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3-D Magnetic Measurement of Neuromagnetic Response of Somatosensory Area to Different Repetition Frequencies

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ABSTRACT

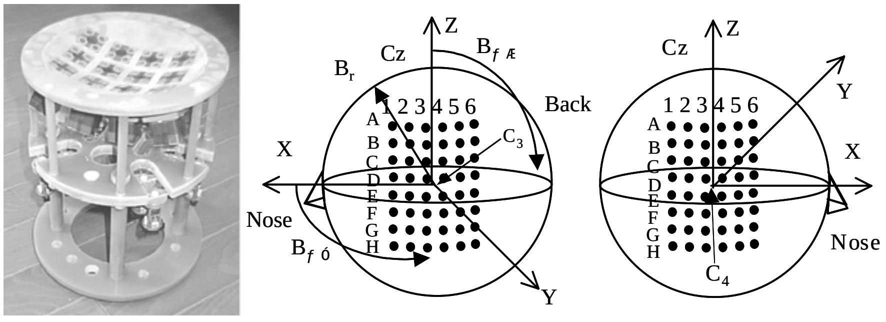
3-D magnetic measurements of the bilateral somatosensory evoked fields (SEFs) by electric stimulus to the right thumb for four normal subjects were carried out, using a three-dimensional (3-D) second-order gradiometer connected to 39-channel SQUIDs, which can detect magnetic field components perpendicular to the scalp (Br) and tangential to the scalp ($B\theta$, $B\phi$) simultaneously. To discuss the relationship between the phase lag and stimulus repetition frequency (SRF), the delay times of a component synchronous with the SRFs (1.99 to 27.02 Hz) were calculated by the convolution of the reference signal and the SEF wave (BPF: 15-40Hz). The phase lag characteristic to the SRF in the contralateral hemisphere to the stimulus was linear in the ranges below 8 Hz and above 8 Hz in all magnetic components. The phase lag characteristic of the ipsilateral hemisphere to the stimulus was linear in only below-8 Hz in all components. It was tested for significance of the linear regression slope ($\beta \neq 0$, $P<0.05$).

KEY WORDS

Contralateral hemisphere, Inter-stimulus interval (ISI), Ipsilateral hemisphere, Somatosensory evoked field (SEF), Stimulus repetition frequency (SRF), SI activity, SII activity, Three-dimensional (3-D) magneticencephalogram (MEG).

INTRODUCTION

Magnetoencephalogram (MEG) measurement of the magnetic field perpendicular to the scalp is widely used for research on brain function. We have developed a three-dimensional (3-D) second-order



(a) (b)

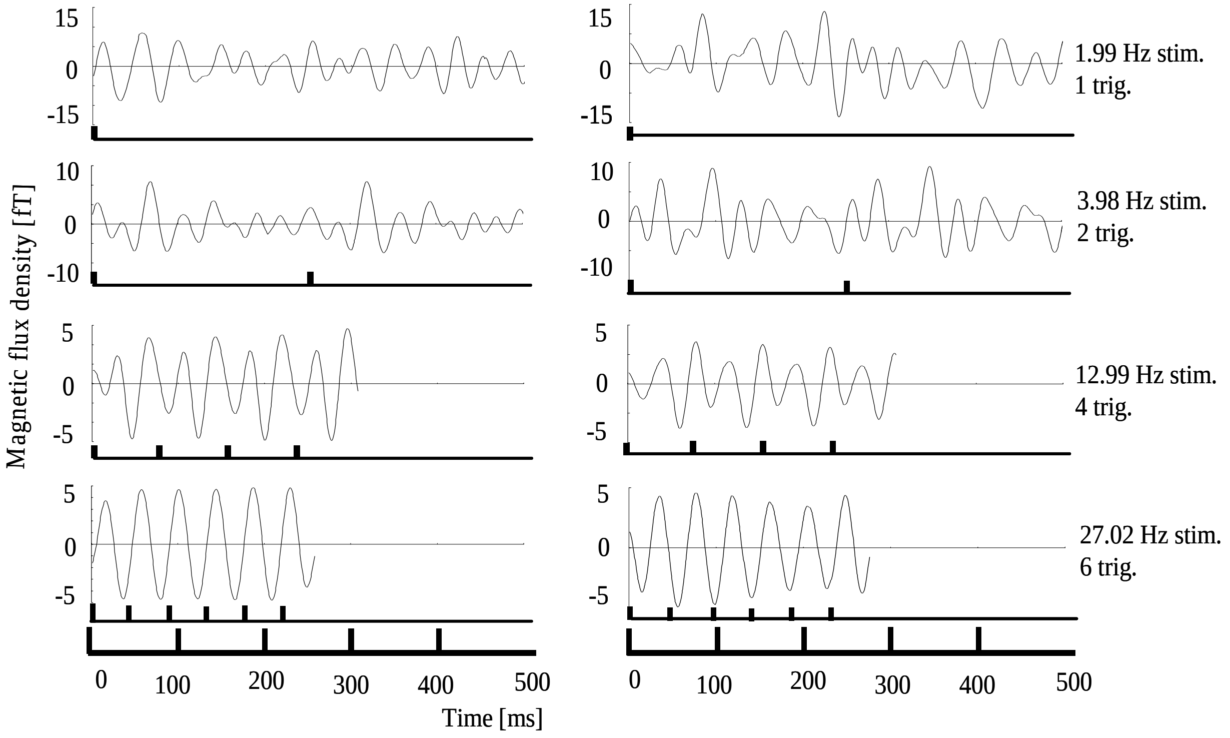
Figure 1. Arrangement of pick-up coil for MEG (a), and measurement points for bilateral SEF measurements (b).

gradiometer connected to 39-channel SQUIDs for vector measurement of the MEG that can detect magnetic field components perpendicular (Br) and tangential (Bθ, Bϕ) to the scalp simultaneously [Kobayashi, 1999].

There are a few reports about the phase lag characteristic of the SEF with a variation of the SRF which was defined as a reciprocal of inter-stimulus interval [Brenner, 1978], [Kuriki, 1987]. They showed the phase lag characteristic of the contralateral neuromagnetic responses to the SRFs in the somatosensory area. Our aim here is to study the phase lag characteristic of the neuromagnetic responses, with the SRFs obtained from both ipsilateral and contralateral somatosensory area, using a 3-D MEG measurement.

METHODS

Four normal subjects participated in the study. A 3-D MEG measurement of bilateral SEF with an electric stimulus to the right thumb was carried out, using 3-D second-order gradiometers connected to 39-channel SQUIDs. Fig. 1 shows the arrangement of the pick up coil for the MEG (Fig. 1a) and measurement points on a subject's head (Fig. 1b). The 3-D second-order gradiometer is wound with Nb-Ti wire on a rectangular solid of 3×3×6 cm^3. The 3-D MEG measurement of SEF was done in a magnetically shielded room. Black circles in Fig. 1b show the measurement points and C_3 and C_4 correspond to ten-twenty electrode system. The SEF was elicited by electric pulses of 0.2 ms duration with 3.0 to 6.5 mA to the right thumb. The SRF was varied from 1.99 to 27.02 Hz. The sampling frequency was 1 kHz. And analog filter was used in the range from 0.5 to 300 Hz. All magnetic data were averaged for 400 measurements at each position. Digital filter was used in the range of 15 to 40 Hz [Kim, 2003].

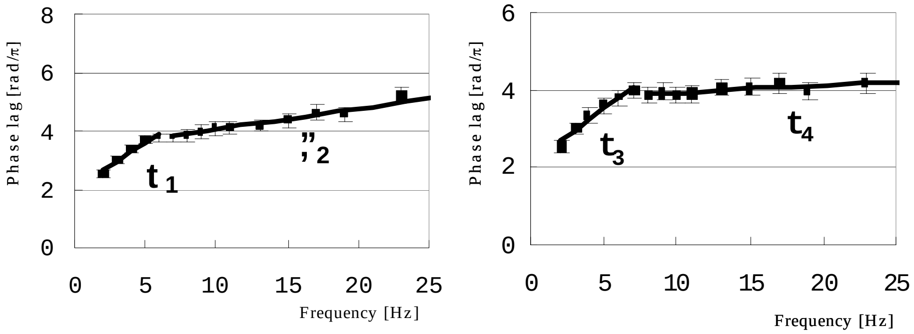


a. Contralateral **b.** Ipsilateral

Figure 2. Examples of SEF waveforms with the various SRFs (Br component, left panel is contralateral hemisphere and right panel is the ipsilateral)

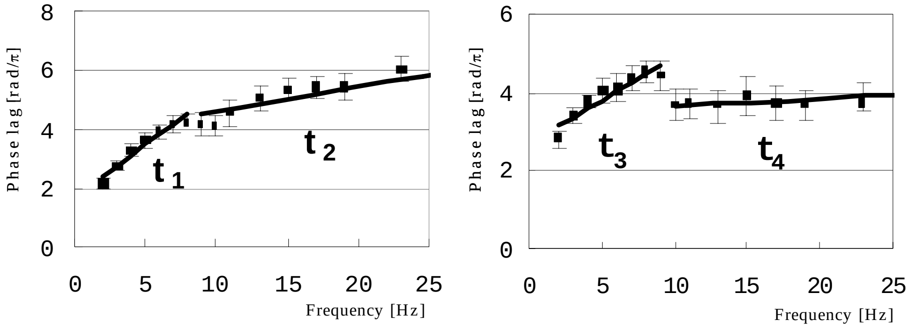
RESULTS AND DISCUSSION

Fig. 2 shows typical waveforms of the SEFs of Br component measured at both hemispheres (contralateral: F4, ipsilateral: F3 in Fig. 1b). The timing of current pulse delivered to the right thumb is indicated by black bars below each waveform. The waveform of 1.99Hz of the contralateral in Fig. 2 shows transient waveform having dominant peaks in some latency (around 20, 40, 80ms). When the SRF was increased, amplitude of the SEFs was decreased and the neuromagnetic response became continuous waveform. Continuous waveforms were observed in the SRF of 27.02Hz. Transient waveform of the ipsilateral hemisphere shorter than about 80 ms latency did not appear significant compared with the contralateral hemisphere. When the SRF was increased, the waveforms of the ipsilateral SEFs also became continuous waveforms as like the contralateral hemisphere.



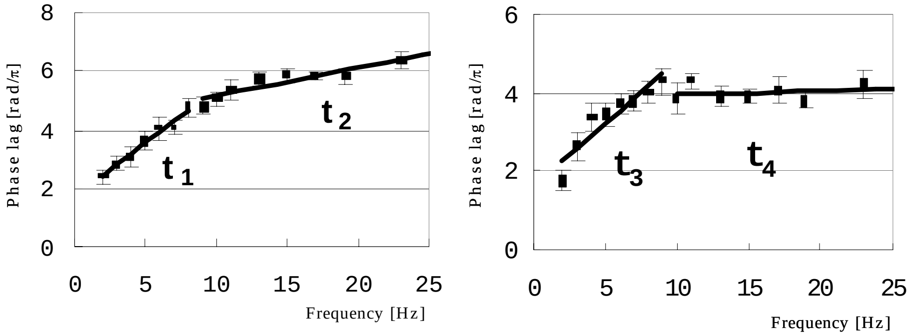
(a) B; component

(d) B; component



(b) Bθ component

(e) Bθ component



(c) Bϕ component

(f) Bϕ component

Contralateral hemisphere

Ipsilateral hemisphere

Figure 3. Averaged phase lag characteristic of each magnetic component for four subjects (left panel ((a)-(c)) is contralateral hemisphere, and right panel ((d)-(f)) is the ipsilateral to the stimulus. Black squares show averaged phase lag and solid lines show regression curves for the averaged phase lag.

Hemisphere	Slope	Br	Bθ	Bϕ
Contralateral	t1 [ms]	157.2 ±33.0	177.2±6.8	188.1±5.2
	t2 [ms]	36.5±12.4	42.4±14.5	47.2±30.9
Ipsilateral	t3 [ms]	141.1±9.0	132.1±30.7	154.1 ±18.4
	t4 [ms]	8.5±11.0	5±5.3	4.5 ±6.5

Table 1. Latencies obtained from the regression slopes shown in Fig.3

In order to obtain the phase lag characteristic of SEF to the SRF, the delay times of a component synchronous with the SRFs (1.99 to 27.02 Hz) were calculated by the convolution of the reference signal and the SEFs [Kuriki, 1987]. Equations for calculating phase lag are:

$$R_{B,S}(\tau) = B(t) * S(t) \qquad (1)$$

$$\tau_{peak@B,S@} = \arg\, peak\, R_{B,S}(\tau) \qquad (2)$$

where *B(t)* is the measured magnetic field. S(t) is the reference signal, which is the same frequency as the SRF. $R_{B,S}(\tau)$ shows cross correlation function; and $\tau_{peak\ B,S}$ is the phase lag with maximum value of the cross correlation function. Figure 3 shows the relationship between the calculated phase lag and the SRFs, which were averaged in four subjects. In this calculation the SEF waveforms were chosen at the point of F4 (contralateral) and F3 (ipsilateral) in Fig. 1b.

The results are summarized in Table 1. Two regression curves were obtained in each hemisphere. The slope of the regression curve corresponds to the latency of the SEF. The slope of the regression curve below 8Hz (t1) in contralateral hemisphere was linear (Br: 157.2 ±33.0 ms, Bθ: 177.2±6.8ms, Bϕ: 188.1±5.2ms). The regression curve above 8 Hz (t2) also showed linear slope (Br: 36.5±12.4ms, Bθ: 42.4±14.5ms, Bϕ: 47.2±30.9 ms). The slope of the regression curve below 8Hz in ipsilateral hemisphere (t3) was linear (Br: 141.1±9.0ms, Bθ: 132.1±30.7ms, Bϕ: 154.1 ±18.4ms). The regression curve above 8Hz (t4) also showed linear slope (Br: 8.5±11.0ms, Bθ: 5±5.3ms, Bϕ: 4.5 ±6.5ms).

These slopes were tested for significance of the linear regression slope ($\beta \neq 0$, $P<0.05$). All linear regression slopes in the contralateral hemisphere (t1, t2) were found significant. Also, the linear regression slope in the ipsilateral hemisphere (t3) was significant. However, the regression slope in the ipsilateral hemisphere t4 it was not significant. This suggests that the magnetic field at the latency of t4 is not related to the SEF since the SII response of ipsilateral hemisphere starts from around 90 ms for ipsilateral stimuli [Lueders, 1983]. Further study is necessary to identify the contribution of primary (SI) and secondary (SII) somatosensory areas using 3-D MEG measurements.

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REFERENCES

Brenner D, Lipton J, Kaufman L, Williamson SJ. Somatically evoked magnetic fields of the human brain. Science 1978;199:81-3.

Kim BS, Uchikawa Y. Separation of overlapping activity in first and second somatosensory evoked fields with 3-D MEG measurement. IEEE Trans Magn 2003;39(5):3387-9.

Kobayashi K, Uchikawa Y. Development of a three-dimensional biomagnetic system with 39-channel SQUIDs. In: Yoshimoto T, Kotani M, Kuriki S, Karibe H, Nakasato N, editors. Recent advances in biomagnetism. Proceedings of the 11th International Conference on Biomagnetism; Sendai, Japan: Tohoku University Press; 1999. p.35-8.

Kuriki S, Mizutani Y, Isobe Y. Transient and continuous response of neuromagnetic field evoked by peripheral verve stimulus. IEEE Trans Magn 1987;MAG-23:1068-72.

Lueders H, Lesser RP, Hahn J, Dinner DS, Klem G.. Cortical somatosensory evoked potentials in response to hand stimulation. J Neurosurg 1983;58:885-94.