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Propagation characteristics of bone-conducted sounds presented to the facial parts assessed by ear-canal sound pressure and head vibration

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1. Introduction

In bone conduction (BC), a vibrator is usually presented to the mastoid process of the temporal bone or the condyle process of the mandible[1]. Recently, however, BC presentations to the facial parts such as the zygomatic and nasal bones have also been investigated[2,3]. The face is one of the most complex structures in the human body, composed of 8 irregularly shaped bones and contains the fat and muscles and hollow structures called nasal cavities and paranasal sinuses. Therefore, it is highly likely that slight changes in the presentation placement of the vibrator will also change the perception and propagation characteristics. BC presentation to the face has been applied to smart glasses[4], goggles, and helmet-type audio devices as an audio interface. However, details of the mechanisms of perception of BC sounds presented to remain unclear.

In the previous paper, to clarify the basic characteristics of BC perception on the face, we measured the hearing thresholds at various facial parts[3] and found that some facial parts have good sensitivities comparable to the mastoid. On the other hand, BC sounds have three components that reach the outer, middle, and inner ear respectively, from the head tissue[5]. To clarify the whole aspects of propagation mechanisms of BC sounds on the facial parts, it is necessary to assess the contribution of each propagation component. In this study, we measured the ear canal sound pressure (ECSP) in the both ears and head vibration at the both mastoid process when BC stimuli were presented to the facial parts, and compared them with the conventional parts (mastoid process, condyle process, and forehead).

2. Method

2.1. Subjects

8 men and 1 woman (21 to 24 years) with normal hearing participated. To observe the perceptual characteristics depending only upon the BC components, the participants wear silicone earplugs (Insta-Moid products, INSTA-PUTTY) in both ears. The measurements were conducted in an anechoic room.

2.2. Stimuli

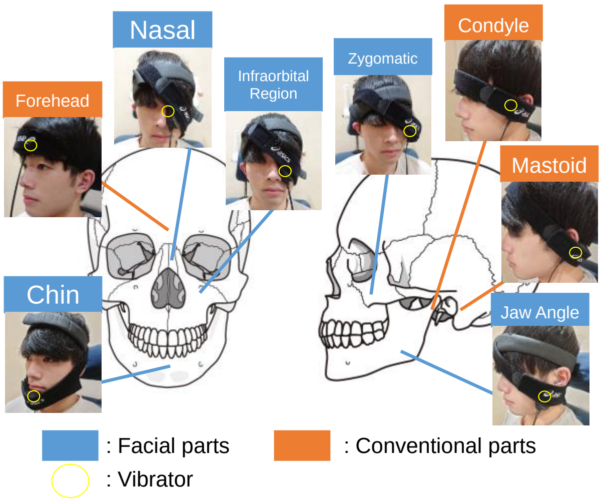

Fig. 1 Presentation of bone-conduction stimuli.

In the ECSP measurements, BC stimuli were presented to the left side of the mastoid process (temporal bone), condyle process (mandible), forehead (frontal bone), nasal bone, infraorbital region (maxillary bone), zygomatic bone, jaw angle (mandible), and chin (mandible) using a vibrator (Radioear, B-81) (**Fig. 1**). In the head vibration measurements, same placements except for the mastoid process were used. BC stimuli were pure tones at seven frequencies (125, 250, 500, 1000, 2000, 4000, and 8000 Hz). The applied voltage to the transducer was 1.7 Vpp.

2.3. Ear canal sound pressure measurements

To examine the magnitude of the BC component that acts on the outer ear, we measured the ECSP at the both ears. The ECSP was measured by probe microphones (Etymotic Research, ER-7C) inserted into the left and right ear canals. The interaural sound propagations were also examined by the difference of ECSP of the both ears to assess the possibility of development of a multi-channel system.

Fig. 2 shows the ECSP in the ear of the ipsilateral (left) side at each placement, and **Fig. 3** shows the difference in ECSP between the ipsilateral (left) and contralateral (right) sides. The ECSP at the nasal bone was lower than that at the conventional parts (condyle process: $p < .001$, mastoid process: p

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< .01) and jaw angle (p < .05). The interaural differences of the ECSP at the facial parts such as the infraorbital region, zygomatic bone, and jaw angle were similar to that of the mastoid process.

2.4. Head vibration measurements

To evaluate the magnitude of the BC components that directly acts on the middle and inner ear, we measured the head vibration at the both mastoid processes. In addition, the bilateral propagations were also examined by the difference of vibration at the both mastoid processes.

The acceleration of head vibration was measured by accelerometers (Ono Sokki, NP-3211) attached to the both mastoid processes. The accelerometer was attached using double-sided tape.

Fig. 4 shows the acceleration level of head vibration at the mastoid process of the ipsilateral side, and **Fig. 5** shows the bilateral difference in the acceleration level between the ipsilateral and contralateral sides. The chin showed lower vibration than the condyle process (p < .001), infraorbital region, zygomatic bone, and jaw angle (p < .01). The bilateral differences at the nasal bone, infraorbital region, zygomatic bone, and jaw angle were comparable to those at the condyle process.

3. Discussion

In our previous study, no significant changes of the sensitivity were found among facial parts tested[3], however, the nasal bone showed smaller ECSP and the chin showed smaller vibration than other facial parts in this study. The hearing threshold results from the sum of all four components[5] of the BC sound. On the other hand, contrast, ECSP results from the sum of just osseotympanic and air-conduction components. It seems that the difference of these results are due to the difference of other two BC components, and this hypothesis consistent with the current result that the nasal bone and chin have a smaller bilateral difference of the BC components. These results also indicate that propagation characteristics at each part should be considered when developing BC devices using facial placements.

In addition, the infraorbital region, zygomatic bone, and jaw angle showed similar the bilateral difference in the BC components as the conventional parts (mastoid process and condyle process). This confirms that these facial parts can also be applied to a multi-channel BC device.

Acknowledgment

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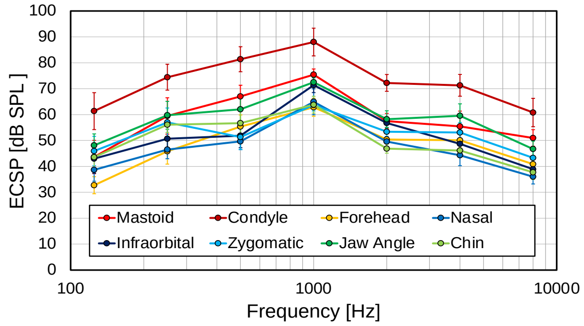

Fig. 2 ECSP for each placement (Ipsilateral side).

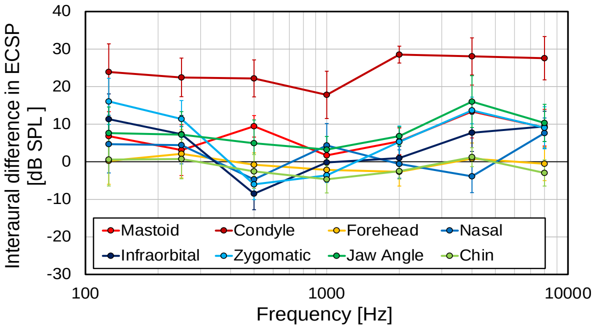

Fig. 3 Differences of ECSP between the ipsi- and contralateral sides.

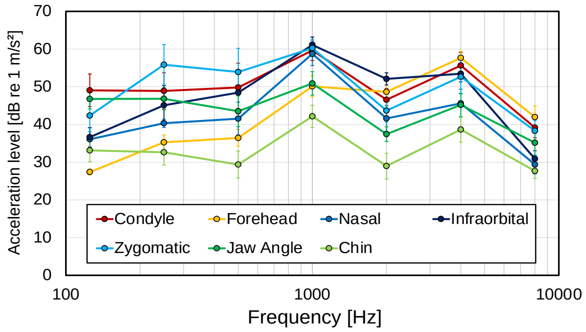

Fig. 4 Acceleration levels for each placement (Ipsilateral side).

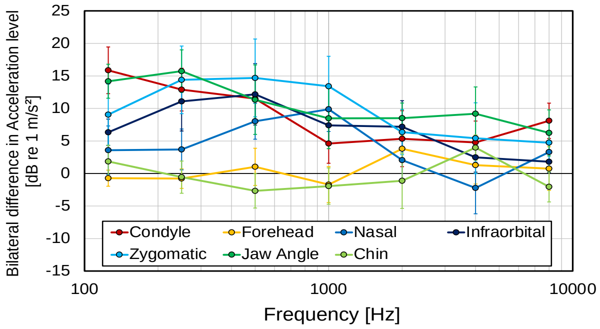

Fig. 5 Differences of acceleration levels between the ipsi- and contralateral sides.