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Propagation and perception characteristics of distantly-presented bone-conducted sounds
- Comparison between ultrasonic and low-frequency ranges-

遠位呈示された骨導音の伝搬および知覚特性
-超音波と可聴音の比較-

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1. Introduction

Several studies have shown that high frequency sound above 20 kHz can be heard clrearly via bone conduction (Bone-conducted ultrasound: BCU).[1-3]

BCU can be perceived even when presented to body parts distant from the head, like the neck, trunk, and arms [4] and expected to be applied for novel devices that transmit sound selectively to persons who touched by a vibrator. In the previous study, we measured thresholds and the vibration of the ear canal when 30 kHz tone bursts were presented to the neck and the upper and lower arms in normal hearing participants.[4, 5] The results showed that BCUs presented to the distal parts, including the lower arm, can be perceived whereas threshold increased and the vibration decreased depending on the distance from the head.

However, details of mechanisms of propagation and perception remain unclear. We have used a 30-kHz stimulus in our previous studies, however, comparioson among other frequencies, especially lower “audible” frequencies may be useful to verify the propagation characteristics of bone-conducted sounds in the human body.

In this study, we investigated perception and propagation characteristics of the ultrasonic and low-frequency sounds presented to the distal parts of the body via bone- conduction.

2. Experiment1: Measurement of hearing thresholds

2.1 Methods

6 participants (male, 21-24 years) who has no history of deficits of hearing functions participated in the experiment.

A 30-kHz tone-burst with duration of 400-ms including 150-ms rising/falling ramps was used as the BCU stimulus. As the low-frequency ranges stimulus, 250, 500, 750, 1000, 1500, 2000, 3000, and 4000 Hz tone-burst were used. Bone-conducted

Fig. 1 Locations of the stimuli: (a) mastoid process, (b) sternocleidomastoid, (c) thoracic vertebrae

stimuli were presented to following parts of the body (**Fig. 1**):

a) Mastoid process of the temporal bone
b) Sternocleidomastoid muscle (muscle of the neck)
c) Thoracic vertebrae (the middle part of the back bone)

BCU stimuli were presented by a piezoelectric ceramic vibrator and low-frequency ranges bone-conducted stimuli were presented by a bone-conduction transducer (Radioear B71).

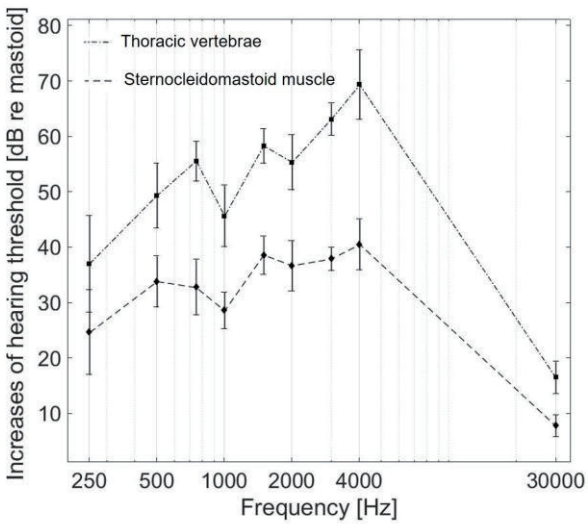

Fig. 2 Increases of the hearing threshold relative to that of the mastoid at each stimulus location.

Moreover, ears of the subjects were plugged by silicone ear plugs not to perceive air-conducted sounds radiated from the vibrators.

Hearing 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.

2.2 Results

Fig. 2 shows increases of hearing threshold when presented to the sternocleidomastoid muscle and the thoracic vertebrae relative to that presented onto the mastoid process. In the experiment, all participants were able to sense BCU and low-frequency bone-conducted tones at each location.

Significant effects of the stimulus location ($p<0.01$) and the stimulus frequency ($p<0.05$) were obtained. When the 30-kHz stimulus was presented, the increase of the hearing threshold was less than 20 dB. On the other hand, in the low-frequency, the increases of the hearing threshold were much larger and range from 25 to 60 dB. The threshold increase was smaller for the sternocleidomastoid than the thoracic vertebrae.

3. Experiment2: Measurement of the vibration in the ear canal

3.1 Methods

The participants were instructed to sit on a comfort chair in an anechoic chamber and relax. According to previous studies[6], the acceleration sensor wrapped in a 10-mm diameter urethane material was inserted in the left ear canal, and the acceleration of vibration caused by the bone-conducted tone was measured for 5 seconds.

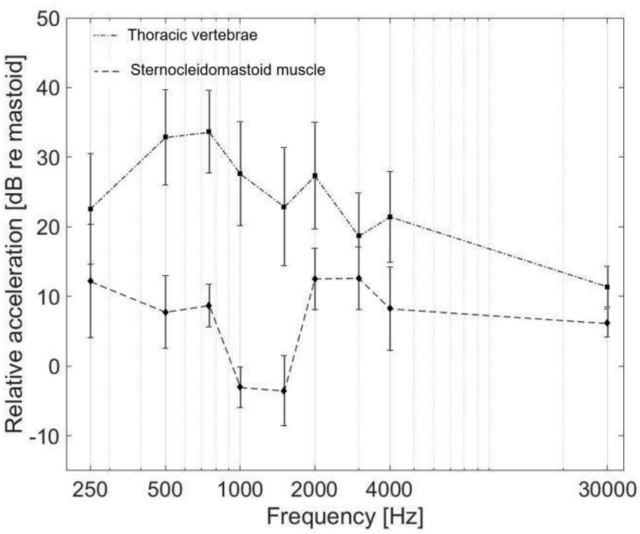

Fig. 3 Attenuation of accelerations at each location relative to that of the mastoid

The same stimulus frequencies as the experiment 1 were used. The level of the stimulus was adjusted to 10 dB SL for all frequency. The frequency spectrum was calculated from obtained signals using the fast Fourier transform.

3.2 Results

Fig. 3 shows attenuation of acceleration per stimulus frequency. Significant effects of the stimulus location ($p<0.01$) and the stimulus frequency ($p<0.05$) were obtained. When stimuli present to the sternocleidomastoid, attenuation is up to 12.5 dB (2000 Hz). However, when stimuli present to the thoracic vertebrae, the higher the stimuli frequency, the lower attenuation of acceleration.

4. Discussion

Fig. 2 shows that the hearing threshold increase relative to the mastoid were less than 20 dB when 30 kHz stimulus is presented. However, since BCU hearing has very narrow dynamic range of loudness, about 20 dB[7], 20-dB increase of intensity in BCU hearing correspond to that of 80 dB in low-frequency hearing. Considering this, the hearing threshold of bone-conducted sound presented at a distant location increase as the frequency get higher.

On the other hand, the vibration in the ear canal was not affected so much by the frequency.

It is expected to perceive clear audio information by changing the frequency of the stimulation sound according to the purpose of use.

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