Auditory Detection of Motion Velocity in Humans: a Magnetoencephalographic Study

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Summary: To investigate the cerebral mechanisms of auditory detection of motion velocity in the human brain, neuromagnetic fields elicited by six moving sounds and one stationary sound were investigated with a whole-cortex magnetoencephalography (MEG) system. The stationary sound evoked only one clear response at a latency of 109±6 ms (first response, or M100), but the six moving sounds evoked two clear responses: an earlier response at a latency of 116±7 ms (M100) and a later response at a latency ranging from 180 to 760 ms (magnetic motion response, or MM). The latency and amplitude of the MM were inversely related to the velocity of the moving sounds (p<0.02). The magnetic source of MM was related to the velocity of the moving sounds (p<0.05). A dynamic neuromagnetic response, MM, was elicited by the moving sounds, which likely encoded the neural processing of auditory detection of motion velocity. A specific neural network that processes the motion velocity in the human brain probably includes the bilateral superior temporal cortices and the brainstem. The left posterior and lateral part of the auditory cortex may play a pivotal role in the auditory detection of motion velocity.

Key words: Magnetoencephalography; Auditory evoked magnetic field; Auditory cortex; Sound motion; Brain; Hearing.

Introduction

One highly dynamic property of sensory stimulation is motion (Doan and Saunders 1999). The perception of motion in auditory space by humans depends on a number of cues, including amplitude, interaural intensity and time differences, muffling, and a Doppler factor (Makela and McEvoy 1996; Wallace et al. 1995). Perception of moving sound in humans is remarkably accurate (Pratt and Polyakov 1996). Several previous studies of the brain (Perrott and Marlborough 1989; Perrott and Musican 1977; Perrott and Tucker 1988) have indicated that the location and velocity of sound are processed separately and that humans have a specialized "motion detector".

Previous studies (Griffiths and Green 1999; Griffiths et al. 1998; Ungan et al. 2001) of the human brain have demonstrated a network of areas that are active during the detection of the movement of sound in humans. The network comprises the bilateral superior temporal lobes, pre-motor areas, and right parietal cortex (Warren et al. 2002). What is not clear is which part of the human brain detects the velocity of auditory motion (Lutfi and Wang 1999).

The development of magnetoencephalography (MEG), a non-invasive technique for investigating neuronal activity in the human brain, has made it possible to follow the ongoing signal representing the neural processing of the motion of sound in the human brain (Xiang et al. 2002). The advantage of MEG, compared with functional magnetic resonance imaging and positron emission tomography (PET), is its superior temporal resolution. This feature should make MEG the best tool for investigating the cerebral mechanisms underlying the auditory detection of motion velocity.

In our previous report (Xiang et al. 2002), we demonstrated that one magnetic response is elicited only by moving sounds and not by stationary sounds. It is unclear whether the velocity of moving sounds can affect the response and the way the human brain detects that velocity. We know that the human brain can estimate the velocity of a moving sound and that MEG can follow the neural
processing with millisecond-by-millisecond temporal resolution. However, to our knowledge, MEG has not been used to study auditory detection of motion velocity in the human brain. The objective of this study was to build on our previous results to investigate the neuromagnetic fields elicited by moving sounds with various velocities.

## Methods

### Subjects

Eight healthy adults (2 women, 6 men) participated in the study. They were recruited randomly through an advertisement and received a financial bonus for participating in the study. Their ages ranged from 26 to 37 years (mean age, 31 years). All subjects were right-handed, as assessed by the Edinburgh-Handedness-Questionnaire (Oldfield 1971; mean index 97.2, range 86-100), and had normal hearing. Subjects gave their written informed consent before they participated in this experiment.

### Stimuli

We used DirectX (Microsoft Company, Redmond, Washington, USA) to simulate the movement of a sound source. DirectX is a standard industry software that simulates sound in real time (Xiang et al. 2002). We used DirectX’s standardized methods to define moving sounds in terms of their position, orientation, direction, and velocity. In this study, the x direction indicated right to left; the y direction, inferior to superior; and the z direction, anterior to posterior. Six moving sounds and one stationary sound were designed. The moving sounds were labeled “MSv”, where “MS” referred to moving sound and “v”, the velocity of a sound. The velocities (name) chosen were 9 m/s (MS9), 12 m/s (MS12), 30 m/s (MS30), 60 m/s (MS60), 90 m/s (MS90), and 180 m/s (MS180). The stationary sound was used as a control; its velocity was 0 m/s. DirectX simulated all moving sounds by linearly changing interaural intensity and time difference, and Doppler and muffling factors in real time.

To account for possible lateralization, two directions were tested: left-to-right (start position: \(x = 6 \, \text{m}; y = 0 \, \text{m}; z = 0 \, \text{m}\)) and right-to-left (start position: \(x = -6 \, \text{m}; y = 0 \, \text{m}; z = 0 \, \text{m}\)). To focus on the velocity of motion, all moving sounds in the same direction started from the same point (6 meters away from the head) and moved for the same period of time (1000 ms). Figure 1 illustrates an example of the moving sounds. In addition, all stimuli had the same sampling rate (44,100 Hz), sample size (16 bits per sample), amplitude modulation (600 Hz square waveform), and duration (1000 ms). The intensity of the stationary sound was constantly 80 dB; the intensity of the moving sound to one ear was linearly decreasing from 89 dB to 71 dB while that to another ear was linearly increasing from 71 dB to 89 dB. All sound stimuli were randomly presented with a CTF pneumatic delivery system (CTF Systems Inc., Port Coquitlam, Canada). Each stimulus was presented 100 times; a total of 700 stimuli were presented for each direction. The stimulation time was 1000 ms. Each sound stimulus was presented every 1500 to 1700 ms (randomly spaced). For example, the first three stimuli in a test was 0, 1604, 3288 ms. All sound stimuli were presented binaurally.

### MEG Recordings

A 151-channel whole-cortex CTF OMEGA system was used in this study (CTF Systems Inc.). Each MEG sensor consisted of an axial first-order gradiometer (diameter, 2 cm; baseline, 5 cm). The gradiometer-to-gradiometer distance was about 4.2 cm. This system included a reference array that allowed for environmental noise cancellation of up to third-order spatial gradient. MEG measurements were done in a magnetically shielded room; the white-noise level for the system was <10 \(\text{ft}^2/\text{s}^2\). The subject’s head was localized relative to the sensor array with three small coils affixed to the nasion and pre-auricular points. The coils were simultaneously activated at different frequencies, and their positions determined from their magnetic signals to within an accuracy of <2 mm. The data were recorded with noise cancellation of third-order spatial gradient.

The sampling rate of data acquisition was 1250 Hz. The time window of data analysis was 200 ms before and 1200 ms after the stimulus; the pre-stimulus period (200 ms) was used as the baseline. Data were filtered using a band pass between 0 and 200 Hz.

To co-register MEG with three-dimensional magnetic resonance imaging (MRI), MRI was obtained for the subjects with a Signa Advantage (GE Medical System, Milwaukee, USA). Three fiduciary points were made with MRI markers on the nasion, and left and right pre-auricular points on the subject’s head. The positions of these fiduciary points were identical to the positions of the three coils used for the MEG.

### Analysis

To investigate neuromagnetic activation associated with auditory detection of motion velocity, we analyzed the waveform, contour map, and dipole location of the magnetic response to each moving sound. The peak latency was measured with a program called DataEditor (CTF Systems Inc.). The amplitude was determined from the peak (maximum value) of each response (deflection). To compare the responses of the left and right hemispheres, we divided all channels into two groups: the channels in the left group (left MEG) covered the left