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Perception of speech in cartilage conduction

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ABSTRACT

Objective: By attaching a transducer to the aural cartilage a relatively loud sound is audible even with a negligibly small fixation pressure applied to the transducer. This form of conduction is referred to as cartilage conduction (CC). Utilizing CC, novel audio devices can be developed, and one possible application is a CC hearing aid. However, there are no studies on speech perception in CC. In this study, CC speech recognition performance was measured and compared with that for air and bone conduction (AC and BC, respectively).
Methods: Nine volunteers with normal hearing participated in the study. The performance-intensity functions were measured for AC, BC and CC. These measurements were performed in the conditions with and without an earplug.
Results: Without the earplug, no differences in speech recognition scores were observed among AC, BC, and CC. With the earplug, the level at which the maximum speech recognition score was obtained did not increase in CC, which agreed with the result of BC but not AC. The maximum speech recognition CC score decreased with the earplug. The performance-intensity functions for AC and BC shifted in parallel with the earplug. These shifts approximated the average threshold shifts. In contrast, for CC, the performance-intensity function did not shift in parallel with the earplug. As for the CC threshold shifts with the earplug, although the threshold at 500 Hz decreased by 15.4 dB, those at 2000 and 4000 Hz increased by 13.8 and 31.1 dB, respectively. Compared with AC and BC, CC excessively emphasized low over high frequency sounds when the earplug was inserted. Confusion matrices analysis demonstrated that 4%, 22%, and 74% of the errors occurred at low, intermediate, and high frequency speech sounds, respectively. Thus, this excessive low frequency sound emphasis probably prevented the recognition of high frequency speech sounds.
Conclusion: The decrease in the maximum speech recognition score for CC with the earplug was derived from the biased frequency composition. It can be improved by frequency composition adjustment.

1. Introduction

Hosoi found that by attaching a transducer to the aural cartilage (the tragus, in particular), a relatively loud sound was audible even with a negligibly small fixation pressure applied to the transducer [1,2]. This form of conduction is referred to as cartilage conduction (CC). Many audiological and acoustical studies on CC have revealed differences in characteristics between CC and conventional air and bone conductions (AC and BC, respectively) [3–9]. An important difference between AC/BC and CC is sound transduction and transmission.

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Utilizing CC, novel audio devices can be developed, and one possible application is CC hearing aid [3,4,10]. Because sound is delivered to the body by vibrating the aural cartilage, CC is superficially similar to BC. An important advantage of CC is the transduction process. For BC hearing aids, they have fixation problems, including skin induration, permanent depressions in the skin, discomfort, and cosmetic problems [11]. Its indications are almost restricted to patients with aural atresia because it is not advantageous to use this hearing aid for general hearing problems. In contrast, CC hearing aids do not have these issues. The CC transducer is designed for vibrating the aural cartilage but not the skull. It differs substantially from a BC transducer in that it is small, lightweight, and can be attached comfortably to the ear with a very small fixation force. Not only patients with aural atresia but also those with sensory neural hearing loss can comfortably use them.

As for sound transmission, there are three possible pathways when the transducer is placed on the aural cartilage [4,5,7,9]. In the first pathway, transducer vibrations directly produce air-borne sounds, some of which reach the ear canal and are transmitted to the cochlea via the conventional AC pathway. This pathway is termed "Direct-AC." In the second pathway, vibrations of the aural cartilage and soft tissue are transmitted to the cartilaginous portion. These vibrations induce an acoustic signal in the canal, which is transmitted by AC to the eardrum. This pathway is termed "Cartilage-AC." In the third pathway, vibrations of the aural cartilage and soft tissue are transmitted via the skull. This pathway is termed "Cartilage-BC."

Previous studies found that both Direct- and Cartilage-AC mostly contribute to sound transmission in ears with normal anatomy [5,7]. On the other hand, the dominant pathway in ears with aural atresia appears to be converted to Cartilage-BC or the fibrotic tissue pathway, which is observed in ears with fibrotic aural atresia [9]. Direct-AC does not exist in those ears. While CC involves these pathways, the contribution of each pathway to the threshold depends on the frequency [5,7]. In addition, signal distortion may occur in the transmission through the aural cartilage. Speech recognition performance is one of the issues to be considered in hearing aid development. Although frequency composition influences speech recognition, there is no study on the speech recognition presented by CC [12]. In this study, the speech recognition performance for CC was measured, and compared with those for AC and BC. Furthermore, to evaluate the lack of Direct-AC, speech recognition performances are also measured in the conditions with an earplug.

2. Materials and methods

2.1. Subjects

Nine volunteers (four females and five males; 29–39 years old) with normal hearing participated in this study. The experimental procedure was approved by the Ethics Committee of Nara Medical University, and informed consent was obtained from all subjects. Before the experiments, AC and BC thresholds at frequencies of 500, 1000, 2000, and 4000 Hz were obtained for each ear, and we confirmed that these thresholds were within 20 dB hearing level (HL). The ear with lower average BC thresholds for the four frequencies was selected for each study subject.

2.2. The measurement of the performance-intensity function

The performance-intensity functions were measured for AC, BC and CC. Measurements were obtained in the conditions with and without an earplug. The initial presentation level was large enough to hear the speech signal. The level was decreased using 10 dB steps until a score of 0% had been reached. If the maximum score was 100%, the same scores were observed at two consecutive levels, or the roll-over effect was observed, and the speech recognition curve was considered to be saturated. If the maximum speech recognition score was not obtained, the level was increased using 10 dB steps from the initial level until the maximum speech recognition score was obtained. Speech-weighted noise was applied to the non-test ear masking. Its levels were adjusted to avoid both excessive masking and cross hearing. All measurements were performed in a sound proof room.

Fifty monosyllables were used for speech stimuli. The 50 monosyllables were derived from 57-S monosyllable wordlists presented by The Japan Audiological Society [13]. Table 1 shows an example of a 57-S monosyllable word list. The original 57-S monosyllable word lists include five types of order. Additional 10 lists were constructed by randomly rearranging the 50 monosyllables using free software for speech analysis (praat; Boersma, Paul & Weenink, David, 2011). The presented list was randomly selected from the 15 lists.

2.3. Threshold measurement

To estimate the changes in frequency composition by the earplug, the thresholds in the conditions with and without the earplug were measured at the frequency of 500, 1000, 2000, and 4000 Hz. Thresholds were measured using a transformed up-down procedure as described in a previous study [5]. A two-alternative forced-choice (2AFC) procedure with a decision rule that estimated the 70.7% positive response on the psychometric function was employed [14]. The stimulus frequencies were set at 500, 1000, 2000, and 4000 Hz. Tone bursts of 500 ms, including rise/fall ramps of 10 ms, were employed for the stimulus. The threshold was measured twice and averaged. A narrow band masking noise was presented to the opposite ear. For convenience, the threshold shifts with the earplug at these frequencies were considered as the change in frequency composition by the earplug.

Table 1
An example of the 57-S monosyllable list.

/zi/	/ra/	/ho/	/o/	/wa/	/e/	/a/	/ni/	/to/	/te/
/ba/	/ri/	/ka/	/ko/	/ke/	/ru/	/ro/	/tu/	/hi/	/mi/
/me/	/do/	/si/	/ne/	/ku/	/i/	/u/	/su/	/yu/	/re/
/so/	/ki/	/zu/	/se/	/yo/	/ga/	/mu/	/na/	/ta/	/sa/
/go/	/no/	/ya/	/mo/	/da/	/hu/	/ha/	/ma/	/de/	/ti/