Journal of the Neurological Sciences 347 (2014) 288–294

Contents lists available at ScienceDirect

Journal of the Neurological Sciences

journal homepage: www.elsevier.com/locate/jns

Somatosensory evoked magnetic fields following tongue and hard palate stimulation on the preferred chewing side

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ARTICLE INFO

Article history:
Received 14 June 2014
Received in revised form 22 September 2014
Accepted 14 October 2014
Available online 22 October 2014

Keywords:
Magnetoencephalography
Mastication
Primary somatosensory cortex
Somatosensory evoked fields
Somatosensory evoked potentials
Trigeminal nerve

ABSTRACT

Although oral sensory feedback is essential for mastication, whether the cortical activity elicited by oral stimulation is associated with the preferred chewing side (PCS) is unclear. Somatosensory evoked fields were measured in 12 healthy volunteers (6 with the right side as the PCS and 6 with the left side as the PCS) following tongue and hard palate stimulation. Three components were identified over the contralateral (P40m, P60m, and P80m) and ipsilateral [P40m(I), P60m(I), and P80m(I)] hemispheres. Since no component was consistently detected across subjects, we evaluated the cortical activity over each hemisphere using the activated root-mean-square (aRMS), which was the mean amplitude of the 18-channel RMS between 10 and 150 ms. For tongue stimulation, the aRMS for each hemisphere was 8.23 ± 1.55 (contralateral, mean ± SEM) and 4.67 ± 0.88 (ipsilateral) fT/cm for the PCS, and 5.11 ± 1.10 (contralateral) and 4.03 ± 0.82 (ipsilateral) fT/cm for the non-PCS. For palate stimulation, the aRMS was 5.35 ± 0.58 (contralateral) and 4.62 ± 0.67 (ipsilateral) fT/cm for the PCS, and 4.63 ± 0.56 (contralateral) and 4.14 ± 0.60 (ipsilateral) fT/cm for the non-PCS. For hard palate stimulation, the aRMS did not differ between the PCS and non-PCS, whereas for tongue stimulation, the contralateral hemisphere aRMS was significantly greater for the PCS than for the non-PCS. Thus, our results show that lateralized cortical activation was associated with the PCS for tongue, but not hard palate, stimulation; a potential reason for this may be the different sensory-inputs between these two areas, specifically the presence or absence of fine motor function.

1. Introduction

The oral region is an important and sensitive anatomical structure that performs vital functions, including mastication, vocalization, and breathing. Mastication is a sensorimotor activity that prepares food for swallowing. Although mastication can be bilateral, most people prefer one side of the mouth, known as the preferred chewing side (PCS) [1,2]. Previous studies reported PCS effects on dental or facial parameters, including occlusion, bite force, facial asymmetry, cusp form, or temporomandibular disorders [3–11]. However, little is known regarding whether the PCS is related to the central nervous system, especially cortical activity related to sensorimotor processing.

Using functional magnetic resonance imaging (fMRI), Shinagawa et al. [12] demonstrated that the intensity of the blood-oxygenation-level-dependent (BOLD) signal in the primary sensorimotor cortex was significantly greater in the hemisphere contralateral to the PCS during tongue movement. This finding suggests that chewing-related cortical activity is associated with the PCS. Although oral sensory feedback is essential for mastication [13,14], limited information exists regarding whether cortical activity evoked with oral stimulation depends on the PCS.

A previous study reported that an asymmetric BOLD signal was observed in the primary somatosensory cortex (SI) between the PCS and the non-PCS with mechanical tongue stimulation [15]. This is interesting given the unique characteristics of the tongue. The tongue serves an investigatory motor function and receives "active touch" sensory input during mastication. Active touch refers to the physical act of "touching" [16]. This type of sensory input can be differentiated from "passive touch," or the passive act of being touched, which is associated with the hard palate in the oral region.

Sensory feedback from the hard palate plays an important role in mastication along with the tongue, as the tongue and hard palate contact each other constantly during mastication. However, the peripheral sensory input mechanism that provides the sensory feedback is different for the tongue and hard palate. The principle difference in sensory perception between these two areas is related to the presence or absence of fine motor function. The hard palate has no motor function and receives "passive touch" sensory input. However, it is unknown

Abbreviations: aRMS, activated root-mean-square; BOLD, blood-oxygenation-level-dependent; ECDs, equivalent current dipoles; fMRI, functional magnetic resonance imaging; MEG, magnetoencephalography; PCS, preferred chewing side; SEFs, somatosensory evoked fields; SEM, standard error of the mean; SI, primary somatosensory cortex.

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http://dx.doi.org/10.1016/j.jns.2014.10.025
0022-510X/

whether the hard palate is associated with a lateralized cortical response specific for the PCS.

The objective of the present study was to investigate the effect of PCS on evoked responses in the SI following tongue and hard palate stimulation using magnetoencephalography (MEG). We used MEG to record evoked cortical activation following trigeminal nerve stimulation since it offers adequate spatial accuracy while maintaining excellent temporal resolution [17,18].

2. Methods

2.1. Subjects

We studied 16 healthy volunteers (13 men and 3 women; age, 23–39 years; mean age, 28.8 years) with no history of neurological illness, orthodontic treatment, or either acute or chronic pain in the orofacial area. Participants were right-handed, as determined by the Edinburgh Handedness Inventory [19].

2.2. Ethics statement

Written informed consent was obtained from all participants before the study; the study protocol was approved by the Hokkaido University Hospital Ethical Committee.

2.3. Determination of the PCS

The PCS was evaluated using 3 methods. First, we determined the first stroke of the chewing cycle. A piece of tasteless paraffin gum (GC, Tokyo, Japan) was placed on the center of the tongue, and the side to which the tongue moved the gum in the first chewing stroke was considered the PCS [10,20]. Second, we determined the primary chewing side during free mastication, by recording subjects on video (Canon, Tokyo, Japan) while they chewed paraffin gum freely for 2 min. The video was reviewed at a reduced speed, and after 1 min, the number of chewing strokes for each side was counted for 1 min. The side with the most strokes was considered the PCS. Lastly, we asked each subject which side they preferred [21].

When all 3 methods indicated the same PCS, that side was judged as the "evident PCS." In 6 participants, it was the right side, and in 6 participants, it was the left side. The PCS in the remaining 4 participants could not be determined; therefore, they were excluded from the MEG recording session.

2.4. Stimulation of the tongue and hard palate

The stimulus was applied unilaterally on both sides of the tongue and hard palate using an electrical stimulator (SEN-3401, Nihon Kohden, Tokyo, Japan). We used a pair of pin electrodes (400-μm diameter) with an inter-electrode distance of 3 mm for stimulation because they can safely deliver a low intensity stimulus to a small oral region [22–24]. The electrodes were affixed using adhesive tape. Tongue stimulation was applied 1 cm from the edge of the tongue, 3–4 cm from the tongue tip. For the hard palate, the stimulus was applied to the mucosa around the greater palatine foramen [25]. We confirmed through self-reports that electrical stimulation occurred only at the stimulation site. During hard palate stimulation, subjects did not report sensations in the teeth or gums. The stimulus consisted of square, biphasic, constant current electric pulses (0.5 ms for 1 phase) applied at 1 Hz. The intensity at each stimulus site was set to 3 times the sensory threshold for that site. On average, stimulation was applied 600 times before stimulating the other side of the tongue or hard palate. The order in which stimulus sites and stimulus sides were selected was counterbalanced across subjects. To monitor subjects' alertness during the recording, the subjects were interviewed about their vigilance level before and after each recording session.

2.5. MEG recordings

Somatosensory evoked fields (SEFs) were recorded with a whole-head neuromagnetometer (VectorView, Elekta Neuromag, Helsinki, Finland) equipped with 204 planar gradiometers. The recording passband was 0.1–330 Hz and the sampling rate was 997 Hz. The analysis window for averaging was from 100 ms before to 500 ms after each trigger signal. The baseline was calculated from −50 to −5 ms before stimulus onset.

To visualize the locations of MEG sources, MRI scans of the head were obtained from all subjects with a Signa Echo-Speed 1.5-Tesla system (General Electric, Milwaukee, WI, USA).

2.6. Data analysis

We defined a response as the period when the signal exceeded 2 standard deviations (SD) of the baseline activity for at least 10 ms. The peak latency was measured from the channel showing the maximal signal over each hemisphere. Isocontour maps were constructed at the selected time points. The digitized shape of each subject's head was fitted using a simple spherical head model. The sources of the magnetic fields were modeled as equivalent current dipoles (ECDs) whose location was estimated from the measured magnetic waveforms. We accepted only ECDs attaining 90% goodness-of-fit and a confidence volume smaller than 1000 mm^3.

To estimate the cortical activation in each hemisphere, we used the activated root-mean-square (aRMS), as was used in our previous studies [22,23]. First, we calculated the spatial summation of the RMS from the 18-channel waveforms, including the maximum amplitude channel over both hemispheres separately. Second, we calculated the amplitude of the RMS between 10 and 150 ms (RMS[10,150]) and subtracted the value of the baseline period (RMS[−50,-5]) to obtain the aRMS.

To judge the effect of head location on the laterality of the aRMS following tongue and hard palate stimulation, distances between the head origin and ECD locations were compared at the peak latency of the maximum magnitude component over the contralateral hemisphere.

Data are expressed as the mean ± the standard error of the mean (SEM). Differences in the sensory threshold between PCS and non-PCS stimulation were examined for the tongue and hard palate data using the Wilcoxon signed-rank test. Differences in the aRMS for each (contralateral and ipsilateral) hemisphere following PCS and non-PCS stimulation were confirmed with the Friedman test and the Wilcoxon signed-rank test with Bonferroni correction. The laterality between PCS and non-PCS stimulation was checked using the Wilcoxon signed-rank test for the distance from the head origin to the ECD location. The significance level was $p < 0.05$.

3. Results

3.1. Sensory threshold

We did not observe a significant difference in the sensory threshold between PCS (0.296 ± 0.037 mA) and non-PCS (0.300 ± 0.033 mA) tongue stimulation ($p = 0.914$), or between PCS (0.248 ± 0.022 mA) and non-PCS (0.229 ± 0.032 mA) hard palate stimulation ($p = 0.345$).

3.2. SEFs by tongue and hard palate stimulation

Clear responses were detected over the bilateral hemispheres in all participants. When the right side of the tongue was stimulated, a deflection was observed over the contralateral hemisphere (P80m) and over the ipsilateral hemisphere [P80m(I)] in a representative subject (subject 11; Fig. 1). In several other subjects, 4 additional components, P40m, P40m(I), P60m, and P60m(I) were identified; however, these components were not observed in subject 11 (Table 1).