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Effects of cartilage conduction vibrator placement in the pinna on the detection threshold and the ear canal sound pressure

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ABSTRACT

Bone-conduction has been used as a hearing aids for people with conductive hearing impairment, but there was a problem in the wearability of the vibrator. To solve the problem, cartilage-conduction (CC) that transmits the vibrator to the auricular cartilage has been proposed and applied to hearing aids and smartphones. The characteristics of CC perception vary depending on a number of variables, including the placement of the vibrator within the pinna, the contact area of the vibrator and the contact pressure, but the effects of such conditions have not been studied. In this study, we observed variations of detection threshold and ear canal sound pressure (ECSP) depending on the position of the vibrator within the auricle. Tone bursts with frequencies from 250 to 8,000 Hz were transmitted to the upper, middle and lower parts of the auricle. Both experiments were conducted under conditions in which the vibrator did not come into contact with the auricle. The results showed that the threshold decreased and the ECSP increased when transmitted to the middle and lower auricles at lower frequencies (250 and 500 Hz). These results provide useful information not only to optimize the devices using CC, but also to elucidate the peripheral mechanism of CC perception.

Keywords: Bone-conduction, Cartilage-conduction, Placement of vibrator, Threshold, Ear canal sound pressure

1. INTRODUCTION

Normally, sound enters the ear canal as a vibration of air and propagates through the middle ear to the cochlea of the inner ear. Thus, the sound propagating through vibration of air is called as the air-conducted sound. On the other hand, the sound transmitted through body structure such as the skin, muscles and skull is called bone-conducted sound. In bone-conduction (BC), the sound is said to be transmitted as 4 components(1): (a) the air-conducted component that is emitted from the vibrator and diffracted to enter the ear canal, (b) the osseotympanic component which involves sound radiated into the ear canal, (c) the inertial osteogenic component which is based on the relative motion between the middle ear ossicles and the temporal bone, and (d) the compressed osteogenic component which results from compression and expansion of the cochlear shell (Figure 1).

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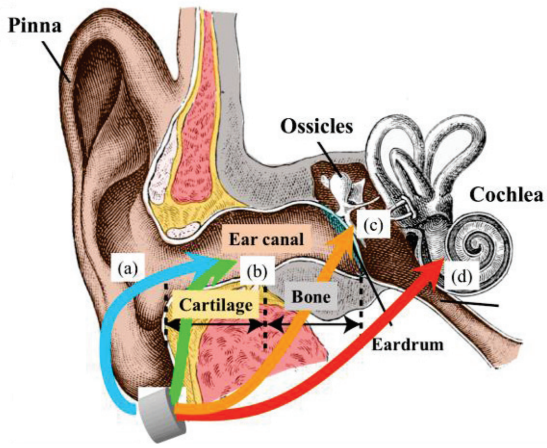

Figure 1 Sound components transmitted by bone-conduction

Thus, some bone-conducted components are transmitted to the inner ear without passing through the outer and middle ears. Therefore, BC has been used as hearing aids for people with conductive hearing loss caused by injuries on the outer and middle ears. BC has been applied to devices such as hearing aids and headphones, however, problems such as pain, discomfort and the difficulty of securing the transducer, have hindered the spread of its application. Therefore, to address these issues, cartilage conduction (CC) has been proposed (2), and applied to hearing aids (3) and smartphones (4).

However, only a limited number of studies have been conducted on CC and the details of the perception characteristics and propagation mechanisms remain unclear. Even in CC, the sound is thought to be transmitted as the same components as the ordinary BC, and the osseotympanic component and air-conduction components are predominant in the normal hearing (4). The characteristics of CC perception vary depending on a number of factors including the placement of the vibrator within the pinna, the contact area of the vibrator and the contact pressure. Despite this, the effects of such stimulus conditions have not been studied.

In this study, we observed variations of the detection threshold and ear canal sound pressure (ECSP) depending on the position of the vibrator within the pinna.

2. Methods

2.1 Vibrator and placements

A vibrator with a plastic diaphragm attached to a piezoelectric element (Figure 2) was attached to the upper part (mainly ear rings), center part (mainly paired rings) and lower part (mainly tragus) of the subjects' pinnae (Figure 3). In addition, for comparison, we also presented stimuli in the "non-contact" condition in which the vibrator did not touch the pinna.

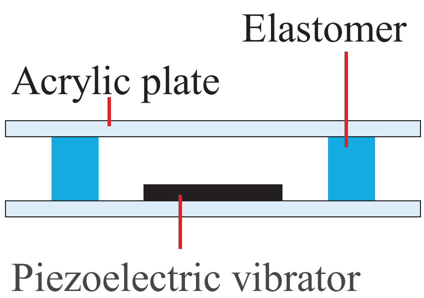

Figure 2
A Schematic diagram of the cartilage-conduction vibrator

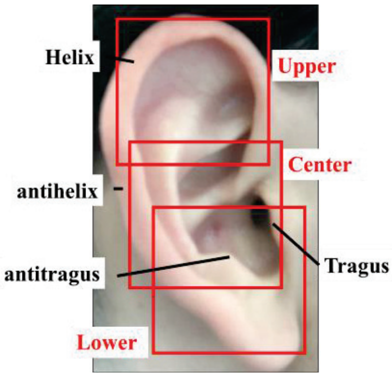

Figure 3 Placements of the vibrators in the experiments

2.2 Measurement of the threshold

The detection threshold at each presentation placement was measured for each condition. Tone bursts of 0.25, 0.5, 1, 2, 4 and 8 kHz (duration 800 ms, including 150 ms rising/falling ramps) were presented. The detection threshold was estimated using a 3-altanating-forced-choice using a 2 down-1 up method. The experiments were coonducted in an anechoic chamber.

2.3 Measurement of the sound pressure in the ear canal

A probe microphone was inserted into the subject's ear canal, and the sound pressure in the ear canal was measured for each vibrator placement. The tip of the probe microphone was inserted near the tympanic membrane. Tone bursts of 0.25, 0.5, 1, 2, 4 and 8 kHz (duration 1 s, including 50 ms rising/falling ramps) were presented. The experiments were conducted in an anechoic chambe

3. Result

An analysis of variance (ANOVA) showed a significant effect of the vibrator placement on the detection threshold ($p < 0.05$). In addition, a Holm’s multiple comparison showed significant differences between the measurements taken at the “center”-“lower” and “upper”-“non-contact” placements ($p < 0.05$). In terms of the ECSP, the vibrator placement had a significant effect ($p < 0.05$), and a Holm’s multiple comparison showed significant differences between the measurements taken at the “center”-“lower” and “upper”- “non-contact” placements ($p < 0.05$).

4. CONCLUSION

A significant difference was observed between the contact- and the non-contact conditions on both the detection threshold and the ECSP. It is inferred that the middle bass range was amplified due to the osseotympanic component. On the other hand, no significant difference was observed between “upper” and “non-contact” placements on both the detection threshold and the ECSP. This result suggests that the cartilage was not vibrated well and the necessary amount of the osseotympanic component was not obtained by the stimulus to the upper pinna.

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