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Influence caused by placement of a bone-conducted vibrator on sound transmission

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ABSTRACT

Bone conduction (BC) is another way of sound transmission for our hearing perception besides of air conduction. It conducts sound through skin and skull, bypassing part of the ear canal. The position where the vibrator is put on one's head makes a difference in BC transmission. Although standards of bone conduction were established on the position of the mastoid (the prominence of the skull behind the ear), nowadays manufacturers favor bone-conducted headphone whose vibrator is put on the position of the condyle (the articular process of the ramus of the mandible bone, in front of the ear). However, there are not enough data in details for the condyle. In this research, hearing thresholds and ear-canal sound pressure on the condyle and the mastoid were measured, and a comparison between them was made to investigate the difference of BC transmission between the two positions, followed by a discussion on the influence of placement on bone conduction.

Keywords: Bone conduction, Mastoid, Condyle

1. INTRODUCTION

Bone conduction (BC) is the conduction of sound by human's skin and skull (1). It is difficult to estimate the frequency characteristics of BC since many linear and nonlinear mechanisms are involved in the BC transmission(2), and various factors affect people's hearing perception of BC, such as the static force added to vibrators or different placements of a vibrator on one's head. There is prior research which has studied the influence of placements on three positions: the forehead, the mastoid, and the vertex (3, 4). They showed that if a vibrator is put on the mastoid, the lowest mean thresholds could be obtained. This discovery makes the positions of the mastoid become a normal position used in BC measurements, especially for testing of BC hearing aids. Standards of bone conduction measurements also were established on the basement of the mastoid by radioear B-71. Nevertheless, with the development of investigation of BC, manufacturers of BC headphones who tend to place the bone-conducted vibrator on the position of the mandibular condyle increasingly appeared because of a better design for easily using. Compared to the position of the mastoid which was studied for several years and almost became the basis for standards, there are not enough data of the condyle. In 2008, Mc Bride (5) used a bone-conducted vibrator Oticon 20 to make a comparison of the perception performance among different locations on people's head, such as the condyle, the mastoid, the forehead, the vertex and other positions which were commonly measured for electroencephalograph. It showed the vibrator on the condyle generated the lowest overall threshold levels in their experiments. Additionally, speech intelligibility of bone conduction transducer was studied (6, 7), but it is still controversial that if significant differences in performance between the mastoid and the condyle exist or not. Since it is unclear that where should be the best position for placing a bone-conducted vibrator, and there are not enough data of the condyle, it is necessary to investigate characteristics of bone-conducted transmission on this position. In this paper, hearing thresholds and ear-canal sound pressure (ECSP) of bone conduction on the condyle and the mastoid were measured by using radioear B-71 which is a bone transducer used as a reference in international standards such as ISO 389(8). By comparing the data of the two positions, the influence of placements on bone-conducted transmission was investigated, and the difference between conditions with/without earplugs in the experiments was also discussed.

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2. EXPERIMENT

2.1 Fundamental Setup

Six subjects with normal hearing (three males and three females) with an average age of 22 years participated in the threshold measurements. Their hearing thresholds were better than 20 dB hearing level for AC stimulation in the frequency range of 0.125 kHz to 8 kHz. All measurements were performed in an anechoic room. As stimuli, tone bursts that were sampled at 48 kHz, and had 16-bit resolution with 0.5 s duration were used. In this experiment, six frequencies from 0.25 kHz to 8 kHz were measured. The measured bone conduction vibrator was radioear B-71.

2.2 Hearing threshold measurement

Each subject was equipped with a headband for fixing the bone-conducted vibrator, and the static force was controlled to about 3±0.5 N. Since bone-conducted transmission will be influenced by air conduction (AC), which is leaked from vibration, the condition whether subjects' ear canals are open or not becomes integral to BC threshold measurements. In this experiment, both open-canal and occluded-canal conditions were measured. Subjects were required to use earplugs to block their ear canal when the data on an occluded condition need to be measured. On both two conditions, the threshold on the condyle and the mastoid were measured in order to estimate the influence from placements of the bone-conducted vibrator.

For obtaining the BC thresholds, an adaptive method was used. The estimation was made by a three-alternative forced choice and a two-down one-up method (9). Subjects were given three options in a sequence and asked to choose which of them was indicated as a pure tone stimulus.

2.3 Ear-canal sound pressure measurement

Ear-canal sound pressures were measured using probe microphones (ER-7C, Etymotic Research). Subjects were also required to use earplugs to block their ear canal when the data on an occluded condition need to be measured. On both two conditions, the ear-canal sound pressure on the condyle and the mastoid were measured in order to estimate the influence from placements of the bone-conducted vibrator. The settings of stimuli were the same as the measurements of BC hearing threshold.

3. RESULTS

3.1 Hearing threshold

Figure 1 shows the average results of hearing threshold measurement of bone conduction. The horizontal axis represents frequency, and the vertical axis is the relative level of hearing threshold referring to interior voltage in MATLAB. When the measured vibrator is put on the condyle, the lowest thresholds were found at 1 kHz both on the open-canal condition and the occluded-canal condition, and the thresholds were descending from 0.25 kHz to 1 kHz while the thresholds were ascending above 1 kHz. About the difference between open and occluded condition on the condyle, at 0.25 kHz the threshold on an occluded condition was lower than it was on open condition but from 4 kHz to 8 kHz the threshold on an open condition became lower. It shows the difference between open and occluded condition on the condyle depends on the change of frequency.

The influence of earplugs insertion also appeared on the mastoid. When the measured vibrator is put on the mastoid, the lowest threshold was found at 1 kHz when the ear canals were occluded but when the ear canals were open the lowest threshold was at 4 kHz. It was similar with the frequency characteristics on the condyle, which shows a decreasing threshold below 1 kHz and a reversing tendency above 1 kHz on the occluded condition on the mastoid. About the difference between open and occluded condition on the mastoid, from 0.25 kHz to 2 kHz the threshold on an occluded condition was lower than it was on open.

Comparing the results of the mastoid to the condyle, on the open-canal condition the thresholds obtained on the condyle were lower than the thresholds on the mastoid at all frequencies. AC may play an important role on a lower threshold of the condyle. On the occluded-canal condition, the thresholds obtained on the condyle were also lower than the thresholds on the mastoid from 0.5 kHz to 2 kHz. It shows the possibility that there are other factors besides AC which influence the BC transmission.

3.2 Ear-canal sound pressure

Figure 2 shows the results of BC ECSP on the four measured conditions. The horizontal axis represents frequency, and the vertical axis is sound pressure level. When the vibrator was put on the condyle, the ear-canal sound pressure on the open condition was higher than it was on the occluded condition above 1 kHz. A sharp decline was observed above 1 kHz on the occluded condition, demonstrating an attenuation at high frequency. On the mastoid, the results of the ear-canal sound pressure of an open condition were lower than its occluded condition below 1 kHz. It may be caused by a weaker effect from AC when the vibrator was put on the mastoid. As the comparison between the condyle and the mastoid, on an open condition the ear-canal sound pressure of the condyle was higher than it was on the mastoid while the similar results could be observed on the occluded conditions below 2 kHz. Nevertheless, at high frequency, the ear-canal sound pressure was higher on the mastoid.

4. DISCUSSION

The data showed lower threshold on the condyle on both open/occluded conditions except of 0.25 kHz while higher ECSPs were obtained on the condyle. When a bone-conducted vibrator is put on the head, not only is the signal transmitted by bone conduction, a part of air conduction is also transmitted through the ear canal and affects the results of thresholds. Nevertheless, because the pinna is on the way of signal transmission as a barrier, the influence from air conduction when vibration is reproduced on the mastoid will not as much as it is on the condyle, just as the results of ECSP on the condyle and the mastoid showed. It is not difficult to hypothesize this is one of the factors which cause lower thresholds on the condyle when ear canals are open.

When subjects use earplugs in the measurements, the thresholds on the condyle were still lower.

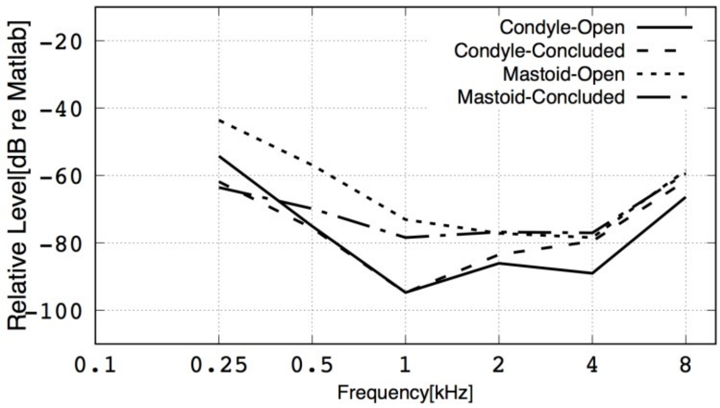

Figure 1 – The hearing thresholds of the four conditions measured by B71.

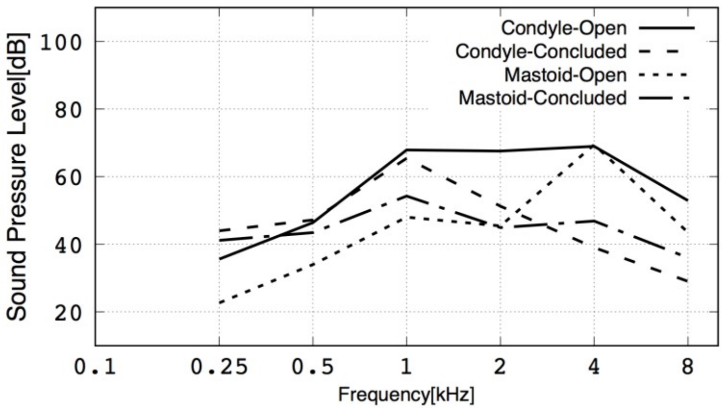

Figure 2 – The ECSP results of the four conditions measured by B71.

The results may be related to the pathways of BC transmission. BC transmission mainly includes three mechanisms, inertial BC, compressional BC and osseo-tympanic BC (10). The osseo-tympanic transmission is related to the sound radiated by the ear canal walls. An occluded ear canal causes an increase in the level of sound in the ear canal by bone conduction, called the occlusion effect. At low frequencies the occlusion effect will have much more effects on thresholds rather than it is at high frequencies (11). The results showed even though on the occluded condition, ECSPs on the condyle were higher than the mastoid, probably causing a lower threshold. If compared with mastoid, the vibrator which is put on the condyle is closer to the ear canal. When the sound signal is transmitted by BC, the vibrator on the condyle may transmit much more vibration on the ear canal, making a difference on osseo-tympanic transmission while the vibrator on the mastoid is not close enough to make another influence on the ear canal. It could be a possible explanation for the results that higher ECSPs were obtained on the condyle.

5. CONCLUSIONS

In conclusion, the threshold on the condyle is lower than it is on the mastoid whatever the ear canal is open or occluded, and the ear-canal sound pressures obtained on the condyle was higher than it was obtained on the mastoid when inputs at the same level were given, showing a possible explanation of a lower BC threshold on the condyle at low frequencies. The difference between the results of the condyle and the mastoid may be caused by the prevention of pinna on the way of air-conducted transmission on an open condition. On an occluded condition, it may come from the difference caused in osseo-tympanic transmission between the condyle and the mastoid. Additionally, by the measurement of BC hearing threshold and ear-canal sound pressure, occlusion effect influenced more on the mastoid, since a larger effect from AC will compensate for the occlusion effect on the condyle. Although the influence caused by placement on BC transmission at low frequency was discussed, the influence at high frequency still needs more measurements in further experiments.

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