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Propagation characteristics of amplitude-modulated bone-conducted ultrasounds distantly presented to the neck, trunk and arms

頸部・体幹・上肢に呈示された振幅変調骨導超音波の伝搬特性

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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 and the application to a novel hearing-aid.

Our recent electrophysiological measurements revealed that the ordinary auditory pathway, from the auditory nerve to the auditory cortex via the brainstem, is activated by BCU and there is no special organ for BCU perception[4, 5]. Additionally, previous studies on psychophysical measurements[6, 7] of BCU perception have shown several characteristics of BCU perception that suggest unique perception mechanisms, although the cochlea contributes substantially to BCU perception. These findings suggest that BCU is received in the cochlea through a special mechanism that is different from that of audible-frequency sound perception.[5]

Further, we have developed a hearing aid using BCU perception (BCU hearing aid: BCUHA) for the profoundly hearing-impaired.[10, 11] Hearing tests using the prototype of the BCUHA in the profoundly hearing-impaired subjects showed that more than 40% of subjects tested were able to perceive some sounds and 17% were able to recognize words,[10] and the temporal resolution of BCU hearing was as good as that of the air-conducted hearing[12]. Also in hearing tests in the normal-hearing, it is suggested that the frequency resolution of the BCU hearing was comparable to that of air-conduction hearing in the range of 250-4000 Hz[13].

In the BCUHA, 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.

On the other hand, one of the largest disadvantages of bone-conduction devices is uncomfortableness of wearing of vibrators. Usually, vibrators are pressed onto the mastoid process of the temporal bone by a headset with a clamping pressure of approximately 5 N (**Fig. 1**). Sometimes it is painful and brings beauty problems. Also, it is hard to hold the vibrator steadily with such a head gear. If it is possible to present bone-conducted sound to distlal location, not to the head, and obtain significant hearing, these problems can be soloved.

In this study, as a first step to verify the possibility of development of distal-presented BCU devices, detection thresholds were measured when BCUs were presented to the neck and the upper limb.

2. Methods

2.1 Measurement of detection threshold

5 normal-hearing subjects (male, 21-24 years) participated. Detection thresholds were measured using a 2 up-1 down three-alternative forced-choice (3AFC) adaptive procedure with a decision rule that estimated the 70.7% correct point on the psychometric function. BCU stimuli were presented to following parts of the body (See **Fig. 1~3**):

1) Mastoid process of the temporal bone
2) Sternocleidomastoid muscle (middle point

Fig. 1 Presentation of bone-conducted ultrasound to the mastoid process of the temporal bone.

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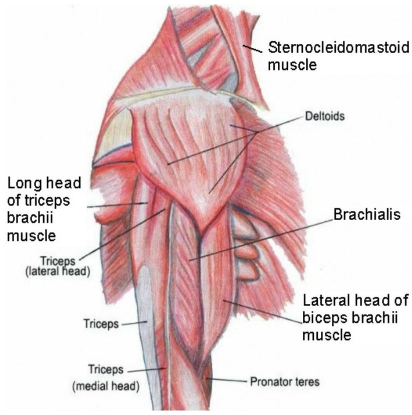

Fig. 2. Muscles of the neck and the upper arm.

between the mastoid process and the

Fig. 3. Examples of the presentation of bone-conducted ultrasound. Left: the triceps brachii muscle, Right: the sternocleidomatoid muscle.

sternoclavicular joint)

3) Lateral head of biceps brachii muscle
4) Long head of triceps brachii muscle
5) Brachialis muscle (Lateral side of the upper arm)

2.2 *Apparatus*

A 30-kHz tone-burst with duration of 800 ms including 150-ms rising/falling ramps was used as the BCU stimulus. BCU stimuli were presented by a piezoelectric ceramic vibrator (Murata Manufacturing MA40E7S) with a newly devised plastic housing. BCU stimulus was generated by a personal computer using MATLAB at a sampling frequency of 96 kHz and fed to the vibrator via a 24-bit digital-to-analog converter (MOTU MK896), an amplifier (Mess-Tek M-2629B), and a programmable attenuator (Tucker-Davis Technologies PA-5). All experiments were carried out in the anechoic room.

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

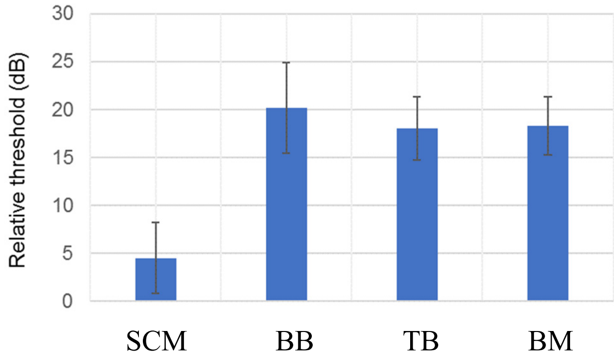

Fig. 4. Relative threshold of distant-presented bone-conducted ultrasonic hearing. Threshold for the mastoid process of the temporal bone in each subject was served as the reference (0 dB). SCM: sternocleidomatoid muscle, BB: biceps brachii muscle, TB: triceps brachii muscle, BM: Brachialis muscle.

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.

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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. T. Nishimura et al.: Hearing Research 175, 171-177, 2003.
8. S. Nakagawa, Trans. Jpn. Soc. Med. Bio. Eng. 44, 184-189, 2006.
9. S. Nakagawa et al. J. Appli. Phys., 52:07GF22, 2013.
10. T. Hotehama and S. Nakagawa, J. Acoust. Soc. Am. 128, 3011-3018, 2010.
11. K. Fujimoto and S. Nakagawa, Hearing Research 204, 210-215, 2005.