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Ocular dominance affects magnitude of dipole moment: an MEG study

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Abstract

To investigate whether ocular dominance affects laterality in the activity of the primary visual cortex, we examined the relationship between ocular dominance and latency or dipole moment measured by checkerboard-pattern and magnetoencephalography (MEG) in 11 right-handed healthy male subjects. Subjects with left-eye dominance showed a dipole moment of 21.5 ± 6.1 nAm with left-eye stimulation and 16.1 ± 3.6 nAm with right, whereas those with right-eye dominance showed a dipole moment of 18.0 ± 5.2 and 21.5 ± 2.7 nAm with left- and right-eye stimulation of the infero-medial quadrant visual field, respectively. Thus, the dipole moment was higher when the dominant eye was stimulated, which

implies that ocular dominance is regulated by the ipsilateral occipital lobe.

Key words: ocular dominance; visual evoked magnetic field; dipole moment; magnetoencephalography

Introduction

The dominant hemisphere is defined as the cerebral hemisphere controlling the dominant arm or leg useful for skilled motion and the use of language. However, close examination of some neurological symptoms, such as landmark agnosia, phonagnosia and aprosodia, indicates that even the non-dominant hemisphere "dominantly" controls some neurological functions. Ocular dominance, the phenomenon that visual information input from one eye is favored over that from the other, may be considered as one of the brain functions correlated with hemispheric dominance [1], and is typically seen in cases of suppression amblyopia. Amblyopic subjects show reduced activation in the visual cortex on functional

magnetic resonance imaging (fMRI) when a non-dominant eye is stimulated [2,3,4]. Rombouts et al. [5] showed that stimulation of the dominant eye activates a larger area of the primary visual cortex than that of the non-dominant eye using fMRI for normal volunteers, although laterality in activation of the visual cortex was not considered in the study. Besides, fMRI detects neuronal activity only indirectly, from changes in blood flow, metabolism or synaptic activity. The brain is a neuronal organ and its function is essentially data processing via electrical cell excitation; therefore, it would be more desirable to evaluate cerebral function in terms of electrical activity. Magnetoencephalography (MEG) has an advantage in both time and spatial resolution because of its magnetic measurement of

electric activity and magnetic penetrability in the human body. The dipole moment is one of the parameters that have been shown to be useful in somatosensory evoked magnetic field (SEF) [6,7], though it has not been applied to investigations of the primary visual cortex response (V1 response). In this study, we focused on the effect of ocular dominance on latency and magnitude of dipole moment of visual evoked magnetic field (VEF).

Methods

Subjects

Subjects were 11 healthy right-handed men. The dipole moment was measured in all 11 subjects. Male subjects were

selected to remove the effects of any differences between the sexes. The procedures had been approved by the Medical Ethics Committee of Kanazawa University, and were conducted in accordance with the Declaration of Helsinki. All subjects provided written informed consent. Hand preference was assessed using the Edinburgh Handedness Inventory [8]. Subjects having handedness scores less than zero were considered to be left-handed; those with scores greater than zero were considered to be right-handed. Ocular dominance was determined by the near-far alignment test [5]. When the result was uncertain, a variant of the Miles test was administered [9].

Visual stimulation

The visual stimuli were generated by Presentation version 0.76 (Neurobehavioral Systems, Albany, CA) installed on a personal computer. In a supine position, the subjects viewed the stimuli back-projected on a screen 60 cm from the subjects' eyes using a liquid crystal display projector EMP-9300NL (Seiko Epson Corporation, Suwa, Japan) outside the shielded room. The stimulus consisted of a reversing checkerboard in the lower visual quadrant, with an eccentricity of 25° from the horizontal and 35° from the vertical meridians. The stimulus was blocked within an eccentricity of 5° from the fixation point (a small gray cross at the center of the screen), in order to stimulate the peripheral visual field and avoid stimulating the central retinal

fovea. The use of a quadrant visual stimulus minimized the possibility of cancellation effects that can occur with MEG owing to current sources being present on the opposing banks of the calcarine sulcus. The stimulus was also blocked in the upper visual field to reduce the effect of blinking. The reversal rate of the checkerboard was 1.7 Hz (i.e., each of the complementary patterns was presented for approximately 550 msec). The contrast of the stimulus was 77% (black 1.5 cd/m^2, white 115 cd/m^2). The subject was monitored using a video camera inside a magnetically shielded room to check that he was alert and fixating on the fixation point. Artifacts of blinking and eye movement were treated by averaging of the results.

Measurement

MEG data was collected using a 160-channel helmet-type MEG system (Eagle Technology, Kanazawa, Japan) in a magnetically shielded room at Applied Electronics Laboratory, Kanazawa Institute of Technology [10,11]. The VEF data was obtained as an average of results of 200 trials of pattern reversal, with a sampling rate of 2000 Hz after low pass filtering at 100 Hz and high pass filtering at 0.1 Hz. Trials were extracted in the range from −50 to 450 msec relative to the onset of each pattern reversal. The system's sensors were co-axial 1st gradiometers and their sensing and reference coils each had a diameter of 15.5 mm, with a 50 mm baseline and 23 mm of separation between each pair of sensing coils. All participants were scanned with

a magnetic resonance imaging (MRI) system (GE Yokogawa Medical Systems, Tokyo, Japan, SIGNA Profile 0.2 T). Using skin markers and coils, the MEG coordinates were transferred to the MRI coordinate system for localization.

Data analysis

The single equivalent current dipole (ECD) model was used to estimate the locations of the cortical activities that produced the magnetic fields. A single ECD was searched for in the data obtained from the sensors over bilateral occipital lobes during the period including each of the response peaks. The goodness-of-fit (GOF) of the model was used to describe the proportion of the measured field variance explained by the

calculated ECD. We established 4 criteria for the application of the ECD model for V1 response. First, GOF of the ECD model must be more than 90% [12]. Second, the magnetic field of the ECD must be more than 30 fT. Third, the estimated ECD must be stable for at least 10 msec within 20 msec around the peak at about 100 msec after stimulation. Fourth, the ECD must be located at the medial region of the occipital lobe along the calcarine sulcus and oriented medially [13,14,15].

Statistical analysis

The data are presented as mean ± standard deviation. The remainder of latency of V1 response and the magnitude of dipole moment were compared between dominant and

non-dominant eyes using the paired t-test. A p value less than 0.05 is considered to be significant.

Results

Of the 11 subjects, 6 had left- and 5 had right-eye dominance. ECDs around the calcarine fissure were measured in all 11 subjects (Fig. 1). In the study of dipole moment, those with left-eye dominance (6 subjects) showed dipole moments of 21.5 ± 6.1 nAm with left-eye stimulation and 16.1 ± 3.6 nAm with right-eye stimulation, by stimulation of the infero-medial quadrant visual field (Table 1, Fig. 2a). The difference in the intensity of dipole moment between the dominant and non-dominant eyes was statistically significant ($p<0.05$). In the

same way, subjects with right-eye dominance (5 subjects) showed dipole moments of 18.0 ± 5.2 and 21.5 ± 2.7 nAm with left- and right-eye stimulations, respectively (Fig. 2b). The dipole moment with dominant-eye stimulation tended to be greater, although the difference between the results for the two groups was not statistically significant ($p=0.12$). Study of the intensity of dipole moment was also conducted using stimulation of the infero-lateral quadrant visual field. However, no statistically significant difference was observed ($p=0.41$ and $p=0.054$ in the left- and right-eye dominance groups, respectively).

Meanwhile, in the study of latency of V1 response, no significant differences were found between left and right eyes

or between the portions of visual stimuli (Table 1).

Discussion

Erdogan et al. [1] reported that the ipsilateral visual cortex as the dominant eye was larger in size than the contralateral visual cortex in healthy subjects using MRI. Although they did not mention functional asymmetry and anatomical dimension, their results were consistent with our study showing the superiority of the ipsilateral visual field of the dominant eye. In experiments of pathologic ocular dominance, it has been reported that stimuli within the amblyopic passband produced reduced-fMRI activation in the visual field [2,3,4]. However, these studies were not focused on behavioral eye dominance of

normal subjects. In fMRI studies of behavioral eye dominance, a larger extent of activation in occipital lobes was stimulated when the dominant eye was stimulated compared to the other eye [5,16]. In fMRI studies, however, temporal characteristics of visual field activation were not mentioned at all, because fMRI has rougher time resolution than MEG. It was also illustrated in the MEG study that the visual evoked responses had longer latencies and reduced amplitudes through the amblyopic eye [17], although the relationship between ocular dominance and asymmetry of V1 response of normal subjects was not shown in the MEG study. In the present study, the magnitude of the V1 response was greater in the stimulation of the dominant eye than that in the other eye, with infero-medial

visual field stimulation of right-handed subjects. This result may illustrate that ocular dominance is regulated by the ipsilateral occipital lobe. Although the subjects were monitored using a video camera to check fixation, it is conceivable that the fixation is better when the dominant eye is used. Thus, the result may be affected by the quality of fixation.

In spite of different electrical characteristics of the skull, scalp and cerebrospinal fluid, there have been many clinical reports in which the assessment of the severity of sensory disorders is conducted on the basis of electroencephalography, especially the amplitude of somatosensory evoked potential (SEP) N20. Compared with SEP, however, the amplitude of

visual evoked potential is weak and difficult to assess because of heterogeneous conductivity and the location of electrodes. MEG is mostly unaffected by these tissues, and electrodes are not required. Since MEG has an advantage in detecting the magnetic field generated from a dipole tangential to a spherically symmetrical head model, the VEF is suitable for MEG because electric activity generates vertically to the visual cortex which is facing the interhemispheric fissure. Recently, some clinical studies have been conducted to examine the usefulness of dipoles and it has been disclosed that dipole moment is a helpful parameter to assess the severity of the sensory disorder in cases of cervical spondylotic myelopathy [6]. Assessing SEF and single photon emission computed

tomography, Tsutada et al. [7] demonstrated that the dipole moment provided a reliable quantitative index of cortical response to somatosensory stimulus by median nerve stimulation, and the moment measurement thus holds promise as a clinical tool for direct quantification of cortical response. On the basis of the principles of MEG technology, the following conditions were identified as being ideal for assessing the intensity of dipoles as absolute values determined by the least-square method in which a spherically symmetrical head model is used: dipole present near the surface with an orientation tangential to the surface; presence of a high GOF. The P100 dipole satisfies these conditions and is considered to be suited for assessing visual function.

Conclusion

Dipole moment of V1 response in the ipsilateral visual cortex as the dominant eye was greater when the dominant eye was stimulated compared with that for the other eye. Ocular dominance can be objectively assessed and quantified as an absolute value using dipole moment with MEG.

Acknowledgments

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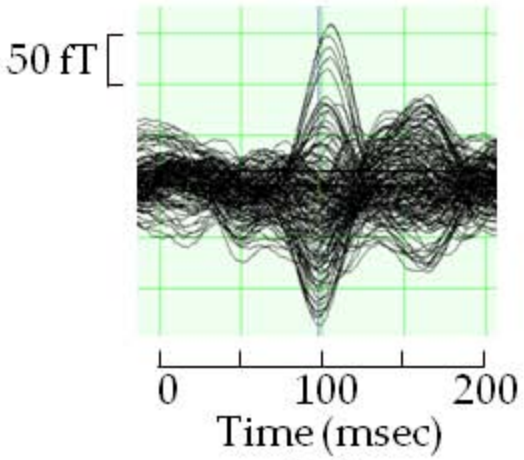
Figure legend

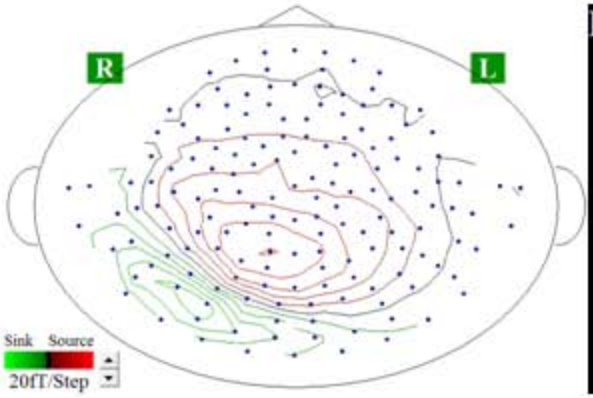
Fig. 1. Visual evoked magnetic field (VEF) in response to infero-medial quadrant field pattern-reversal stimulation for a subject with right hand and left eye dominance by right (a, b, c) and left (d, e, f) eye stimulation, respectively. Waveforms are obtained as results of whole sensors (a, d). Isofield contour maps are indicated as top down view on the schematic head (b, e). Equivalent current dipole for the VEF superimposed on the subject's own magnetic-resonance-imaging slice. The *dot* represents the dipole location, and the *bar* represents the dipole's strength and direction (c, f). Note that the dipole locations are identical for the two eyes.

Fig. 2. (a) Magnitude of dipole moment for the group with a

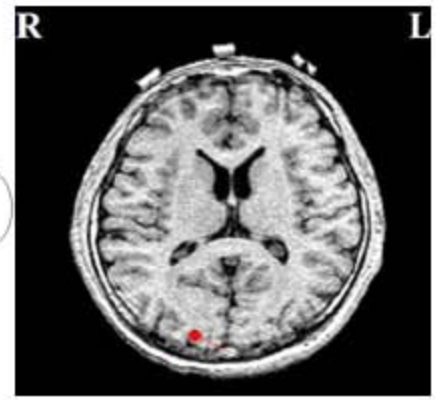
dominant left eye (n=6). Five subjects show a greater dipole moment when the dominant eye is stimulated (left > right) compared with that of the other eye. (b) Magnitude of dipole moment for the group with a dominant right eye (n=5). Four subjects show a greater dipole moment when the dominant eye is stimulated (right > left) compared with that of the other eye.


50 fT
0
100
200
Time (msec)

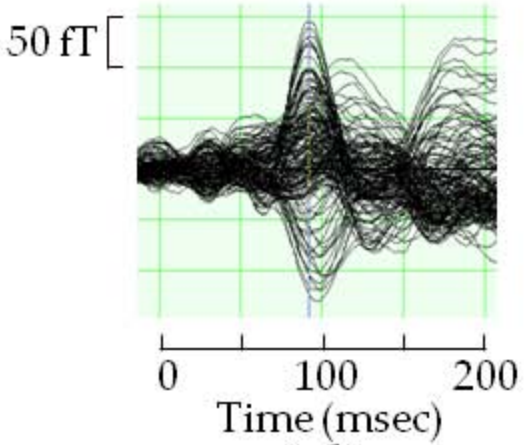
(a)


R
L
Sink
Source
20fT/Step

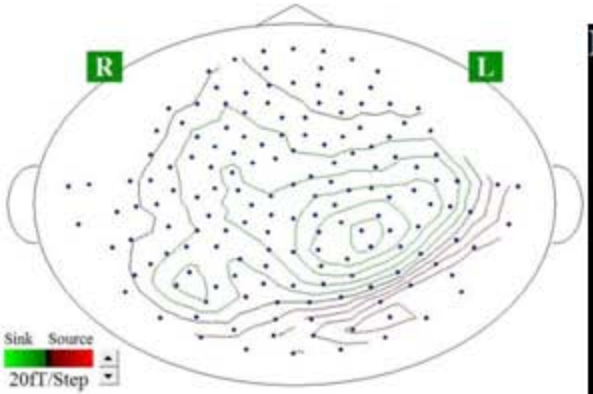
(b)


R
L

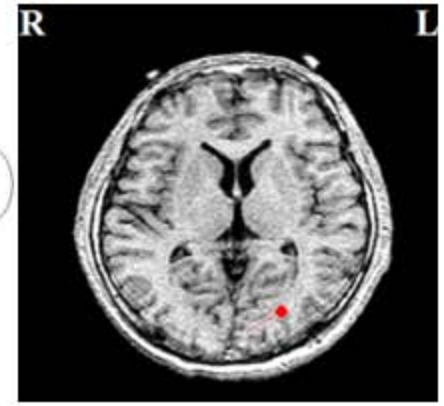
(c)


50 fT
0
100
200
Time (msec)

(d)


R
L
Sink
Source
20fT/Step

(e)


R
L

(f)

Fig. 1.

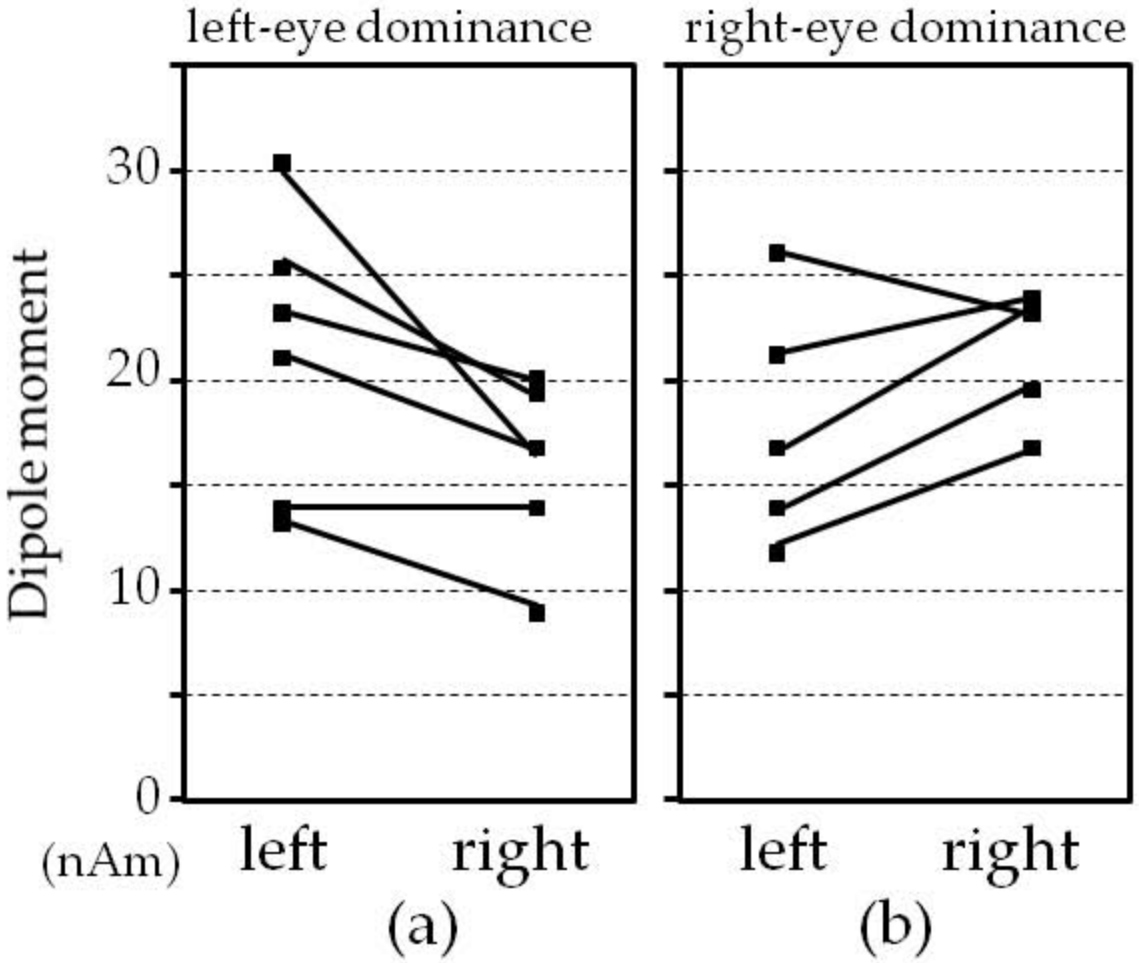

left-eye dominance
right-eye dominance
Dipole moment
30
20
10
0
(nAm)
left
right
left
right
(a)
(b)

Fig. 2.

Table 1. Latency and dipole moment of V1 response classified according to ocular dominance and portion of visual stimuli

			Left-eye stimulation				Right-eye stimulation			
			Left VF (Infero-lateral)		Right VF (Infero-medial)		Left VF (Infero-medial)		Right VF (Infero-lateral)	
No.	Age	Ocular dominance	Latency (msec)	Moment (nAm)	Latency (msec)	Moment (nAm)	Latency (msec)	Moment (nAm)	Latency (msec)	Moment (nAm)
1	65	L	94	11.6	98	21.8	101	16.8	100	16.9
2	62	L	85	8.7	98	14.4	103	14.7	94	15.4
3	58	L	96	9.9	93	23.4	101	20.0	108	11.1
4	42	L	98	15.6	97	13.1	97	9.1	98	5.2
5	30	L	93	11.1	93	30.4	91	16.7	93	29.4
6	27	L	91	18.4	92	25.6	98	19.1	92	28.1
mean	47.3		92.8	12.6	95.2	21.5	98.5	16.1	97.5	17.7
SD	16.6		4.1	3.4	2.5	6.1	3.9	3.6	5.5	8.7
7	64	R	100	30.3	101	21.0	111	24.0	103	36.9
8	60	R	98	10.5	108	14.4	103	19.7	95	21.1
9	46	R	95	11.4	98	17.3	98	23.6	95	17.0
10	32	R	90	27.5	92	26.3	92	23.2	89	27.4
11	22	R	86	12.0	95	11.2	96	17.1	88	14.2
mean	44.8		93.8	18.3	98.8	18.0	100.0	21.5	94.0	23.3
SD	17.9		5.2	8.7	5.5	5.2	6.5	2.7	5.4	8.1

VF, visual field; L, left; R, right.