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Demodulation Characteristics in Propagation Process of Amplitude-modulated Bone-conducted Ultrasound Presented to the Neck, Trunk and Arms

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ABSTRACT

Bone-conducted ultrasound (BCU) can be heard clearly and can transmit speech information using amplitude-modulation (AM). Additionally, BCU is perceived even when presented to body parts distant from the head, like the neck, trunk, and arm. It is expected that demodulated low-frequency components appear as a result of the nonlinearity existing in the human body when amplitude-modulated BCU (AM-BCU) is presented to such distal locations. First, to elucidate demodulation characteristics in the propagation process of such distantly-presented BCU, vibration at the external auditory meatus was measured when AM-BCU was presented to the neck, shoulder, upper limb, breastbone and backbone. The results showed spectrum peaks corresponding to the carrier frequency (30 kHz) and the modulation frequency. The level of the peak of the carrier tended to decrease depending on the distance between stimulation and measurement points, however, the peak of the modulator did not change with distance. Second, vibrations around the cartilage of the auricle, tragus and articulations, which have strong nonlinearity, were measured. The demodulation components were larger for the auricle and tragus than for the peripheral articulations. These results suggest that demodulation mainly occurs in the vicinity of the ear even when BCU is presented to distal body parts.

Keywords: Bone-conduction, Ultrasound, Amplitude-modulation, Demodulation

1. INTRODUCTION

High-frequency sound at least up to 100 kHz presented via bone conduction can be perceived even by the sensorineural deaf (1). This "audible" ultrasound through bone conduction is referred to as bone-conducted ultrasound (BCU). Additionally, BCU can transmit speech information using amplitude-modulation (AM). Utilizing this information, we have developed a new hearing aid for the profoundly deaf, called the bone-conducted ultrasound hearing aid (BCUHA) (2-4).

In BCUHA, both high pitch tone due to the ultrasonic carrier and the envelope of the modulated signal are perceived (5). Profoundly deaf people perceive the envelope as temporal information. On the other hand, normal hearing people may perceive it as a demodulated low frequency component generated by the nonlinearity of the human body (6).

With bone-conducted devices, sound is usually presented onto a part of the head, such as mastoid process of the temporal bone, using a vibrator. However, the devices have several disadvantages, such as the discomfort of wearing a vibrator and difficulty of fixing it to the head. 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 (8), these problems identified with bone-conducted devices can be solved. Furthermore, distantly presented BCU can be applied to develop a new device that can present sound information selectively to the users.

When BCU is presented to a distal body part, vibration propagates through various tissues in the body. Therefore, demodulation may occur in the propagation process through tissue with strong nonlinearity, such as articular cartilage. Demodulated sound may contribute to improving BCU sound quality.

In this study, to elucidate demodulation characteristics in the propagation process of such distantly-presented BCU, vibration in the outer ear canal was measured when AM-BCU was presented to a distal body part. Further, to examine the body parts in which more demodulation occurs, vibrations around the cartilage that has strong nonlinearity were measured.

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2. EXPT. 1: 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 (9). 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 body parts 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 body part relative to the mastoid tended to decrease depending on the distance between stimulation and measurement points, and the presentation body parts 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 presentation body parts showed no effect on the relative value ($p=0.99$) (Fig. 2).

3. EXPT. 2: MEASUREMENT OF VIBRATIONS AROUND CARTILAGE

3.1 Method

Six males with normal hearing (21-24years) participated in the experiment. Measurement points were following parts: I. Tragus, II. Pinna, III. Cartilago thyroidea, IV. Shoulder, V. Thoracic vertebrae, VI. Cartilago costalis, VII. Elbow. The vibrator and the accelerometer were placed so that it was located at the center of the measurement points. 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 carrier component relative to the modulation frequency component at the tragus and pinna were larger than at distal parts, 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 level of the carrier component tended to decrease depending on the distance between stimulation and measurement points, however, the demodulation component did not change as a result of distance. In addition, more demodulation component was generated at the tragus and the pinna than in distal cartilage. These results suggest that demodulation mainly occurs in the vicinity of the ear, even when BCU is presented to distal body parts.

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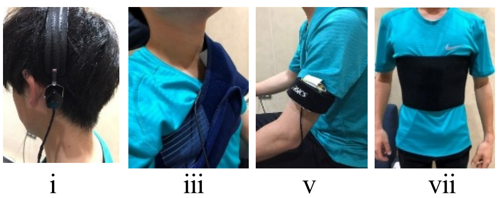

Fig. 1 – Examples of the placements of BCU stimuli: i. Mastoid process, iii. Clavicle, v. Brachialis muscle, vii. Sternum

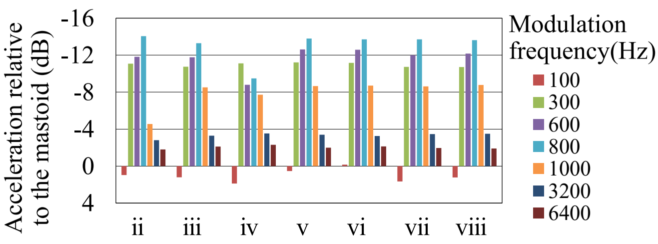

Fig. 2 – Spectrum peaks corresponding to the demodulation component at each body part relative to the mastoid process

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