Study on Perceptual Characteristics of Bone-Conducted Sound

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Human can communicate easily by using speech sound because their hearing systems have a great auditory processing ability. However, hearing impairment and hearing loss make their listening ability decrease, then interfere with their communication. Moreover, people cannot communicate by using air-conducted (AC) sound in noisy environments.

Bone-conducted (BC) sound reaches inner ears through skull vibrations although AC sound reaches to the inner ear through air vibrations into outer ear and mechanical vibrations of middle ear. BC is widely used for hearing aids for conductive hearing-impaired people and special headphones for communications in noisy environments because BC has different pathways from AC. However, its transmission process is exceedingly complex and the entire mechanism of BC perception is not clear.

In order to investigate how BC sound is transmitted and perceived, computational models of BC sound have been proposed. However, a large number of parameters and complex models are needed to simulate the vibration characteristics of BC sounds. In this research, we consider another model which regards each of BC pathways as a transmission system (sub system) which has frequency characteristics. By discussing the amplitude and phase characteristics through each of BC pathways, it may be possible to reveal the mechanism of the BC perception.

The aim of this study is to make clear the mechanism of BC perception by regarding each of BC pathways as a transmission system and discussing the relationships between BC and AC perception. The goal of this research is to propose approaches in order to achieve the theme by surveying and summarizing previous studies related to the BC transmissions and perception.

Firstly, we surveyed previous studies about physiological approaches which measured vibration characteristics of BC sounds. According to the survey, it was suggested that there are main pathways relating the perception of BC sound as follows; (1) osseo-tympanic effect, (2) middle ear ossicle inertia, (3) inertia of cochlea fluids, (4) compression of cochlear walls, (5) pressure transmission from cerebrospinal fluid. The osseo-tympanic effect (1) relates to a BC pathway through an outer ear. The middle ear ossicle inertia (2) relates to a BC pathway through a middle ear. In the two pathways, vibration characteristics at BC pathways to the input of inner ear (cochlea) have been physically measured. The other pathways (3), (4), (5) relate to BC pathways through an inner ear. It is indicated that these BC sounds directly affect inside of cochlea. However, the transmission mechanism of BC sounds which directly affect inside of cochlea and its influences on BC perception remain unclear. It was revealed that there are some evidences which explain the effect of BC sound to inner ear by measuring vibration characteristics of outside of cochlea.

Secondly, we surveyed previous studies which measured perceptual characteristics by psychophysical approaches. According to the survey, it was revealed that although many researches focused on loudness of BC sounds, the phase characteristics of BC perception were not investigated carefully. However, psychophysical experiments which cancels BC perception with AC sound focus on not only amplitude (loudness) but also phase characteristics of BC sound. Moreover, this method can be discussed with the mechanism of the BC transmission from the result of perceptual characteristics. Therefore, we inferred that it may be possible to clear the mechanism of the BC transmission by considering the loudness and phase characteristics of BC perception respectively.

Based on the surveys about physiological approaches, we illustrated the entire BC transmission systems of BC pathways. We then considered whether vibration characteristics of each BC pathway is correspond to transfer characteristics of transmission system of BC perception. As a result, it was revealed that the vibration characteristics of BC sound were able to correspond to the transfer characteristics until inertia of cochlea fluids (3). However, the transfer characteristics of compression of cochlear walls (4) and pressure transmission from cerebrospinal fluid (5) could not be represent as transmission systems because the mechanism of BC transmission through pathways reach inner ears are not clear.

Finally, in order to solve these problems, we consider a new psychophysical approach which estimates the mechanism of BC transmission by comparing the phase characteristics of BC perception with that of AC perception. In AC perception, it was reported that the variation of phase characteristics were perceived as that of timbre. Therefore, it may be possible to measure the phase characteristics of BC sound by the result of this approach. In this approach, a phase compliant filter used to vary the phase characteristics of stimuli and it is calculated from phase characteristics of each transmission system.

In conclusion, it is suggested that the proposed approach can estimate the perceptual characteristics and the mechanism of BC transmission through pathways relating to the inside of inner ears by comparing phase characteristics of BC perception and that of AC perception.