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Dynamic Neuromagnetic Responses to Auditory Motion: A Novel Index for Evaluation of Attention

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ABSTRACT

Our previous studies have demonstrated that there is a motion-related magnetic response evoked by moving sound but not stationary sound. The motion-related response reflects the dynamic activities of brain processing of auditory motion. This study focuses on the effect of attention on the response. Six normal hearing subjects were studied using a 151-channel whole-cortex magnetoencephalography (MEG) system. Four sound stimuli were designed: two sounds moved from left to right (rightward) and the other two sounds moved from right to left (leftward). Two sounds moving in the same direction were separated with an attention task. The attention task was a mathematical calculation. The results showed that when subjects listened to the moving sound, there was a clearly auditory motion related response at a latency of 649± 14.2 ms. However, when subjects were doing the calculation while listening to the moving sounds, the motion related response completely disappeared. Strikingly, there was a dent at a latency of 600 ms. To our knowledge, this is probably the first study showing a neuromagnetic response which can be clearly elicited or inhibited by an attention task. We consider that the motion related response has the potential to be an objective index for the study of attention.

KEY WORDS

Magnetoencephalography (MEG), Auditory evoked magnetic field (AEF), Auditory motion, Attention, Brain.

INTRODUCTION

Previous work using event-related potentials, MEG, and more recently neuroimaging techniques has provided fundamental information on the neural correlates of attention in the central cortical system. Giard and colleagues proposed an adaptive filtering mechanism for selective auditory attention that can be flexibly and dynamically tuned depending on the attentional demand [Giard, 2000]. Recent findings indicate that mismatch negativity (MMN)/mismatch magnetic fields (MMF) elicited in auditory cortex by intensity deviants are not strongly automatic but rather can be gated or suppressed if attention is strongly focused elsewhere [Woldorff, 1998]. Attention can modify the activity of two different areas in the supratemporal auditory cortex. Both attention effects serve as alterations of the exogenous evoked response components: the earlier effect as changed activity in neurons underlying N100m to relevant tones and the later effect as a modification of P200m to irrelevant tones [Rif, 1991]. Our previous study has demonstrated that there is a motion-related magnetic response evoked by moving sound but not stationary sound. Since this response reflects the dynamics of brain processing of sound motion, it is very interesting to investigate whether attention will affect this response. Though MEG has been used in attention study and neuromagnetic changes have been found in attention task, to our knowledge, the effect of attention on sound-motion evoked response has not been studied.

METHODS

Subjects: Six normal hearing adults (2 women and 4 men, aged 24 – 39 years, with a mean age of 30 years) were studied. All subjects were free of known neurological disorder, and had normal hearing. Informed consent for the study was obtained from all subjects.

Stimuli: The sound motion was produced by custom designed software using Direct 3D sound technology (Microsoft Company, Redmond). Four sound stimuli were designed: two sounds moved from left to right and the other two vice versa. The two sounds moving in the same direction were separated with an attention task. The attention task was 100 simple mathematic calculations. Based on our previous results [Xiang, 2002], sound motion parameters were chosen to ensure that subjects could clearly perceive sound motion. The sound strength was 80 ± 6 dB, interval time was random with an average 1.2 ± 0.1 s. The auditory stimuli were identical in the two conditions. In the condition without doing mathematic calculations, subjects were passively listening to the moving sound. To avoid head movement, there was no behavioral response to the sounds. The presented sounds were 600 Hz square waveform tones; their duration of the sounds was 1000 ms. The sounds started moving immediately. The inter-stimulus interval (ISI) varied randomly between 500 and 700 ms.

MEG Recordings: A 151-channel whole cortex CTF OMEGA system was implemented in this study (CTF Systems Inc., Vancouver, Canada). The MEG measurements were performed in a magnetically shielded room with a total system white noise level below 10 fT/√Hz. The localization of the subject's head relative to the sensor array was accomplished with three small coils affixed to the nasion and pre-auricular points. The coils were simultaneously activated at different frequencies and their positions were determined from their magnetic signals. The system also allows for head localization to an accuracy of better than 2 mm. The three coils were identical to the three fiduciary points used in MRI. Data was recorded with 3rd order gradients noise cancellation. The sampling rate of data acquisition was 1250 Hz. One hundred epochs were averaged for one session. The analysis window was 0.2 s before and 1.2 s after the stimuli, and DC was offset using a pre-stimulus period (0.2 s) as the baseline. Peak latency was measured for each recognizable component by a computer cursor. Spatial temporal dipoles were calculated at each component.

Data analysis: Peaks in the averaged signal were identified using the CTF DataEditor. The source location corresponding to each peak latency was estimated individually using the CTF DipoleFit.

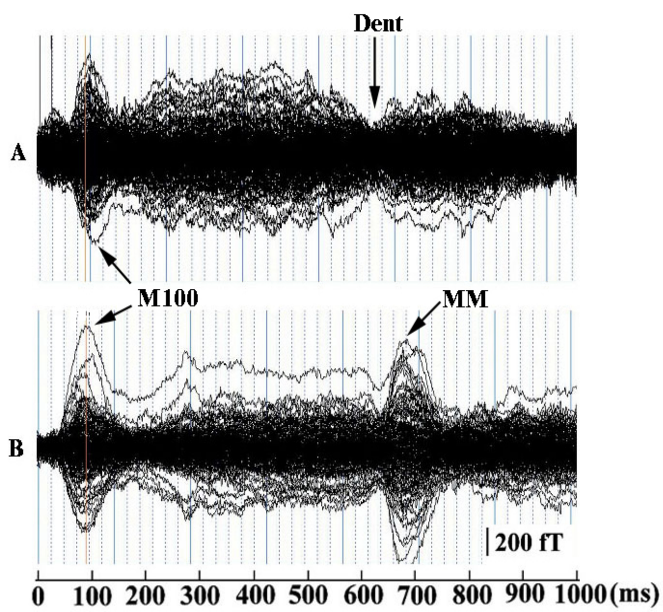

Figure 1. Averaged MEG waveforms from a representative subject. (A) Auditory evoked magnetic field (AEF) evoked by moving sound combined with calculation. (B) AEF evoked by moving sound alone. M100 are clearly identifiable in both A and **B**; however, MM is only clearly identifiable in B. Interestingly, there is a dent in the waveform (A) elicited by moving sound combined with calculation.

RESULTS

Auditory evoked magnetic fields (AEF) were successfully recorded from all six subjects. The waveforms and contour maps recorded from the six subjects were very similar. Typical averaged waveforms are shown in Fig. 1. In all six subjects, moving sound elicited two clear responses (Fig. 1B): one response was identified at a latency of 100 ± 8.2 ms (M100); and the other response at 649± 14.2 ms (MM). There were magnetic activities after the M100; we called it long-term component (or magnetic residency). The contour maps of the first and the second responses indicated consistently two dipoles in the bilateral superior temporal cortices.

Interestingly, when subjects were doing calculations, the moving sound could only elicited one clear response which was identified at a latency of 107± 9.5 ms (M100). There were some magnetic activities before the M100 in 4 subjects (4/6); however, the morphology of those magnetic activities was variable. The long-term component, magnetic activities after the M100, were observed in all subjects; however, there were large inter-individual differences. The contour maps of the first responses indicated consistently two dipoles. The most striking finding was a dent in the waveform at a latency of 600 ± 4.3 ms (Fig. 1A).

A comparison of averaged waveforms between the pure moving sound and the moving sound combined with calculation task suggested that the attention task mainly affected the MM. In 4 out of the 6 subjects, the long-term component elicited by the moving sound combined with calculation task was much stronger than that elicited by the pure moving sound. Statistical comparison of the data from the six subjects showed that there were no differences between the two conditions in terms of the amplitude and latency of M100; the amplitude of MM evoked by pure moving sound was significantly higher than the corresponding activities evoked by unattended stimuli ($p < 0.001$).

Though we used two moving directions in this study, the effect of the moving direction on the magnetic response was not significant ($p > 0.05$).

DISCUSSION

Our previous work using MEG has demonstrated that one response is elicited only by moving sound but not stationary sound. Dipole based source localization indicates that the right parietal cortex is involved in sound motion processing [Xiang, 2002]. This study has further confirmed our previous report; therefore, we consider that the right parietal cortex, in association with the left and right superior temporal cortex, form a network to process sound motion information. This result is in agreement with previous reports [Griffiths, 2000]. Previous functional imaging work using positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) has demonstrated a network of areas that are active during the perception of sound movement. The network includes bilateral premotor areas and the right parietal cortex. The frontal activation includes both dorsal premotor activity in the region of the frontal eye fields and discrete ventral premotor activation in an area corresponding to primate areas for multimodal spatial analysis and motor planning. The right parietal activation includes both superior and inferior parietal cortex.

To our knowledge, there are no reports focusing on the effect of attention on the auditory–motion-related response. Since the auditory-motion-related response could be totally inhibited by a calculation task, we consider that the neuromagnetic response to auditory motion has the potential to be a novel index for evaluation of attention. The effect of attention on auditory motion has been studied using event-related potential (ERP). Stimuli moving in the attended direction elicit ERPs that are more negative than ERPs to stimuli moving in the unattended direction. This difference starts around 140 ms post stimulus onset for visual and around 120 ms for auditory stimuli [Beer, 2004]. The ERP results are in agreement with our results: the attention task did not significantly affect the early response (M100), but significantly inhibited the later response (MM). It is worth pointing out that we used 1000 ms moving sound, the latency of our MM is different from that identified by Beer and colleagues due to the stimulation differences. It is not clear how and why the MM nearly disappeared in the stimulation of moving sound combined with calculation task. We consider that it would be very interesting to further confirm that the motion-related response is a novel objective parameter for studying the cerebral mechanisms underlying attention in the auditory system.

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