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Assessments of propagation of bone-conducted ultrasound presented to the arm using laser-Doppler vibrometry

レーザードップラー計測による遠位呈示骨導超音波の伝搬過程の検証

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1. Introduction

Bone-conducted ultrasound (BCU) can be experienced as sound by the severely hearing-impaired as well as the normal-hearing[1-3]. We have been working on elucidation of perception mechanisms of BCU[4-6]. and the application to a novel hearing-aid (BCU hearing aid)[7, 8].

In the BCU hearing aid, ultrasonic sinusoids with a frequency of about 30 kHz are amplitude-modulated by speech or environmental sounds and presented to the mastoid process of the temporal bone, which is located behind the pinna and known to be one of the most suitable position to hear BC sounds, by a vibrator. However, BCU can be heard not only on the mastoid process. but also on wider area of the body; for example, the forehead, the muscle of the neck, the clavicle, the superior limb, and the inferior limb. In the previous study, we measured thresholds of 30-kHz tone bursts presented to the neck and the upper and lower arms in normal hearing participants. The results showed that BCUs presented to the distal parts, including the lower arm, can be perceived whereas threshold increased depending on the distance from the head[9].

To elucidate the propagation mechanisms of the dinstantly-presented BCU, we also measured vibrations of the ear canal using an accerelation sensor when 30 kHz tone bursts were presented to distal parts of the human body[10]. The results showed that prominent spectrum peaks corresponding to the stimulus-frequency were observed at all parts, and the vibration tended to decrease depending on the distance between the stimulus and measurement points. However, such kind of vibtation measurements are sometimes affected by the coupling between the skin and sensors. To confirm the previous results, other kinds of measurements that are not affected by coupling are needed.

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In this study, to verify the propagation characteritics of the distantly-presented BCU in the human body, surface vibrations of the human skin were measured using laser-Doppler vibrometry.

2. Methods

2.1 Subjects

Normal-hearing subjects (male, 21-23 years) participated.

2.2 Stimulus Placements and measurement

The forearm, from the styloid process of the ulna to the olecranon,was divided into five equal parts. Also, the upper arm, from the olecranon to the acromial process, were divided into five equally parts. BCU stimulus was presented to the next position from the styloid process of the ulna. Vibrations were measured at nine surface points lined up straight alongthe long axis of the upper limb, from the next division of thestimulation site (measurement point #1) to acromial process.

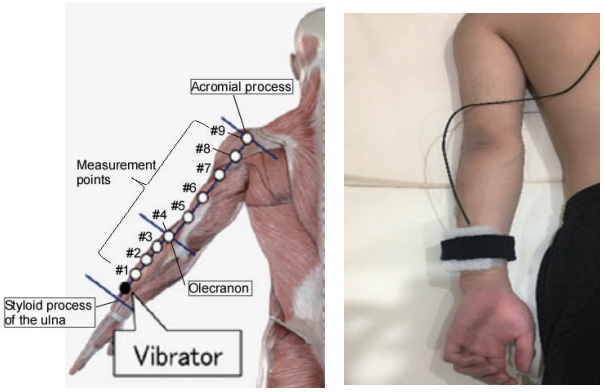

Fig. 1 Presentation of the stimuli in the experiment. Left: Stimulation and measurement points. Right: Placement of the vibrator on the forearm.

2.3 Stimulus

A 30-kHz BCU tone was presented by a piezoelectric ceramic vibrator. The BCU vibrator was pressed against brachioradial muscle using an elastic band. Pressures of the presentation was adjusted to 5 N.

2.4 Measurement of vibration of the upper limb

The vibration of upper limb surface caused by the BCU stimulus was measured for 5 s using an laser-Doppler vibrometer (Ono Sokki LV-1720) . The acceleration signal was amplified 5 times by an amplifier and taken into a PC at a sampling frequency of 192 kHz.The frequency spectra were calculated.

3. Results and Discussion

All subjects sensed BCU at all body parts tested. Detection threshold for each part was shown in **Fig. 4**. Compared to the mastoid process of the temporal bone, detection thresholds increased from about 5 dB (sternocleidomatoid muscle) to 20 dB (Upper arms). Furthermore, all subjects were able to sense BCU on the lower-arm muscles and bones of the palm. The results obtained clearly show that BCU presented to the distal part like the neck or the upper limb can be perceived at least in the normal-hearing subjects. Especially, increase of the detection threshold from the mastoid process was as little as 5 dB when BCU was presented at the sternocleidomatoid muscle. This result indicates that presentation to the neck can be available even in the profoundly hearing impaired.

Acknowledgment

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References

1. R. J. Pumphrey: Nature **166,** 571, 1950.
2. R. J. Bellucci and D. E. Schneider: Ann. Otol. Rhinol. Laryngol. **71**, 719-726, 1962.
3. M. L. Lenhardt et al.: Science **253,** 82–85, 1991.
4. S. Nakagawa and A. Nakagawa: J. Acoust. Soc. Am. **120**, 3123-3124, 2006.
5. S. Nakagawa: Brain Topography and Multimodal Imaging, 95-101, 2009
6. S. Nakagawa and M. Tonoike: Unveiling the Mystery of the Brain, ICS1278, 333-336, 2005.
7. S. Nakagawa et al.: Jpn. J. Appli. Phys. **51** (2012) 07GF22.
8. S. Nakagawa et al.: Jpn. J. Appli. Phys. **52** (2013) 07HF06.
9. S. Nakagawa et al., Jpn. J. Appl. Phys. **57** (2018) 07LD22.

Fig. 2 The laser-Doppler vibrometer used in the experiment (Ono Sokki LV-1720).

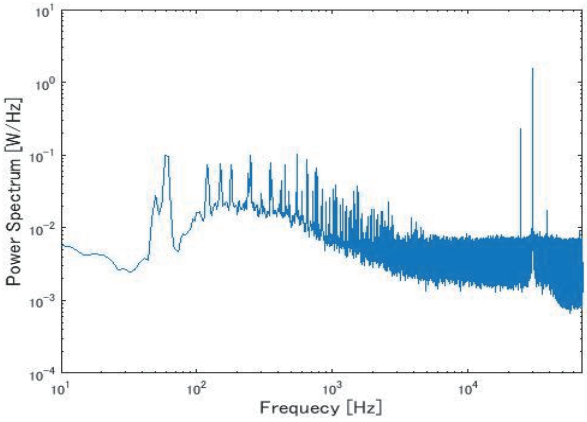

Fig. 3 Frequency spectra of the vibration obtained at the point #2.

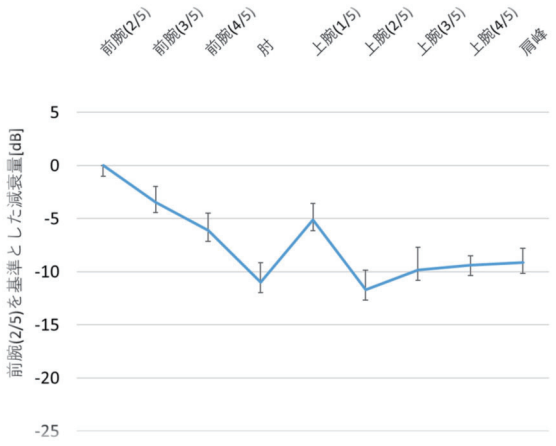

Fig. 4 Vibrations of the 30-kHz component measured for each stimulus-point. The value for the point #2 in each participant was served as the reference (0 dB).

10. R. Ogino et al., Jpn. J. Appl. Phys. **58**, SGGE12, 2019.