2P2-12

Proceedings of Symposium on Ultrasonic Electronics, Vol. 33 (2012) pp. 191-192
13-15 November, 2012

Estimation of the Propagation Sequence of the Bone-conducted Ultrasound in the *in vivo* Head by Ultrasonic Pulse Wave Responses

超音波パルス波応答による骨導超音波の頭部内伝搬過程の推定

Takuya Hotehama[1‡] and Seiji Nakagawa[1] ([1]Health Research Institute, National Institute of Advanced Industrial Science and Technology (AIST))
保手浜 拓也 [1‡]，中川誠司 [1] ([1]独立行政法人産業技術総合研究所 健康工学研究部門)

1. Introduction

An ultrasound with frequency above 20 kHz up to at least 100 kHz, generally exceeding the upper limit of human auditory perception by air-conduction, can be heard via bone-conduction (BC)[1]. This "audible" ultrasound through BC is referred to as the bone-conducted ultrasound (BCU). Since BCU can be perceived not only by normal hearing persons but also by sevior hearing impaired persons[2], a new type of hearing aid using BCU hearing (bone-conducted ultrasonic hearing aid) is being deveroped for profoundly hearing impaired[3].

For better deveropment of the BCUHA, the propagation charcteristics of the BCU in the head need to be clarified, though there exists critical difficulties in observing the phenomena taking place inside of the human heads.

In the previous study, Hotehama and Nakagawa (2012) estimated the propagation velocity of BCU in a living human head as approximately 300 m/s by using the pattern of acoustic interference, which was extracted from the distribution of the acceleration responses induced as a function of frequency and inter lateral phase difference of bilaterally presented BCU stimuli[4]. However, there were considerable differences between the estimated BCU velocities and that for biotic materials measured *in vitro*: the speed of sound through dry bones ranges from approximately 2000 to 3000 m/s and that through brain matter ranges from approximately 1000 to 1400 m/s[5], and the reason of the relatively slow velocity of BCU in a living human head in comparison with the biotic materials was unclear.

In this study, to estimate propagation sequence of the BCU in the *in vivo* head, we measured the response for ultrasonic pulse.

2. Measurements

2.1 Methods

The experimental setup is shown in **Fig. 1**. Ultrasonic pulse as excitation signals were 10-wave sinusoids with frequencies from 28 kHz to 32 kHz in 100-Hz steps. The ultrasonic pulse were presented unilaterally via vibrators (Murata Manufacturing MA40E7S) placed over the left and right mastoid processes. The excitation signals were synthesized digitally by a PC at a sampling frequency of 192 kHz, generated through a 24 bit digital-to-analog converter (Echo Digital Audio Audiofire12), filtered by a low-cut filter (NF 3625) with a 20 kHz cutoff frequency, and amplified by a piezo driver (Mess-Tek M-2629B). The acceleration responses were measured using accelerometers (Ono Sokki NP3211) placed inside the left and right ear canals.

The acceleration responses at the left and right ears were obtained simultaneously each for the left or right unilateral excitation.

2.2 Results and discussion

Figure 2 and **3** show the time-frequency responses for left-side stimulation at the ipsi- and the contra-lateral ears, respectively. **Figure 4** and **5** indicate the superposed waveform of the pulse responses for left-side stimulation at the ipsi- and the contra-lateral ears, respectively.

In **Fig.2** and **4**, the arrival times for ipsi-lateral ear seem to be about 10 μs. The superposed waveforms are aligned at arrival time and the subsequent waveforms are shifted simply depending on the wavelength of the stimulus frequencies.

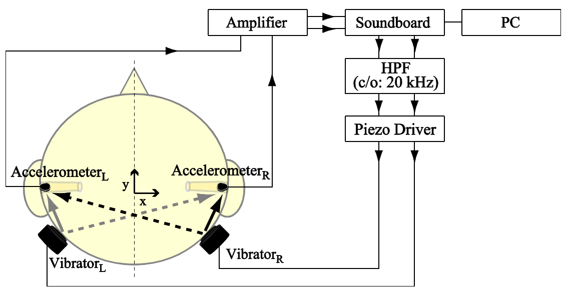

Fig. 1 Experimental setup for the measurements of propagation characteristics of BCU in the head.

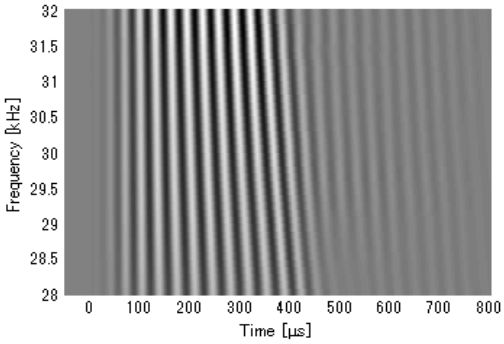

Fig. 2 Time-frequency responses of acceleration at ipsi-lateral ear for unilateral stimulations with the left vibrator.

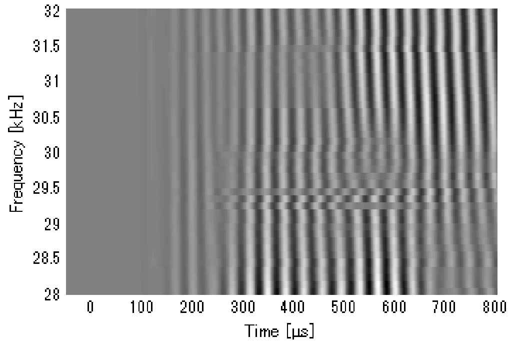

Fig. 3 Time-frequency responses of acceleration at contra-lateral ear for unilateral stimulations with the left vibrator.

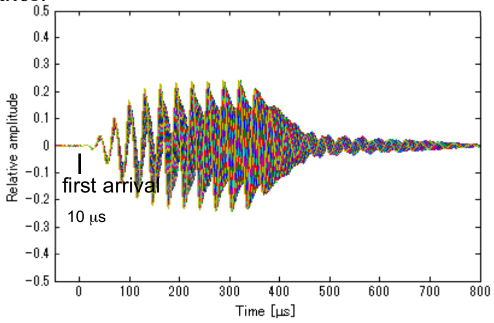

Fig. 4 Superposed waveforms of the pulse responses for left-side stimulation at the ipsi-lateral ear.

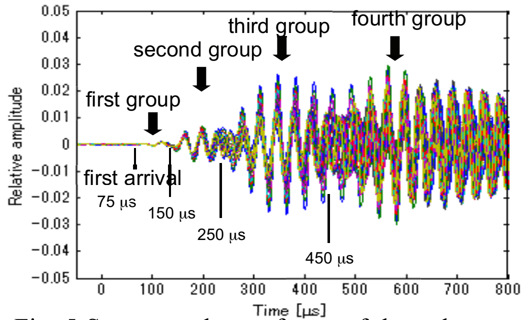

Fig. 5 Superposed waveforms of the pulse responses for left-side stimulation at the contra-lateral ear.

In **Fig.3** and **5**, the first arrival times for contra-lateral ear seem to be about 75 µs. In contrast to the ipsi-lateral responses, the subsequent waveforms of the contra-lateral responses to the first arrival times are not simply shifted depend on the wavelength of the stimulus frequencies. In Fig.5, the superposed waveforms subsequent to the first arrival times can be divided into several groups, as result in the existence of different transmission pathways or transmission modes.

Although the start times of the subsequent groups cannot be clearly indicated, there seem to be the border of the group around 150, 250 and 450 µs after the first arrival time.

Referring to the distances between the transducers and the accelerometers as shown in Table I, the first arrival time for ipsi-lateral side (10 µs), that for contra-lateral side (75 µs), and border of each group for contra-lateral side (150, 250 and 450 µs) correspond to propagation velocities of 3090, 1744, 872, and 523 and 291 m/s, respectively. Considering that the amplitude of the fourth group was the largest in Fig.5, the obtained phase velocities of BCU[4] seen to be reflected the transmission modes or pathways of the fourth group.

4. Conclusions

In the present study, we measured ultrasonic pulse wave responses inside the left and right ear canals for unilateral presentations. The obtained pulse wave responses show that there are several transmission pathways or modes and the dominant pathways or modes for BCU velocity was identified.

Acknowledgment

This research was supported by the Funding Program for Next-Generation World-Leading Researchers provided by the Cabinet Office, Government of Japan.

References

1. R. Pumphrey: Nature. **166** (1950) 571.
2. M.L. Lenhardt, R. Skellett, P. Wang, A.M. Clarke: Science. **253** (1991) 82-85.
3. S. Nakagawa, Y. Okamoto, Y. Fujisaka: Trans. Jpn. Soc. Med. Bio. Eng. **44** (2006), 184-189.
4. T. Hotehama, S. Nakagawa: Jpn. J. Appl. Phys. **51** (2012) 07GF21.
5. P. Henry and T. Letowski: Bone Conduction: Anatomy, Physiology, and Communication (U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 2007).

Pathway	Distance (mm)
$\overrightarrow{\text{Vib.}_L\ \text{Acc.}_L}$	30.9
$\overrightarrow{\text{Vib.}_L\ \text{Acc.}_R}$	130.8
$\overrightarrow{\text{Vib.}_R\ \text{Acc.}_L}$	130.4
$\overrightarrow{\text{Vib.}_R\ \text{Acc.}_R}$	35.2

Table I. Distances between the vibrator and the accelerometer.