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Self-demodulation Characteristics of Amplitude-modulated Bone-conducted Ultrasound in the Human Body Presented to the Neck, Trunk and Arm

遠位呈示された AM 骨導超音波の体内自己復調の検討

Koichiro Doi[1‡], Riki Ogino[1], Sho Otsuka[1,2,3], and Seiji Nakagawa[1,2,3]
([1]Grad. School Sci. and Eng., Chiba Univ.; [2]Center for Frontier Med. Eng., Chiba Univ.; [3]Med-Tech Link Center, Univ. Hospital, Chiba Univ.)
土井 公一朗 [1†], 荻野 利基 [1], 大塚 翔 [1,2,3], 中川 誠司 [1,2,3]
([1] 千葉大院 融合理工学府, [2] 千葉大フロンティア医工学センター, [3] 千葉大医学部付属病院メドテック・リンクセンター)

1. Introduction

Several studies have reported that high-frequency sound at least up to 100 kHz presented via bone conduction can be heard clearly perceived (1, 2). This "audible" ultrasound through bone conduction is referred to as bone-conducted ultrasound (BCU). Moreover, BCU is perceived even by the profoundly deaf who cannot obtain enough hearing using a conventional hearing aid (3).

Additionally, BCU can transmit speech information using amplitude-modulation (AM) (3). Utilizing it, we have developed a new hearing aid for the profoundly deaf, called the bone-conducted ultrasonic hearing aid (BCUHA) (4-6).

One of the disadvantages of bone-conducted devices is uncomfortableness of wearing a vibrator and difficulty of fixing it to the head. Even in BCUHA, the vibrator is pressed onto the mastoid process of the temporal bone using a headband and it sometimes brings pain and beauty problems.

With bone-conducted devices, the sound is usually presented onto a part of the head, such as the mastoid process. On the other hand, BCU is perceived even when presented to the body parts distant from the head -like the neck, arm, and trunk (7). If it is possible to present BCU sound to distal body parts and obtain significant perception, these problems can be solved. Furthermore, distantly-presented BCU can be applied to develop a novel device that can transmit sound information selectively to the specific persons who touch the device.

In BCUHA, both high pitch tone due to the ultrasonic carrier and the envelope of the modulated signal are perceived (8). Normal hearing people may perceive the latter one as a low pitch tone due to self-demodulation generated by the nonlinearity in the human body (9). When BCU is presented to distal body parts, vibration propagates through various tissues in the body. When BCU is presented to a distal body part, vibration propagates through various tissues in the body including the cartilage that have strong non-linearity, therefore, more demodulation may occur. The demodulated sound may contribute to improving BCU sound quality, however, mechanisms of the demodulation in the propagation process in the human body remains unclear.

In this study, to elucidate demodulation characteristics in the propagation process of such distantly-presented AM-BCU, vibrations of in the external auditory meatus was measured when AM-BCUs were presented to the neck, the clavicle, upper limb, the breastbone and the back bone participants. Also, the vibrations around the cartilage of the outer ear that has strong nonlinearity were measured.

2. Measurement of vibrations in the ear canal

2.1 Method

Seven subjects with normal hearing (one female and six males, 21-24 years) participated in the experiment. Vibrations were measured using a small accelerometer (Ono sokki, NP-3211), which was wrapped in a sponge tube and inserted into the ear canal (10). A vibrator (Murata Manufacturing MA40E7S) was placed against the following body parts: i. Mastoid process of the temporal bone, ii. Sternocleidomastoid muscle (muscle of the neck), iii. Clavicle, iv. Acromial process, v. Brachialis muscle (muscle of the upper arm), vi. Brachioradial muscle (muscle of the lower arm), vii. Sternum, viii. The 10-12th thoracic vertebrae. To the mastoid, the vibrator was fixed using a headband, and to the other parts, using an elastic support band (Fig. 1). The carrier frequency of BCU stimuli was 30 kHz and the modulation frequencies were varied at 0, 100, 300, 600, 800, 1000, 3200 and 6400 Hz.

2.2 Result

The spectrum peak corresponding to the carrier frequency (30 kHz) and the modulation frequency were confirmed at all stimulus locations and these differences ranged from 40 to 70 dB. According to the previous study (10), the current results suggest that the demodulation component reached the perceptual level.

The level of the carrier component at each stimulus location tended to decrease depending on the distance between stimulus and measurement points, and the stimulus location showed a significant effect on the attenuation amount of the vibration ($p<2.2e-16$). However, the level of the modulation frequency component at each part relative to the mastoid did not change with distance, and the stimulus location showed no effect on the relative value ($p=0.99$) (Fig. 2).

3. Measurement of vibration around the cartilage

3.1 Method

Six males with normal hearing (21-24years) participated in the experiment. Measurements of vibrations were carried out in the following locations: I. tragus, II. pinna, III. cartilago thyroidea, IV. shoulder, V. thoracic vertebrae, VI. cartilago costalis, VII. Elbow (Fig. 3). The vibrator and the accelerometer were placed so that the measurement cartilage was located at the center of them. For the tragus and pinna, the accelerometer was inserted into the ear canal, and for the other parts, it was fixed on the skin using masking tape and wax. The AM-BCU stimuli were identical with indicated in 2.1.

3.2 Result

The level of the modulation frequency component relative to the carrier component at the tragus and pinna were larger than at distal parts (Fig. 4), and the presentation body parts showed a significant effect on the relative value ($p<2.2e-16$). In distal parts, the thoracic vertebrae showed the largest relative value.

4. Discussion

The carrier components, propagating between the stimulus location and the head, tended to decrease depending on the distance. On the other hand, the demodulation components did not show significant decreases depending on the distance. In addition, more demodulation component was generated at the tragus and the pinna than the cartilage in the distal location. These results suggest that demodulation mainly occurs near the ear canal even when BCU is presented to distal locations.

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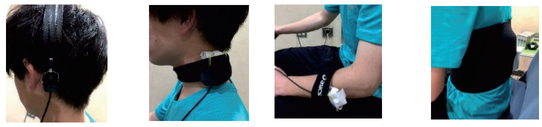

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Fig. 1 Locations of the BCU stimuli: i. mastoid process, ii. sternocleidomastoid muscle, iv. brachioradial muscle, viii. thoracic vertebrae.

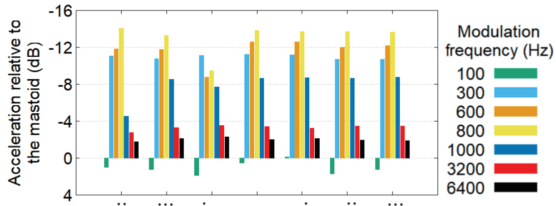

Fig. 2 Spectrum peaks corresponding to the demodulation component for each stimulus location.

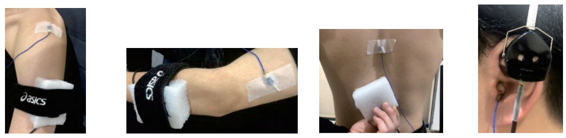

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Fig. 3 Locations of the BCU stimuli and the accelerometer: II. Pinna, III. Cartilago thyroidea, V. Thoracic vertebrae, VI. Cartilago costalis. In each location, the accelerometer was placed so that the distance between the vibrator and the accelerometer was 13 cm.

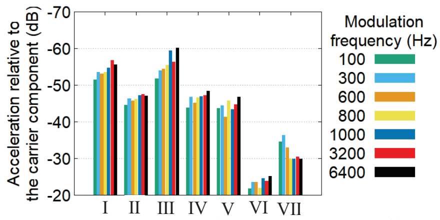

Fig. 4 Spectrum peaks corresponding to the demodulation component at each body part relative to the carrier component.

References

1. V. Gavreau: Comptes Rendu Acad. Sci. **226** (1948) 2053.
2. R. J. Pumphrey: Nature, **166** (1950) 571.
3. M L Lenhardt, et al.: Science **253** (1991) 82-85
4. S. Nakagawa et al.: Trans. Jpn. Soc. Med. Bio. Eng. **44** (2006) 184-189.
5. S. Nakagawa et al.: Jpn. J. Appli. Phys. **51** (2012) 07GF22.
6. S. Nakagawa et al.: Jpn. J. Appli. Phys. **52** (2013) 07HF06.
7. S. Nakagawa et al.: Tech. Rep. IEICE WIT99-15 (1999) 89.
8. K. Fujimoto and S. Nakagawa.: Hear. Res. **204** (2005) 210-215.
9. K. Ito and S. Nakagawa: Jpn. J. Appli. Phys. **54** (2015) 07HF07.
10. K. Ito and S. Nakagawa: Jpn. J. Appl. Phys. **49** (2010) 07HF31.
11. K. Ito and S. Nakagawa: Proc. ICA. **19**(1-PPA-09-13) (2007) 1-6.