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Effect of auricle and head sizes on propagation components of the cartilage conduction

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1. Introduction

Bone conduction (BC) is a method of perceiving sound via biological tissues. The sound is said to be transmitted as four components: (1) the osseotympanic component, which involves sound radiated into the ear canal; (2) the inertial BC component, which is based on the relative motion among the middle ear ossicles and the temporal bone; (3) the compressional BC component, which results from compression and expansion of the cochlear shell; and (4) the air-conduction component, which radiated from the transducer into the air and enters the ear canal[1)]. In BC, since some components directly reach the middle or inner ear, such as (2) and (3), it has been applied to hearing aids for conductive hearing loss caused by disorders of the outer or middle ears. However, in ordinary BC, since the transducer needs to be pressed strongly to the skull, it causes pain and discomfort.

To solve these problems, "cartilage conduction (CC)," which is used the auricular cartilage for the transducer placement, was proposed[2)]. Since the auricular cartilage is soft and elastic tissue, it leads to less pain and is actually applied to hearing aids with the ear canal atresia[3)] and smartphone screens[4)]. In CC, although the sound is transmitted as four components, same as BC, (1) the osseotympanic component and (4) the air-conduction component are dominant[4)]. However, (2) the inertial BC component and (3) the compressional BC component are significantly increased when the presentation state of the transducer was changed in the auricle[5)].

Only a few studies have reported the relationship between auricular characteristics itself and the hearing of CC. One of the studies have shown that larger auricle sizes lead to higher hearing threshold of CC[6)]. However, there are few studies on the effects of auricle size and head size on each propagation component of CC.

In this study, we measured vibrations of the auricle/head, auricle/head dimensions, and CC hearing threshold to clarify the relationship among them.

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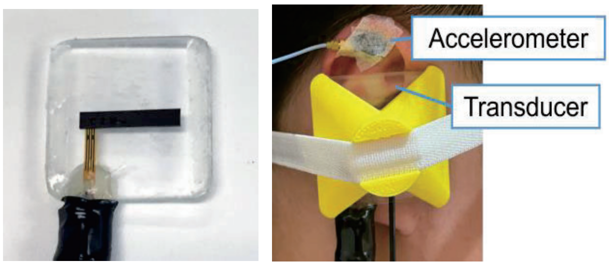

(a) (b)

Fig. 1 (a) A homemade transducer. (b) Presentation position of accelerometer and transducer.

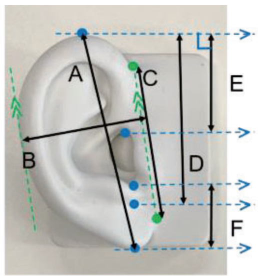

Fig. 2 Locations of the measurements taken on the auricle.

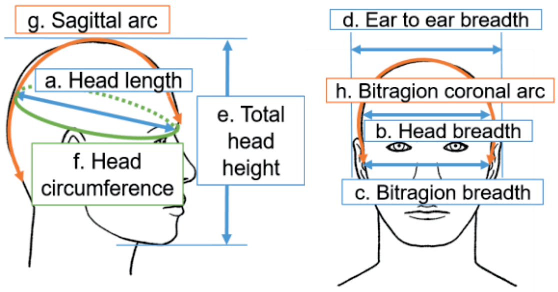

Fig. 3 Measured dimensions of the head.

2. Experiments

7 subjects (4 males, 19-23 years) with 14 ears participated. A sound transducer was newly devised from a small piezoelectric device and a flat acrylic plate (R-11-244018-01, TOKIN, 50 mm × 50 mm × 2.1 mm) (**Fig. 1 (a)**).

Vibrations of the auricle and head were measured with a accelerometer (352A24, PCB Piezotronics, Inc) attached to the upper antihelix and mastoid, when the transducer was attached to the pinna (**Fig. 1 (b)**). Tone bursts at 125-8000 Hz with 10 s were used as stimuli. Input voltage to the transducer was set to 0.54 Vpp.

Hearing thresholds were determined using a 3-alternative forced-choice procedure (3 AFC) with a “2-down/1-up” rule.

Dimensions of the auricle and head were measured in each ear/subject (**Figs. 2, 3**).

3. Results

Fig. 4 shows the acceleration level of the auricle and head. Accelerations of the auricle were significantly larger than that of the head in all the frequencies ($p<.001$). The largest vibration was detected at 1000 Hz, where the threshold decreased most. On the other hand, vibration did not decrease significantly at 125-250 Hz, where the thresholds increased significantly. The relationship between vibration and threshold was not simply proportional. However, a main effect of vibration of the auricle on the hearing threshold was observed ($p<.05$), whereas there was no main effect of the head vibration.

In terms of the auricle dimensions, the significant main effect of (E) Distance from the superior auricle to ear canal ($p<.05$) and the main effect of (D) Auricle cartilage length ($p<.10$) on the vibration of the auricle were observed. **Table II** shows the correlation coefficient between auricle size and auricle vibration. Significant correlations ($p<.05$) are shown in red, and marginally significant correlations ($p<.10$) are shown in blue; all of them were negatively correlated.

In terms of the head dimensions, significant effects of (b) Head breadth, (h) Bitragion coronal arc ($p<.05$) and (f) head circumference ($p<.10$) on the head vibration were observed. Negative correlations were observed in most regions at some frequencies.

4. Discussion

A significant effect of the auricle vibration on the hearing threshold was observed. However, there was no effect of the head vibration. Since the auricle vibration is considered as a main generator of radiation in the ear canal, these results are consistent with the previous research, which shows the osseotympanic component and the air-conduction component become dominant when the transducer is presented to the auricle[4].

Significant negative correlations between auricle/head size and vibration of auricle were observed in multiple regions. These results indicate again that the smaller the auricle/head size, the more efficiently it vibrates, i.e., the smaller the auricle/head size, the more efficiently sounds are transmitted in CC.

5. Conclusion

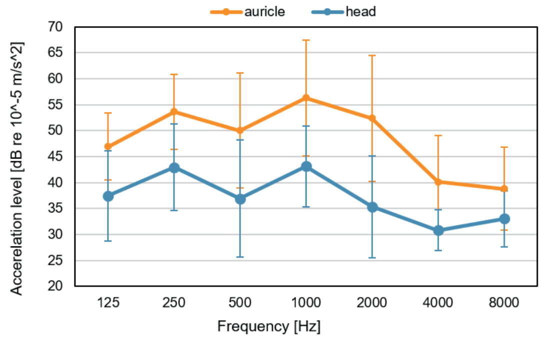

Fig. 4 Acceleration levels of the auricle and head.

Table I Correlation coefficients between each auricular size and vibration of the auricle.

Frequency [Hz]	Auricular size					
	A	B	C	D	E	F
125	-0.064	-0.257	0.091	0.046	-0.055	-0.120
250	0.281	0.162	-0.109	-0.163	-0.342	0.107
500	-0.393	-0.355	0.27	-0.639	-0.617	0.182
1000	-0.106	-0.067	0.026	-0.361	-0.215	0.295
2000	0.083	-0.089	0.251	-0.267	-0.449	0.238
4000	-0.553	-0.304	0.350	-0.545	-0.624	-0.066
8000	-0.51	-0.465	0.205	-0.517	-0.400	0.388

Dimensions and vibration of the auricle and head were measured to examine the relationship between them. Our results indicated that the auricle vibration is larger than the head vibration, and the auricular vibration affects the hearing threshold. Moreover, several auricle/head dimensions showed negative correlations with the vibration of the auricle/head.

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