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ACOUSTICAL LETTER

Assessment of temporal resolution of bone-conducted ultrasonic hearing using neuromagnetic measurements

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1. Introduction

Several studies have shown that bone-conducted ultrasounds (BCUs) can be perceived by the profoundly deaf, i.e., those who can hardly sense sounds even with conventional hearing aids, as well as people with normal hearing [1]. In 1991, Lenhardt *et al.* reported that BCUs modulated by speech sounds were intelligible to some extent [2], suggesting the possibility of developing a novel hearing aid based on BCU perception. However, Dobie and Wiederhold disputed Lenhardt's results, which had been obtained from subjective psychological experiments [3], and ever since the subject has been controversial.

We previously objectively supported Lenhardt's argument by using magnetoencephalography (MEG) [4,5] and developed a novel hearing aid for the profoundly deaf using BCU perception (BCU hearing aid, BCUHA) [6]. In the BCUHA, ultrasounds are amplitude-modulated by speech or environmental sounds and presented to the mastoid or sternocleidomastoid by a vibrator. With the BCUHA, both the modulator signal and the pitch of the carrier signal, of about 10–18 kHz [7], are perceived simultaneously. To assess and optimize the BCUHA, the features of BCU perception should be better specified.

In this study, as one of the fundamental capabilities of our BCUHA, temporal resolutions were objectively assessed by measuring mismatch fields (MMFs) in normal-hearing subjects. MMFs generally reflect the perceptual properties of sound discrimination.

2. Methods

Previous psychophysical measurement suggested that the auditory system has a sufficient ability to process timing information in the envelopes of amplitude modulated BCUs at lower modulation frequencies [8]. To assess the temporal resolution of the BCUHA objectively, MMFs for changes in stimulus duration were measured in normal-hearing subjects.

2.1. Subjects

Eleven normal-hearing subjects (8 males, 22–52 years, right-handed) participated. The subjects were certified as being able to sufficiently sense BCU via both the left and right mastoids. During recordings, the subjects sat on a chair in a magnetically shielded room and were requested to watch self-selected silent movies with subtitles.

2.2. Stimuli

One-kHz air-conducted tone bursts (AC), 30-kHz BCU tone bursts, 30-kHz BCU tone bursts amplitude-modulated by a 1 kHz sinusoid (AM-BCU), and complex air-conducted tone bursts consisting of 1- and 13-kHz sinusoids (Complex-AC) were presented in different sessions. AM-BCU and Complex-AC have approximately the same pitch. Each session consisted of one standard stimulus (duration: 75 ms; probability of appearance: 85%) and three types of deviant stimulus (durations: 52.5, 37.5, and 22.5 ms; probability of appearance: 5% each). Stimuli were presented randomly, and the evoked responses were averaged over more than 120 times for each deviant. The stimulus onset asynchrony (SOA) was set at 300 ms.

2.3. MEG recording and analysis

Event-related magnetic fields were recorded in a magnetically shielded room using a 122-channel whole-head neuromagnetometer (Neuromag-122™; Neuromag Ltd., Finland). The averaged data were digitally band-pass-filtered between 2 and 20 Hz. For each subject, we employed the MMF peak latency with a channel that showed the maximum amplitude placed over the left temporal region. At the peak latencies, equivalent current dipoles (ECDs) in the left temporal lobe were estimated.

3. Results

Figure 1 shows MMF wave forms elicited for each stimulus. In each session, MMFs were elicited for each deviant stimulus. Figure 2 shows the MMF magnitude and latency for each deviant. For all types of stimulus, larger and faster MMFs were observed for shorter deviants ($p < 0.01$, Fig. 2). The stimulus type had a significant effect on ECD moments ($p < 0.01$); however, no significant difference was observed between AM-BCU and Complex-AC (AC : BCU : AM-BCU : Complex-AC = 1.0 : 0.53 : 0.91 : 0.92). No significant differences were observed in MMF latency among the stimuli.

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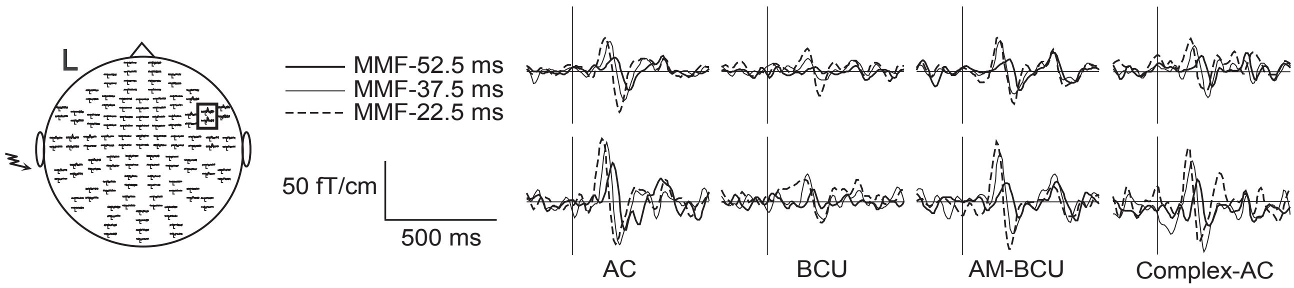

Fig. 1 MMF wave forms for changes in stimulus duration. Two channels that cover the right auditory cortex were enlarged: the upper and lower channels show latitudinal and longitudinal tangential derivatives of magnetic fields, respectively.

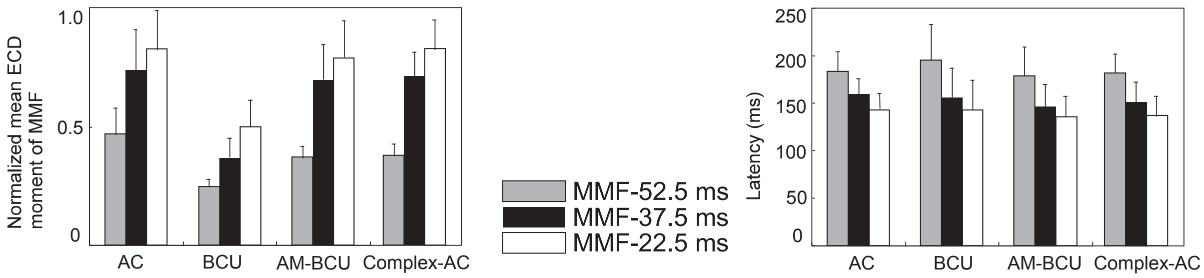

Fig. 2 MMF magnitudes and latencies evoked by changes in stimulus duration.

4. Discussion and conclusion

No significant difference was observed in MMF between AM-BCU and Complex-AC. Since MMF is generally more related to the perceptual properties of stimuli than to the physical properties, the current results show the difference between BCU and AC in terms of their perceptual attributes rather than their pathways. The results also indicated that the BCU hearing aid has practical temporal resolution.

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