3P5-34

Proceedings of Symposium on Ultrasonic Electronics, Vol. 34 (2013) pp. 557-558
20-22 November, 2013

Characterization of Human Head Vibration with Bone-conducted Ultrasonic Stimulation

骨導超音波刺激による生体頭部振動の特性評価

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1. Introduction

Ultrasound is generally described as inaudible sound with a frequency above approximately 20 kHz, but it actually becomes audible through bone conduction (BC). Several studies have reported that bone-conducted ultrasound (BCU) 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)] Therefore, a novel hearing aid using BCU hearing (bone-conducted ultrasonic hearing aid: BCUHA) is being developed for profound deafness.[2)] However, the mechanisms of BCU hearing remain unclear and need to be clarified for better development of the BCUHA.

In the BCUHA, ultrasounds are amplitude-modulated by speech or environmental sounds and fed to the subject through a vibrator. The vibrator is usually attached and held to a subject's mastoid with a contact pressure of approximately 5 N using a headset. Although the vibrator mainly used in this system has a dominant resonance peak at approximately 40 kHz as shown by the dotted curve in **Fig.1**, a 30-kHz BCU tone is adopted as a career signal because we can often find that perceptual sensitivity is higher at around 30 kHz than at other ultrasonic frequencies when listening to BCU tones using the BCUHA. Actually, the frequency characteristics of the living human head, measured by a small accelerometer in the ear canal under BCU stimulation with a constant excitation level using the vibrator, also formed a broad spectral peak between 30 and 40 kHz (**Fig. 1**).[3)] Thus, there appears to be a rough correlation between the human head vibration and the psychoacoustical property, while what responsible for the frequency characteristics of the head vibration is unclear. Possible explanations for these phenomena had been considered to be due to a shift of the resonance frequency of the vibrator by a strong contact pressure with the headset or effects of intrinsic resonance properties of the living human head. However, the previous study showed that the spectral peak of head vibration was likely not to directly reflect the resonance property of the vibrator because the frequency of the spectral peak was not affected by a change in contact pressure between the vibrator and the human head.[3)]

In this study, to understand the intrinsic resonance properties of the living human head, the frequency characteristics of head vibration were re-examined, especially regarding effects of elasticity of contacting surface with the vibrator on the spectral peak of head vibration.

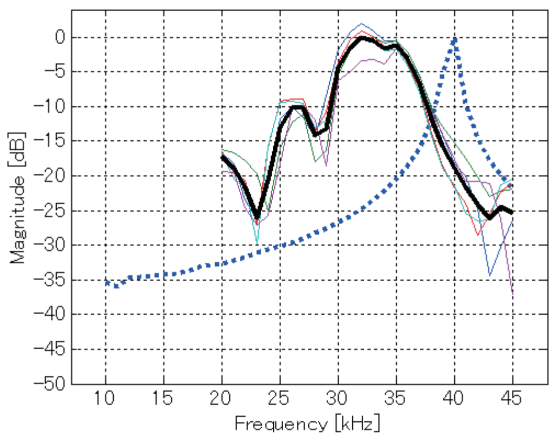

Fig.1 Accelerations of human head vibration under BCU stimulation with a constant excitation level. The solid curve denotes the mean value. The dot curve shows the frequency response of the vibrator MA40E7S.

2. Methods

Frequency characteristics of head vibration of a subject with normal hearing under BCU stimulation were measured. The vibrator (Murata Manufacturing, MA40E7S) was attached onto a mastoid portion of the subject's temporal bone and held by the headset with a contact pressure of approximately 5 N. The frequency characteristics were measured with an accelerometer (Ono Sokki, NP3211: a resonance frequency of 92.6 kHz), which was wrapped with a sponge tube and set firmly inside the ear canal on the stimulated side.

The head of the subject was excited by stepped sine signals from 20 to 45 kHz in 1 kHz steps. Each excitation force level was set to a level selected so that the frequency spectrum of acceleration of total stimulation was flattened over this frequency range, based on a sensation level (SL) of approximately 0 dB at 30 kHz. All measurements were performed in an anechoic room.

To examine effects of elasticity of contacting surface with the vibrator, a skull model attached with various skin-like surfaces made of gum rubber or silicon rubber was used. Three types of materials were used as the contacting surfaces: soft gum rubber, hard silicon rubber, and soft silicon rubber. The vibrator was set to a skin-like surface at the mastoid position and held by the headset with 5-N contact pressure. The skull model was excited by stepped sine signals from 10 to 45 kHz in 1 kHz steps. Each excitation level was set to the same level as that of the previous measurement for the subject. The frequency characteristics were measured with the sponge-wrapped accelerometer in the skull's ear canal.

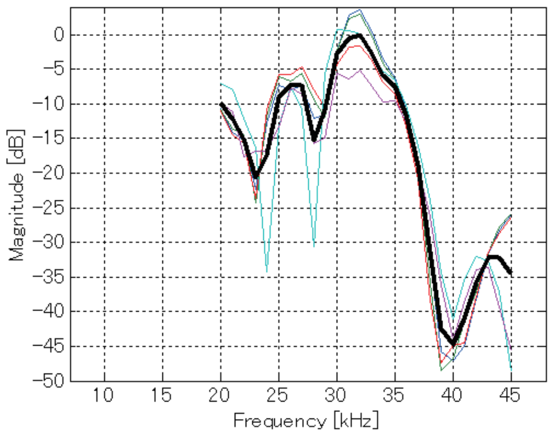

Fig. 2 The frequency characteristics of human head vibration of a subject with normal hearing. The black thick line represents the mean value.

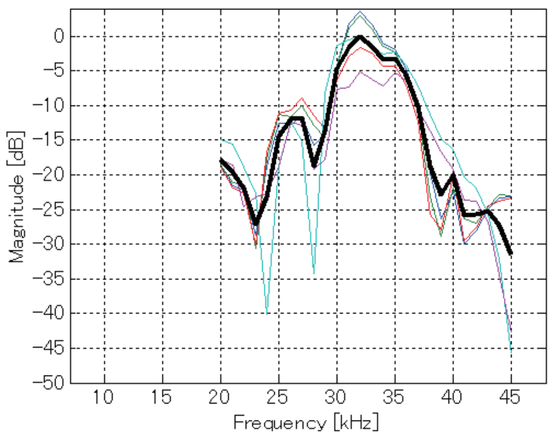

Fig. 3 The frequency characteristics synthesized by two spectra of frequency response of the human head and the vibrator.

3. Results and Discussions

The frequency characteristics of head vibration of the subject were plotted in **Fig. 2**. Results for the three types were superimposed. The black thick line denotes the mean value. There is a remarkable spectral peak around 32 kHz. Further, the spectral shape represents a low pass filter response with a cutoff frequency of around 30 to 35 kHz. The synthesized spectra of the two frequency responses of the human head and the vibrator were shown in **Fig. 3**. It was confirmed that the average synthesized spectrum coincided with the average frequency characteristic of the head vibration in **Fig. 1**. These results suggested that the spectral peak of head vibration is likely to reflect the intrinsic resonance properties of the living human head.

The frequency characteristics of a skull model measured on the basis of elasticity of contacting surface with the vibrator were shown in **Fig. 4**. Result showed that the frequency characteristics for the soft silicon were relatively similar to those of the living human head. Since soft silicon rubber well simulates the elasticity of the living human skin, it is suggested that the spectral peak of head vibration under BCU stimulation may result in the effects of the elasticity of the living human skin contacting with the vibrator.

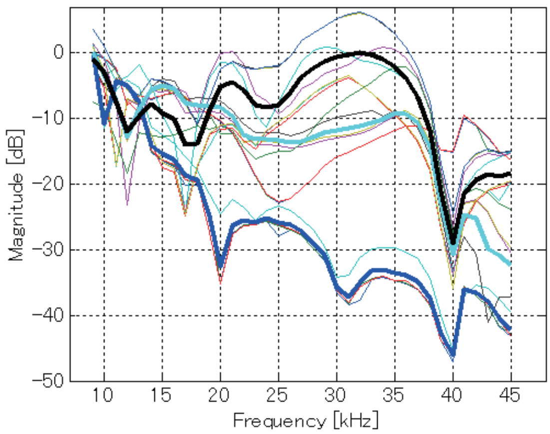

Fig. 4 The frequency characteristics of a skull model; the blue thick line represents the mean value for soft rubber, the cyan for hard silicon rubber, and the black for soft silicon rubber.

Acknowledgment

A part of this work was supported by the Funding Program for Next-Generation World-Leading Researchers provided by the Cabinet Office, Government of Japan, and the Grants-in-Aid for Scientific Research (22680038) of Japan Society for the Promotion of Science.

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