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Evaluation of Propagation Characteristics of Bone-conducted Ultrasound Presented to the Neck, Trunk and Arms

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ABSTRACT

High-frequency sound above 20 kHz can be heard clearly via bone conduction (Bone-conducted ultrasound: BCU). Additionally, BCU is perceived even when presented to body parts distant from the head, like the neck, trunk, and arms, and is expected to be applied for novel devices that transmit sound selectively to persons who touched by a vibrator on the arm or other parts of the body. First, hearing thresholds were measured when 30-kHz tone-burst was presented to the neck, trunk and arms in normal hearing participants. The results showed that BCU presented to the distal parts, including the lower arm, can be perceived at least in normal hearing participants, but threshold increased depending on the distance from the head. Second, the vibration of the ear canal was measured using an acceleration sensor when a 30-kHz tone was presented to the neck, arms, and trunk. A prominent spectrum peak corresponding to the stimulus frequency was obtained. Further, the vibration tended to attenuate when the stimulus points were moved away from the head, although some exceptions existed. Third, the vibration of the upper limb was measured at 9 surface points lined up from the forearm to shoulder when BCU was presented near the wrist. The vibration basically tended to attenuate depending on the distance from the vibrator; however, some points at raised upper-arm muscle showed larger amplitudes. These results suggest that efficiency of the propagation varies depending on the stimulus points, and the upper-arm muscle are suitable also on a stimulus location of BCU.

Keywords: Bone conduction, Ultrasound, Upper arm, Trunk, Threshold, Sound propagation.

1. INTRODUCTION

Several studies have shown that high frequency sound above 20 kHz can be heard clearly via bone conduction (Bone-conducted ultrasound: BCU) (1-3). Moreover, BCU hearing in humans has been found under various auditory pathological conditions, including sensorineural hearing loss and middle-ear disorders (3). In addition, 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 on the arm or other parts of the upper body. However, there are many unclear points in details of perceptual characteristics and propagation mechanisms in distantly presented BCU.

In this study, in order to acquire useful information on elucidation of perceptual characteristics and propagation characteristics, hearing thresholds, the vibration in the external auditory meatus, and the vibrations of the upper limb were measured.

2. EXPERIMENTS

2.1 Participants and Stimulus Locations

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

BCU stimuli were presented to the 8 locations: (A) the mastoid process of the temporal bone, (B) the sternocleidomastoid muscle, (C) the sternal extremity of the clavicle, (D) the acromial process,

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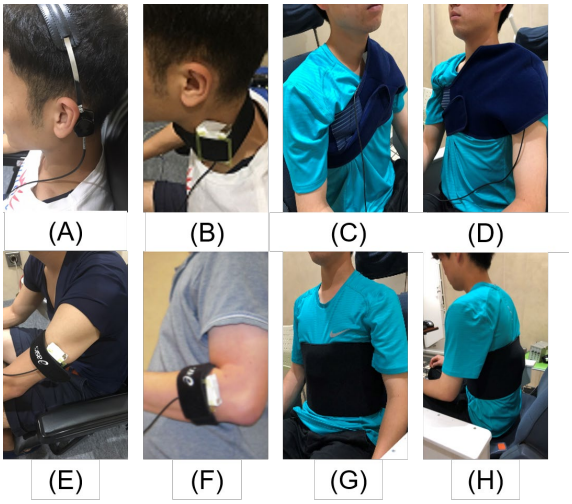

Figure 1 – Stimulus locations

(E) the brachialis muscle, (F) the brachioradial muscle, (G) the xiphoid and the thoracic vertebrae (Figure 1), by a piezoelectric ceramic vibrator (Murata Manufacturing MA40E7S). To the mastoid process, the vibrator was pressed using a head band. For other locations, an elastic band was used to hold the vibrator.

2.2 Experiment 1: Measurement of Hearing Thresholds (5)

Hearing thresholds were measured using a 2 up-1 down three-alternative forced-choice (3AFC) adaptive procedure. A 30-kHz tone-burst was used as the BCU stimulus.

The results showed that BCU presented to the distal parts, including the lower arm, can be perceived at least in normal hearing participants, but threshold increased depending on the distance from the head.

2.3 Experiment 2: Measurement of the Vibration in the Ear Canal (6)

In order to acquire useful information on elucidation of perceptual characteristics, as in previous studies (7), the acceleration sensor (Ono Sokki NP-3211) wrapped in a 10-mm diameter urethane material was inserted in the left ear canal, and the vibration generated by the 30-kHz BCU tone in the external ear canal was measured. The frequency spectrum was calculated from obtained signals.

The peak of the spectrum corresponding to the stimulation frequency (30 kHz) was clearly confirmed at all tested body parts. On the other hand, no significant peak other than 30 kHz was confirmed. As the stimulation part moved away from the head, the vibration tended to attenuate. However, although the distance from the thoracic vertebrae and the xiphoid were almost equal, the vibration was larger for the thoracic vertebrae than the xiphoid.

2.4 Experiment 3: Measurement of the Vibration of the Upper Limb (6)

In order to investigate only attenuation due to propagation distance, when BCU was presented to near the wrist, the vibration of the upper limb was measured at 9 surface points lined up straight from the next division of the stimulation site (measurement point 1) to the acromial process (measurement point 9). The acceleration sensor was attached to each measurement point with nonwoven surgical tape. The frequency spectra were calculated from obtained signals.

At all subjects and measurement points, spectral peaks corresponding to the stimulation frequency (30 kHz) were obtained. Figure 2 shows the spectral peak value corresponding to the stimulus-frequency obtained at each measurement point. The surface vibration decreased as the distance from the vibrator increased at the lower arm or the oval head point. On the other hand, at the upper arm, although the distance from the vibrator increased, the surface vibration was not attenuated.

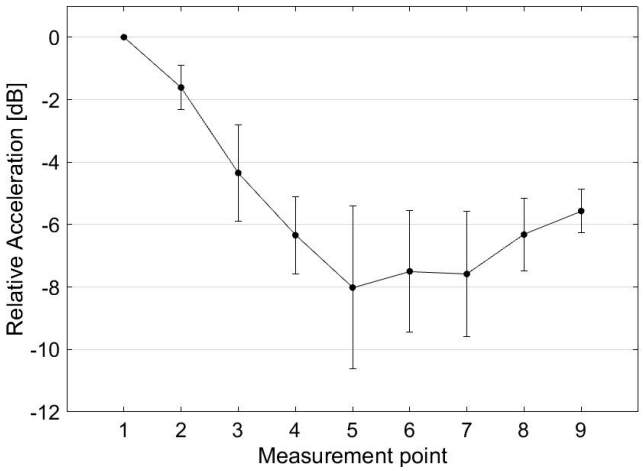

Figure 2 – Acceleration for the 30-kHz component measured at each point on the upper limb.

3. DISCUSSION AND CONCLUSIONS

In this study, to assess basic properties of distal-presented BCU hearing, hearing thresholds, the vibration in the ear canal and the vibration of the upper limb were measured.

The auditory threshold increased as the stimulus locations moved away from the head, and the vibration caused by BCU stimulation in the ear canal attenuated. Also, the vibration on the body surface was attenuated as the measurement points moved away from the stimulation point. From these results, it is suggested that BCU stimulation is attenuated due to the propagation distance. However, it was also found that there is a difference in propagation efficiency depending on the stimulus location. For example, a raised and hard location like the upper arm or the thoracic vertebrae is suitable as a stimulation point.

These results provide useful information not only for the improvement of the existing BCU hearing aid, but also for the development of novel “distantly-presented BCU” devices that can provide sound information selectively to at specific person who touches the device with their arms or hands.

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REFERENCES

1. Gavreau V. Audibillite de sons de frequence elevee. Comptus Rendus Acad. Sci. 1948;226:2053-2054.
2. Pumphrey R J. Upper limit of frequency for human hearing. Nature. 1950;166:571.
3. Bellucci R J, Schneider D E. Some observations on ultrasonic perception in man. Ann Otol Rhinol Laryngol. 1962;71:719-726.
4. Lenhardt M L, Skellet R, Wang R, Clerke A M. Human ultrasonic speech perception. Science. 1991;253:82-85.
5. Nakagawa S, Ogino R, Otsuka S. Assessment of detection threshold and temporal resolution of distantly presented bone-conducted ultrasonic hearing. Jpn. J. Appl. Phys. 2018;57:07LD22.
6. Ogino R, Otsuka S, Nakagawa S. Measurements of vibration in the external auditory meatus caused by distantly presented bone-conducted ultrasonic hearing. Jpn. J. Appl. Phys. 2019; Accepted.
7. Ito K, Nakagawa S. Perception Mechanisms of Bone-Conducted Ultrasound Assessed by Acoustic Characteristics in the External Auditory Meatus. Jpn. J. Appl. Phys. 2010;49:07HF31.