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Frequency Characteristics of the Living Human Head Vibration under Bone-conducted Ultrasonic Stimulation
骨導超音波刺激下での生体頭部振動特性について

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1. Introduction

Although ultrasound is usually described as inaudible sound with a frequency above 20 kHz, it actually becomes audible through bone conduction (BC). Several studies have reported that bone-conducted ultrasound (BCU) also can be perceived by some of the profoundly deaf people with conductive and/or sensorineural hearing loss as well as those with normal hearing.[1,2] Therefore, a novel hearing aid using BCU hearing (bone-conducted ultrasonic hearing aid: BCUHA) is being developed for profound deafness.[3] However, the mechanisms of BCU hearing remain unclear and need to be clarified for better development of the BCUHA.

The BCUHA mainly consists of a microphone, a sound signal processor, a career generator, an amplitude modulator, a piezoelectric ceramics vibrator (Murata Manufacturing, MA40E7S) with a plastic housing, and a headset. The vibrator is usually attached and held to a subject's mastoid with contact pressure of approximately 5 N using the headset. Ultrasounds are amplitude-modulated by speech or environmental sounds and fed to the subject through the vibrator. The vibrator itself has a dominant resonance peak at approximately 40 kHz as shown by the dot curve in **Fig.1**. However, the BCUHA uses a 30-kHz tone as a career signal because we can often find that perceptual threshold values exhibit a minimum around 30 kHz when listening to BCU tones using this system. Actually, the previous study showed that frequency characteristics of the living human head, measured by a small accelerometer (Ono Sokki, NP3211: a resonance frequency of 92.6 kHz) in the ear canal under BCU stimulation using the vibrator, also had a remarkable resonance peak around 30 kHz.[4] Thus, there appears to be a rough correlation between the human head vibration and the psychoacoustical property, whereas what is responsible for the frequency characteristics of the head vibration is unclear. Possible explanations for this phenomenon are effects of intrinsic resonance properties of the living human head and a shift of resonance frequency of the vibrator under strong contact pressure. Moreover, it is possible that resonance properties of the measurement system can be affected by the coupling of the accelerometer and the human head.

In this paper, the effects of the contact pressure, the stimulation locations of the head, and the coupling of the head and the accelerometer on the frequency characteristics of the human head vibration were examined.

2. Methods

The frequency responses of the head vibration of a subject with normal hearing under BC stimulation were measured. The head was excited by stepped sine signals from 10 kHz to 45 kHz in 0.5-kHz steps. The excitation force level was set to a level corresponding to 5 dB sensation level (SL) at 30 kHz. This level is loud enough to hear because of the narrow dynamic range of BCU hearing.[3,4]

As described above, the vibrator MA40E7S is housed by a plastic housing. The vibrating surface of the vibrator protrudes from the housing by 2 mm. In the usual way, the vibrating surface is attached onto a mastoid portion of the subject's temporal bones and held by the headset. At this time, the vibrating surface suffers contact pressure of approximately 5 N directly. To reduce the contact pressure on the surface, a rubber spacer of 2 mm thick was settled round the vibrating surface. The signals were presented to the subject's mastoid or forehead through the vibrator with or without the rubber spacer.

The frequency responses were measured with an accelerometer NP3211. The accelerometer was wrapped with a sponge tube and set firmly inside the ear canal on the stimulated side. For comparison of different measuring ways, acoustic fields in the ear canal under the same stimulation condition as above were measured by a probe microphone (Brüel & Kjær type 4182) instead of the accelerometer. All measurements were performed in an anechoic room.

3. Results and Discussions

The average response accelerations of the head vibration under different contact pressures were plotted in **Fig. 1**. The green and blue spectral curves indicate the cases with and without the spacer, respectively. Each curve was normalized on the basis of its maximum value. These spectral shapes are similar and the peak frequencies are almost same. The spectral peak seems not to be largely affected by a change in contact pressure.

The average response accelerations of the head vibration at different BC stimulation locations are plotted in **Fig. 2**. The green and blue spectral curves indicate the cases at the forehead and at the mastoid, respectively. Each curve was normalized on the basis of its maximum value. Although two spectral shapes are somewhat different, the peak frequencies are not exactly coincident but very close. Thus, the spectral peak seems to appear around 30 kHz even if the BC stimulation location is changed.

The average response velocities of the head vibration with different measuring procedures were plotted in **Fig. 3**. The green and blue spectral curves indicate the cases of measuring acoustic fields and of measuring vibrations inside the same ear canal, respectively. Each curve was normalized on the basis of its maximum value. Two spectral shapes are apparently different. There were some peaks but not a dominant one in the acoustic fields.

As a result, the spectral peak of the head vibration is likely not to reflect the resonance properties of the vibrator because a change in contact pressure did not shift the frequency of the spectral peak. The spectral peak seems rather to be induced by other factors such as the resonance properties of the human head and of the measurement system. However, it is still not clear which factor is more responsible for the spectral peak, because the different BC stimulation locations yielded similar peak frequencies of the head vibration and also the acoustic fields in the ear canal was lifted up from about 27 to 40 kHz.

An underlying problem in this study is that the frequency response of an accelerometer can be affected by how it is connected to a vibrating object. Adhesive agents such as glue, tape, and so forth can vary the resonance properties of the sensor very easily. The way of firmly plugging the ear canal with a small accelerometer wrapped by a sponge tube, as adopted in this study, can measure head vibrations more stably than ever but there is still a room for further improvement in this measurement system.

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References

1. M. L. Lenhardt, R. Skellett, P. Wang, A.M. Clarke: Science, **253** (1991) pp.82-85.
2. H. Hosoi, S. Imaizumi, T. Sakaguchi, M. Tonoike, K. Murata: The Lancet, **351** (1998) pp. 496-497.
3. S. Nakagawa, Y. Okamoto, Y. Fujisaka: Trans. Jpn. Soc. Med. Bio. Eng.,**44**(1) (2006) pp.184-189.
4. K. Ito, S. Nakagawa: Jpn. J. Appl. Phys., 50 (2011) 07HF04.

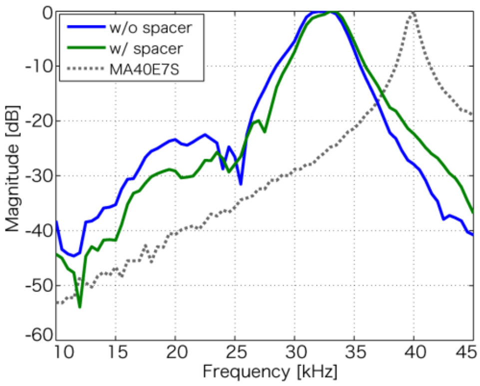

Fig. 1 Accelerations of the head vibration under different contact pressures.

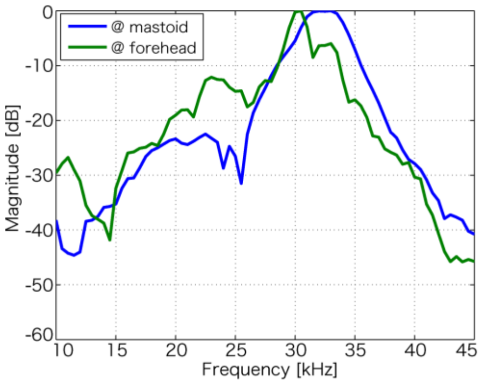

Fig. 2 Accelerations of the head vibration at different BC stimulation locations.

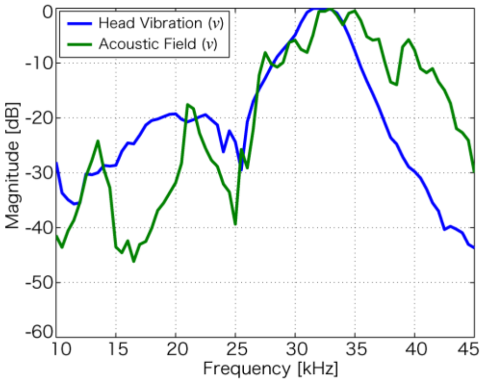

Fig. 3 Velocities of the head vibration measured with different measuring procedures.