EFFECTS OF THE STIMULUS FREQUENCY TO THE BRAIN ACTIVITIES BY MEG AND FMRI

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ABSTRACT

This study focuses on the physiological responses of somatosensory stimulation using MEG and fMRI. To investigate the relationship between neural activity and hemodynamic responses, the effect of the stimulus rate of electrical stimulation was investigated. The signal power of fMRI and the dipole moment of MEG responses were compared. When the stimulus frequencies were changed from 0.5 Hz to 10 Hz, the dipole moments of MEG signals were the largest at 1 Hz or 2Hz. A maximum signal power of fMRI occurs at a frequency higher than 2 Hz, approximately at 3 Hz or 5 Hz, and then decreases progressively.

INTRODUCTION

This study focuses on the physiological responses of somatosensory stimulation using fMRI and magnetoencephalography (MEG). The neural activities and the hemodynamic responses in the brain to the electrical stimulation to the right thumb were investigated.

Since the development of fMRI [1], the relationships between MEG and fMRI have been studied [2]-[7] to clarify the origin of brain electrical activities. However, the relationships between the BOLD effects and neuronal activities are not fully understood yet. Although there are many studies related to somatosensory responses in EEG and MEG, few studies of somatosensory responses in fMRI have been performed [8]-[11]. Specifically, there are a few studies that investigate the effects of the stimulus parameters, such as intensity, stimulus rate and stimulus duration, on the cerebral blood flow [12].

Both fMRI and MEG are functional brain imaging techniques that are used today. fMRI is based on the idea that regional cerebral blood flow could reflect neuronal activity. There are many causes of intensity changes in MR signals caused by neuronal activity, such as blood flow, blood volume, blood oxygenation, and neuronal electric current. In most fMRI studies, the BOLD effect is measured. Hence, fMRI provides high spatial resolution (less than a few mm), but poor temporal resolution. MEG measures the electrical activities of populations of neurons, and it provides good temporal resolution (a few ms), but its spatial resolution, although consistent and repeatable, is less precise (several mm).

This study focuses on the physiological responses of somatosensory stimulation using fMRI, and MEG. To investigate the relationship between neural activity and hemodynamic responses, the effect of the electrical stimulus rate to the right thumb on fMRI and MEG responses was measured.

METHODS

fMRI was performed with a single shot echo-planar imaging using a 4T whole body system (TE:30 ms, TR:1 sec, slice thickness:5 mm, matrix:64 x 64, FOV:200 mm x 200 mm). MRI experiments were conducted on three volunteers. fMRI activation images were produced by pixel-by-pixel t-test processing. The stimulation was a constant current square wave applied to the thumb with a duration of 0.5 ms at an intensity two times the sensory threshold. The stimulus rate was changed in nine levels, 0.5, 1, 3, 5, 10, 20, 30, 50, and 100 Hz.

Somatosensory evoked magnetic fields were measured using a whole-head 122-channel SQUID (Neuromag 122. The stimulus rate was changed in six levels, 0.2, 0.5, 1, 3, 5, and 10 Hz. MEG data were averaged 300 times. The best fitting dipole for the measured magnetic fields was calculated by an iterative least squares method. To estimate the accuracy of dipole fitting, the goodness-of-fit was calculated using a correlation coefficient between the magnetic fields derived from a model dipole and measured fields. Only dipoles with a goodness-of fit exceeding 95% were taken into account.

RESULT AND DISCUSSION

The primary somatosensory cortex area (SI) was activated by stimulation at all frequencies. There were, however, no common activated pixels to all frequencies. Depending on the stimulus frequency, a different number of activated pixels appeared in each experiment. At 3 Hz, 20 Hz and 30 Hz, there were more activated pixels than at any other stimulus frequencies. Different areas besides the somatosensory area were activated. The change of the signal intensity was from 2 % to 4 % in each experiment. The signal time course was notably different in response to the stimulus frequency. The signal intensity decreased about 10 sec after stimulation except in the case of the stimulation at 3Hz. At 3 Hz, sustained responses appeared and continued for about 20 sec. To evaluate the sustained response, the signal power was calculated. The signal power is the integrated value from the beginning of the stimulation to the end of the sustained response, the point at which the signal recovers to the baseline. The signal power increased as the stimulus frequency increased up to 3 Hz, and decreased when the stimulus rate increased as shown in Fig.1. Especially when the subject experienced pain signal power showed a large value which was due to the sustained response. In essence, an increase of blood flow at the SI area continued for a longer duration when the subject experienced pain when exposed to strong stimulation.
To investigate the relationship between the stimulus frequency and neuronal activities, dipole moments of M20 and M30 components were calculated, respectively. Estimated dipoles of these two components were located in the primary somatosensory area and distributed within a 10 mm cubic area. When stimulus frequencies were changed from 0.5 Hz to 10 Hz, dipole moments of M20 and M30 components of MEG signals were the largest at 1 Hz and 2 Hz, respectively as shown in Fig.2. That is, when the stimulus frequency was low, the dipole moments became large.
The results obtained indicate that the dipole moment became large when the stimulus frequency was low, which reflects the properties of neural activity. The results obtained by fMRI, however, were different because the signal power peaked at the 3 Hz stimulus frequency. The area activated at the 3 Hz rate seemed larger than the area activated at the higher stimulus rate. The increased neuronal activity observed from MEG responses is different from the spatial and temporal hemodynamic responses.

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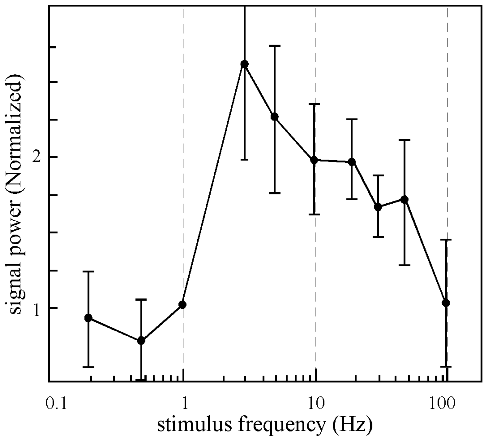

Fig.1. Superimposed waveforms at six stimulus frequencies obtained from Subject 1. The upper waveforms show the dBz/dx components and the lower waveforms show the dBz/dy components.

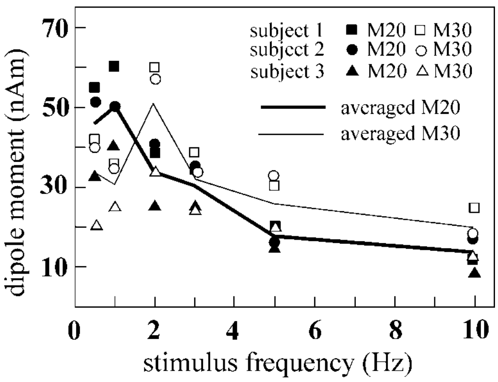

Fig.2 Relationships between stimulus frequency and dipole moment for two components. The two lines represent the averaged data of three subjects. The squares, circles and triangles correspond to the data of each subject.