest in the lateral cortical surface (Isobe et al. 2001; Noguchi et al. 2002) but allows more flexible task selection than fMRI (Miyai et al. 2001). Some investigators have used rhythmic jaw movement tasks in NIRS studies (Narita et al. 2009; Shibusawa et al. 2009; Takeda et al. 2010). However, no NIRS studies have addressed the potential contribution from periodontal membrane receptors evoked by tooth contact. Since fMRI and NIRS techniques are to a certain extent complementary, several groups have reported simultaneous measurements using fMRI and NIRS (Kleinschmidt et al. 1996; Benaron et al. 2000; Cannestra et al. 2001; Toronov et al. 2001a, b; Okamoto et al. 2004; Sakatani et al. 2007).

The present study was designed to detect differences in cerebral activity and masticatory muscle activity during teeth-tapping (periodontal input) and sham teeth-tapping (no periodontal input) using EMG, fMRI, and NIRS. The specific hypothesis was that teeth-tapping and associated periodontal afferent stimulation would lead to a differential activation pattern during rhythmic jaw movements. As a separate control experiment, we included recordings of EMG activity and jaw movement to characterize the differences between the two motor tasks.

Materials and methods

Subjects

This study included a total of 30 participants (23 men and 7 women, mean ± SE age of 28.2 ± 0.9 years) with no history of neurological disorders and without abnormalities of stomatognathic function based on a dental history including standard questionnaires and an oral examination. Fourteen subjects (12 men and 2 women, mean ± SE age of 27.3 ± 0.7 years) participated in the fMRI study, eight subjects (6 men and 2 women, mean ± SE age of 27.2 ± 1.5 years) participated in the NIRS study, and eight subjects (5 men and 3 women, mean ± SE age of 30.7 ± 1.4 years) participated in the EMG study. Each study was performed on a separate day. Informed consent was obtained prior to the experiment from all subjects. This protocol was approved by the Ethics Committee of the Nihon University School of Dentistry at Matsudo (EC 07-009 and EC 10-006) and Local Ethics Committee in Aarhus, Denmark (20110101) based on the guidelines set forth in the Declaration of Helsinki.

Experimental motor tasks

The study involved two motor tasks: a sham teeth-tapping task (ST) and a teeth-tapping task (TT). During the teeth tapping task, subjects were instructed to perform teeth tapping at a rhythm of 1.0 Hz (Takeuchi et al. 2001; Hasegawa et al. 2007). During the sham teeth tapping task, the subjects were instructed to mimic teeth tapping

movements at a rhythm of 1.0 Hz, but not to bring the teeth into contact during this task (no periodontal input). All subjects were instructed that the lower jaw should be kept in mandibular rest position during the rest blocks. The subjects were trained in these tasks (ST and TT) to ensure consistency in the performance. After each measurement (EMG, fMRI, NIRS), subjects were asked whether they had adhered to the instructions during measurement, and if not or in doubt, the measurement was repeated.

fMRI acquisition and data analysis

Functional magnetic resonance imaging was performed using a Philips 1.5 T Achieva system (Philips Medical Systems, Best, The Netherlands) with parameters identical to those in our previous study (Iida et al. 2010a). The duration of each effort was 30 s, with 30-s rest intervals, and subjects successively performed each task four times in a single scan (Fig. 1a). Therefore, each scan consisted of 160 scans for a total duration of 480 s. The first trial in each scan began with a rest block, randomly followed by a task block (ST or TT) at an auditory signal. Subjects heard only noise from the scanner during the rest blocks.

Functional image analysis was performed using statistical parametric mapping (SPM2 software from The Wellcome Trust Centre for Neuroimaging, Institute of Neurology, University College London, UK) implemented in MATLAB 2009a (Mathworks Inc., Natiek, MA, USA). All functional images were realigned to correct for head movement. Images were corrected if the head moved within 1.5 mm (translational) and 1° (rotational) compared to the first image in the time series. T1-weighted anatomical images were co-registered with the mean EPI image and transformed to standard stereotaxic space (Montreal Neurological Institute [MNI] template). Functional images were normalized by applying the same transformation parameters. An isotropic Gaussian kernel of 8 mm full-width at half-maximum (FWHM) was applied to spatially smooth the data. A general linear model (GLM) design was used for the analysis of regional activity differences in ST, TT, and baseline (BL) with each condition modeled by convolving a box-car function for each participant (Friston et al. 1994). Statistical parametric maps of the *t*-statistic were generated on a voxel-by-voxel basis, and these individual data were then analyzed as a group in a random-effects model. The statistical threshold level for individual analysis was set to $P < 0.001$ (corrected) at cluster level. The statistical threshold level for group analysis was set to $P < 0.001$ (uncorrected) at voxel level and cluster volume >10 voxels (Byrd et al. 2009; Jiang et al. 2010). Cerebral activation was rendered either onto T1 brain slices or the surface of a standard MNI brain. Locations of brain regional activities were transformed from MNI coordinates

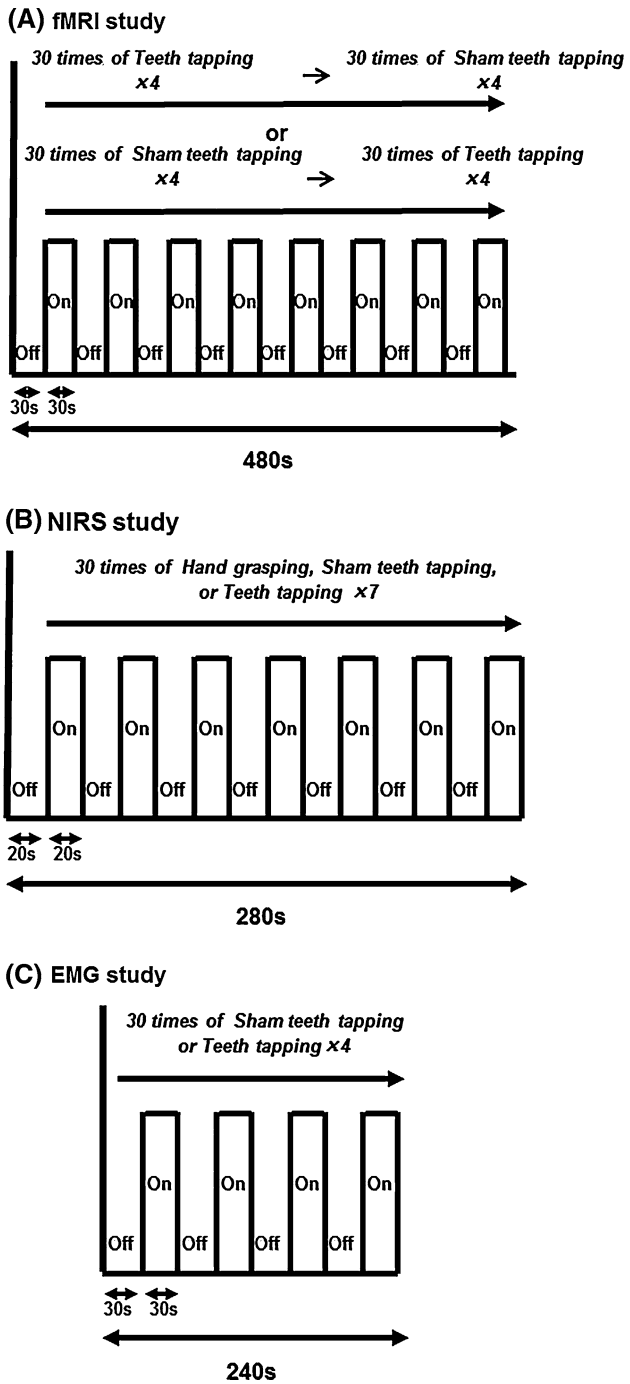

Fig. 1 Experimental task paradigm and NIRS channel setting. **a** In the fMRI study, each participant performed sham teeth-tapping (ST) and teeth-tapping (TT) alternating between a 30-s rest block and a 30-s task block for 480 s. Each measurement started with a rest block, followed by a randomly assigned task block (ST/TT). **b** In the NIRS study, each participant performed a 20-s rest block and a 20-s task block for 280 s in a single measurement, consisting of ST, TT, or hand-grasping and rest. Each participant performed 2 measurements for each task. **c** In the EMG study, subjects alternately performed 30-s rest block and 30-s task block for 240 s in a single measurement, wherein a single measurement consisted of one task (ST or TT) and rest. All subjects performed both tasks

to Talairach standard coordinates (Talairach and Tournoux 1988) using TALAIRACH DAEMON CLIENT software (version 2.4.2; University of Texas Health Science Center, San Antonio, TX, USA).

NIRS acquisition and data analysis

We employed an OMM-2000 Oxygenation Multichannel Monitor (Shimadzu, Kyoto, Japan) to undertake 2D imaging of the changes in concentration of oxyhemoglobin (oxyHb), deoxyhemoglobin (deoxyHb) and total-hemoglobin (= Oxy-Hb + Deoxy-Hb; Total-Hb) in the activated cortices of the bilateral frontal lobes. This system consists of 16 light-source fibers and 16 detectors resulting in 48 channels; each light source has three laser diodes with wavelengths of 780, 805, and 830 nm. The placement of the probe over the SMC was in accordance with other NIRS studies (Murata et al. 2002; Fujiwara et al. 2004). The optical electrodes of the NIRS system were placed on the skull to cover the bilateral frontal lobes, including the SMC, employing a holder cap to avoid motion-related artifacts; the distance between each optical electrode was 30 mm. During the measurements, subjects alternately performed a 20-s rest block and a 20-s task block for 280 s in a single measurement (Fig. 1b), wherein a single measurement consisted of one task (ST, TT, or hand-grasping) and rest. Since limitations of NIRS with respect to fMRI are the lower spatial resolution, we applied a hand-grasping task as a control task to determine the optical channel related to the jaw motor task (Svensson et al. 2003, 2006; Baad-Hansen et al. 2009). During the hand-grasping task, subjects were instructed to perform hand grasping with both hands at a rhythm of 1.0 Hz. The first trial in each session began with a rest block. Each subject performed 2 sessions for each task. During measurement, the subjects sat on the chair in a relaxed position in a quiet room. The arm was also relaxed on an armrest. We focused the analysis on changes in oxyHb since it has been reported that oxyHb is the best indicator of change in cerebral blood flow in NIRS studies (Hoshi et al. 2001; Shibusawa et al. 2009). The oxyHb value for the 20 s period during each task was averaged from each channel from all trials in each subject. Initially, oxyHb levels were compared in each channel between the hand-grasping task and TT to determine the optical response in the hand motor area. Second, oxyHb levels were compared in each channel between the hand-grasping task and TT, and the optical channel related to the jaw motor task was determined. Finally, oxyHb levels were compared between ST and TT in the optical channel of the SMC related to the jaw motor task. OxyHb levels were also compared between hand-grasping task and ST in the optical channel of the SMC related to the jaw motor task. Comparisons of oxyHb levels were achieved with the use of paired *t*-test. Statistical analyses were conducted at a 95% confidence level, with *P* values less than 0.05 considered significant.

Electromyographic acquisition and data analysis

During the measurements, subjects alternately performed 4 times of 30-s rest block and 4 times of 30-s task block for 240 s in a single measurement (Fig. 1c), wherein a single measurement consisted of one task (ST or TT) and rest. All subjects performed both tasks. In each subject, surface electromyographic (EMG) activity was recorded from left masseter muscle (LM), right masseter muscle (RM), left anterior temporalis muscle (LT), and right anterior tempo-

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the use of a paired *t*-test. Durations were compared between opening, closing, and occlusal phase for ST and TT. RMS was also compared between opening, closing, and occlusal phase in LM, RM, LT, and RT muscles. Duration and RMS in LM, RM, LT, and RT muscles were analyzed with two-way analysis of variance (ANOVA). When appropriate, the ANOVAs were followed by post hoc Tukey's tests to compensate for multiple comparisons. *P* values less than 0.05 were considered significant.

Results

fMRI experiment

Mean and standard error (SE) values of head movement in the image correlation analysis were 1.17 mm (SE ± 0.12 mm). The head movements of all subjects were less than 1.5 mm (translational) and 1° (rotational). ST and TT activated bilateral SMC and bilateral SMA in all participants. Statistical maps of the brain regions with significant increases in blood oxygenation level–dependent (BOLD) contrast during ST and TT group analysis are shown in Fig. 2a, b, respectively. Cerebral regional activation did not differ significantly between ST and TT (relative to BL). The locations of the most significant foci of activation (multiple comparisons) for these regions are summarized in Table 1, in which Talairach coordinates of anatomical regions with maximum *t*-values are shown. ST and TT significantly activated bilateral primary somatosensory cortex, bilateral primary motor cortex, bilateral SMA, and bilateral insula cortex ($P < 0.001$) (Table 1). The SMA activations extended into the cingulate cortex during both tasks. Cerebral activation in the auditory cortex was not detected during any tasks. Due to limited slice coverage, no cerebellar ROIs could be defined. A direct comparison of cerebral regional activity with TT minus ST revealed no cerebral activation ($P < 0.001$) (not shown in Table 1). Typical cerebral areas with activation in the axial planes $x = 56$, $y = 6$, and $z = 26$ during ST and TT are shown in Fig. 2c, d, respectively. Overall, there was a similar cerebral activation in ST and TT.

NIRS experiment

Figure 3a and b shows a comparison of oxyHb concentration changes between hand-grasping, ST and TT. Changes in oxyHb concentrations during the hand-grasping task were significantly higher than those for TT in channels 13 and 36 ($P < 0.05$). Changes in oxyHb concentrations during TT were significantly higher than in the hand-grasping task in channels 12 and 37 ($P < 0.05$). Changes in oxyHb concentrations during ST were significantly higher than in the hand-grasping task in channels 12 and 37 ($P < 0.05$). OxyHb concentration changes in channels 12

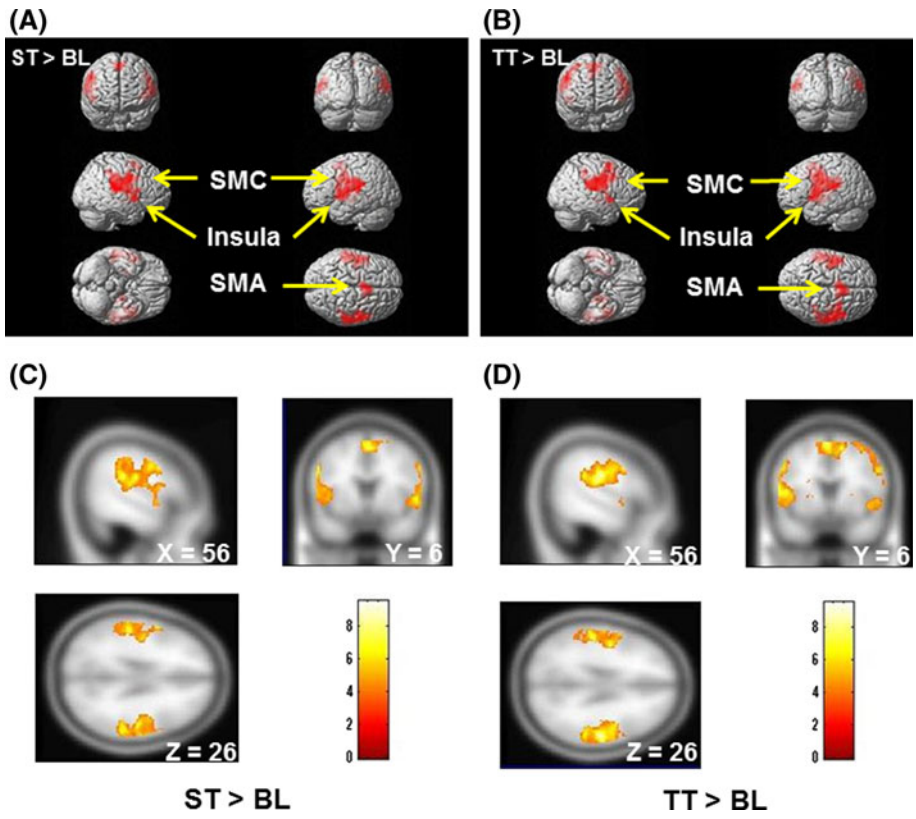

Fig. 2 Surface projection of statistical parametric maps superimposed onto a standard MNI standard template brain, and cerebral areas typically activated in the axial planes $x = 56$, $y = 6$, and $z = 26$ on the MNI standard template brain. Shown are clusters of at least 10 neighboring voxels ($P < 0.001$, uncorrected for multiple comparisons). **a** ST minus BL, **b** TT minus BL, **c** ST minus BL, **d** TT minus BL. *ST* sham teeth-tapping activity, *BL* baseline activity, *TT* teeth-tapping activity, *Insula* insula cortex, *SMC* sensorimotor cortex, *SMA* supplementary motor area

Table 1 Significantly activated regions in the group analysis during sham teeth-tapping and teeth-tapping minus baseline

Brain region activated	BA	Coordinates			*t*-value
		X	Y	Z	
ST > BL					
PSC	2L	−54	−22	28	5.19
PSC	3R	60	−16	24	8.52
PMC	4L	−58	−14	28	5.6
PMC	4R	54	−16	24	8.6
SMA	6L	−4	4	62	7.81
SMA	6R	6	10	52	8.71
Insula	13L	−44	0	2	6.67
Insula	13R	46	2	0	6.1
ST > BL					
PSC	3L	−54	−16	26	4.37
PSC	3R	58	−18	22	7.18
PMC	4L	−54	−14	30	4.4
PMC	4R	52	−14	24	6.29
SMA	6L	−4	2	62	8.08
SMA	6R	2	6	56	7.61
Insula	13L	−42	−8	18	9.35
Insula	13R	32	−8	16	5.72

Uncorrected $P < 0.001$. *BA* Brodmann's area, *ST* sham teeth-tapping activity, *BL* baseline activity, *TT* teeth-tapping activity, *L* left hemisphere, *R* right hemisphere, *PSC* primary somatosensory cortex, *PMC* primary motor cortex, *SMA* supplementary motor area, *Insula* insula cortex

and 37 did not differ between ST and TT ($P = 0.40$ (channel 12), 0.49 (channel 37)).

EMG experiment

The EMG activity in all jaw muscles were significantly dependent on task ($F = 13.715$; $P < 0.001$ in LM), ($F = 10.204$; $P < 0.001$ in RM), ($F = 16.365$; $P < 0.001$ in LT), ($F = 10.211$; $P < 0.001$ in RT). Post hoc tests demonstrated that the RMS values during TT in the occlusal phase were significantly higher than the RMS during ST in the "occlusal" phase (Tukey: $P < 0.001$ in LM, RM, LT, and RT) (Fig. 4a, b, c, d). However, the duration of each of the different phases did not differ between ST and TT ($F = 0.801$; $P = 0.502$) (Fig. 4e). Additionally, the maximum displacements in the vertical axis were not significantly different between ST and TT ($P = 0.145$) (Fig. 4f).

Discussion

In this fMRI study, we have shown that ST and TT activated bilateral primary somatosensory cortex, bilateral primary motor cortex, bilateral SMA, and bilateral insula cortex and that activity in cerebral regional areas did not differ significantly between ST and TT. The NIRS study demonstrated that oxyHb increased in the SMC during ST and TT; however, no significant difference in degree of oxyHb changes was observed between ST and TT. The EMG study demonstrated that although masticatory muscle activity in the opening and closing phases did not significantly differ between ST and TT, masticatory muscle activity in the occlusal phase during TT was significantly higher than during ST. Importantly, duration and displacement of the vertical jaw movements were not significantly different between ST and TT.

Takada et al. demonstrated that rhythmic gum-chewing caused significantly higher activity in the dorsolateral prefrontal cortex (DLPFC) than sham gum-chewing (Takada and Miyamoto 2004). Our recent fMRI study demonstrated that light teeth-clenching activated bilateral SMC, bilateral SMA, and bilateral DLPFC (Iida et al. 2010a). In this fMRI study, we found that ST and TT did not activate the DLPFC. These findings suggest that cerebral activity in DLPFC is influenced by food-related contacts of the teeth or continuous teeth contact.

The present study also demonstrated that there was no correlation between masticatory muscle activity and cerebral activity. Shibusawa et al. reported that the intensity of teeth-clenching could influence the magnitude of cerebral activity in SMC (Shibusawa et al. 2009). Yan et al. also demonstrated that there is a significant difference in cerebral activation in SMC between patients with complete dentures and those with implant-supported dentures during various teeth-clenching tasks (Yan et al. 2008). However, these studies investigated cerebral activity during teeth-clenching tasks. Although teeth-clenching involves a continuous masticatory muscle action without jaw movements, gum-chewing and teeth-tapping are classified as repetitive or rhythmic masticatory muscle actions. Takada et al. found no significant difference in cerebral activation in SMC between rhythmic gum-chewing and sham gum-chewing (Takada and Miyamoto 2004). Kimoto et al. also reported no significant difference in cerebral activation in SMC between patients with complete denture and those with implant-supported removable overdentures during gum-chewing (Kimoto et al. 2011). Our fMRI and NIRS findings revealed no significant difference in cerebral activation in SMC between ST and TT. It suggests that rhythmic afferent output from the periodontal mechanoreceptor did not significantly influence the cerebral activation in SMC. In addition, the present findings suggest that cerebral activity during rhythmic jaw movements is not influenced by the phasic inputs from periodontal mechanoreceptors, but rather is reflecting the continuous and rhythmic activity from muscle spindles, and other mechanoreceptors related to jaw movement.

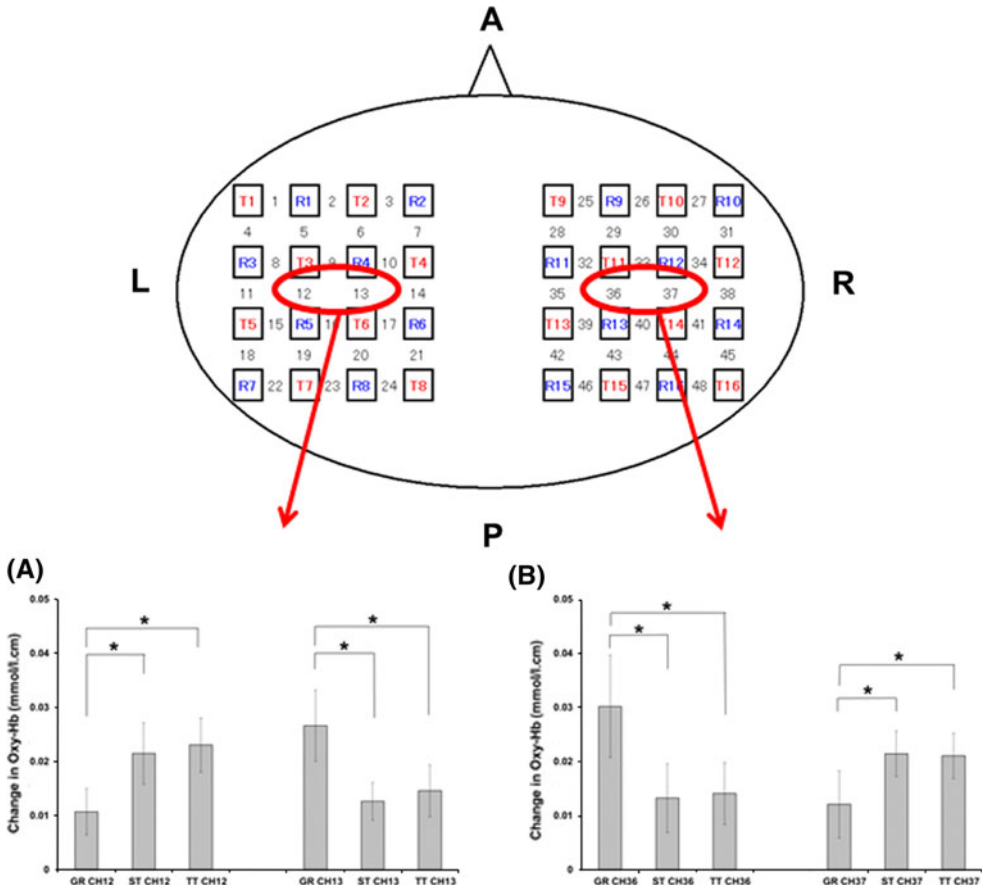

Fig. 3 Comparison of oxyHb levels in cerebral cortex between hand-grasping tasks, teeth-tapping, and sham teeth-tapping on both sides. **a** OxyHb levels during the hand-grasping task were significantly higher than during teeth-tapping in channel 13 ($P < 0.05$). OxyHb levels during the teeth-tapping task were significantly higher than in the hand-grasping task in channel 12 ($P < 0.05$). OxyHb levels during the sham teeth-tapping task were also significantly higher than in the hand-grasping task in channel 12 ($P < 0.05$). There was no significant difference between ST and TT in channel 12. **b** OxyHb levels during the hand-grasping task were significantly higher than in the teeth-tapping task in channel 36 ($P < 0.05$). OxyHb levels during the teeth-tapping task were significantly higher than in the hand-grasping task in channel 37 ($P < 0.05$). OxyHb levels during the sham teeth-tapping task were also significantly higher than in the hand-grasping task in channel 37 ($P < 0.05$). There was no significant difference between ST and TT in channel 37. *GR* hand-grasping activity, *ST* sham teeth-tapping activity, *TT* teeth-tapping activity

Recent fMRI study demonstrated that teeth-clenching induces a more complex cerebral activity compared with the performance of a hand motor task. (Iida et al. 2010a). Other fMRI studies have indicated that there are differences in cerebral activation patterns between a normal control group and patients with self-reported bruxism (Byrd et al. 2009; Wong et al. 2011). The present findings suggest that the characteristic cerebral activity related to orofacial parafunctional habits may be dependent on the rhythmicity of the jaw movements rather than the actual amount of EMG activity in the jaw muscles which would point to the importance of afferent signals from jaw muscle spindles and other mechanoreceptors related to jaw movements. However, sham teeth-tapping may require more masticatory muscle control, but not EMG activity, than teeth-tapping in order to avoid teeth contact. Further studies will be needed to clarify the relationship between cerebral activity and periodontal afferent inputs during teeth-clenching and the possible implications for awake or sleep-related bruxism.

The sound of teeth contacts may also have induced an auditory input during teeth-tapping, but no cerebral activation in the auditory cortex was observed in this study. This observation is in agreement with other fMRI studies on cerebral activity during gum-chewing and teeth-tapping (Onozuka et al. 2002; Tamura et al. 2003; Kimoto et al. 2011). In addition, Takada et al. found no cerebral activation in the auditory cortex during rhythmic gum-chewing or sham gum-chewing (Takada and Miyamoto 2004). However, Tachibana et al. investigated the cerebral activities related to finger movement using auditory feedback and detected audiomotor-related activities from SMC, SMA, and the auditory cortex (Tachibana et al. 2010). We suggest that auditory cortex activation is not a critical part

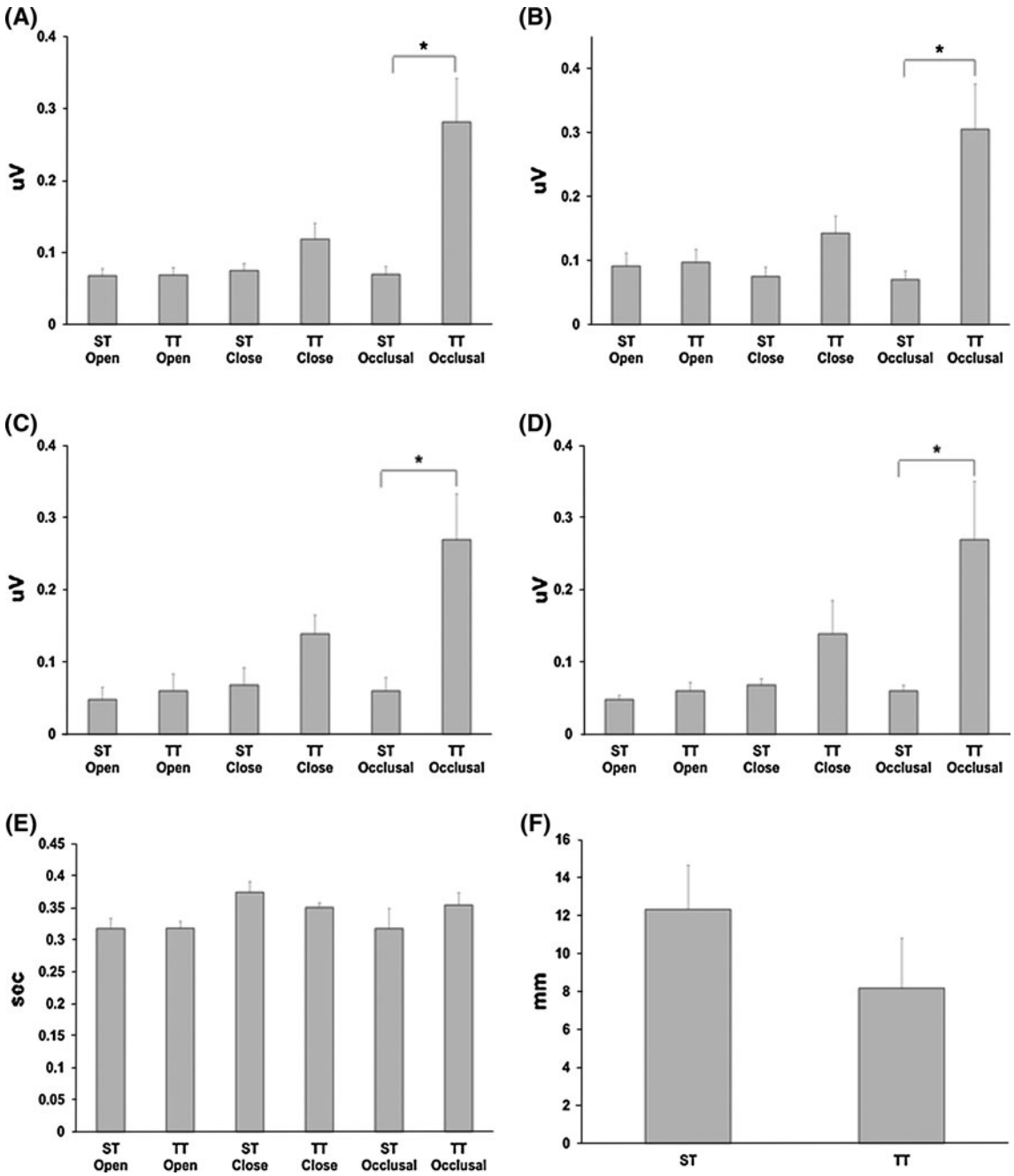

Fig. 4 Comparison of root-mean-square (RMS) between sham teeth-tapping (ST) and teeth-tapping (TT) in left masseter muscle (**a**), right masseter muscle (**b**), left temporalis muscle (**c**), and right temporalis muscle (**d**). RMS during TT is significantly higher than during ST in occlusal phase ($P < 0.001$). Figure 4e shows comparison of duration in each phase between ST and TT. Durations in each phase are not significantly different between ST and TT. Figure 4f shows comparison of displacement of vertical movement in one cycle between ST and TT. Displacements of vertical movement in on cycle are not significantly different between ST and TT

of the cortical activation pattern during teeth-tapping or sham teeth-tapping.

Penfield et al. showed that the location of the cortical mastication area is in the lower part of SMC (Penfield and Boldrey 1937). Our previous fMRI study reported BOLD responses during fist clenching in the axial plane ranging from $z = 54$ to $z = 58$ and during teeth-clenching in the axial plane ranging from $z = 34$ to $z = 36$ (Iida et al. 2010a). In addition, Onozuka et al. have reported BOLD responses during gum-chewing in the axial plane ranging from $z = 30$ to $z = 38$ (Onozuka et al. 2002). Our study also demonstrated BOLD responses during TT and ST in the axial plane ranging from $z = 22$ to $z = 30$. These findings suggest that the

cortical masticatory area may be located around $z = 30$ in humans.

Since bruxism is defined as an awake (non-sleep) or a sleep parafunctional activity that includes clenching, bracing, gnashing, and grinding of the teeth (Okesson 1996), two methods (fMRI and NIRS) were used in this study to test the hypothesized differences in cerebral activation between a supine position and a seated position during execution of the same jaw movements. Since NIRS possess low spatial resolution, our NIRS study focused only on the SMC during ST and TT by references to a hand-grasping task. Neither the fMRI nor the NIRS study found any differences in cerebral activation in SMC between ST and TT and may therefore suggest that body posture during jaw movement does not significantly influence the cerebral activation pattern in SMC. However, some investigators have suggested that prefrontal cortex is a major component in cerebral activity during mastication and teeth-clenching (Toronov et al. 2001a, b; Narita et al. 2009; Iida et al. 2010a; Kimoto et al. 2011). Further studies related to jaw movement are needed, focusing on the prefrontal cortex, for example, using NIRS.

Although some recent studies have reported that nonferrous EMG methods can be used to simultaneously measure and compare muscle activity during fMRI scans (van Duinen et al. 2005; Ganesh et al. 2008; Manganotti et al. 2010), this method was not feasible in the present study. Therefore, we included a separate EMG session to characterize the EMG and jaw movement during ST and TT. Direct recordings and analysis of EMG signals during fMRI scans or NIRS measurement will be needed to further clarify the correlation between masticatory muscle activity and cerebral activity during jaw movements.

Based on the present findings, we propose that there is no correlation between masticatory muscle activity and the phasic afferent activity from periodontal mechanoreceptors and cerebral activity in SMC. Although the clinical significance of the present findings remains unknown, they may have implications for the understanding of awake or sleep-related bruxism characterized by subconscious and rhythmic teeth-grinding or teeth-clenching.

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