Effects of wearing earplugs on hearing of one's voice: Estimation of bone-conducted components

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1. Introduction

We usually hear our own utterance and control our speech production. This feedback system is called "auditory feedback (AF)". AF plays an essential role in smooth speech production. Further, AF modifies our utterance depending on ambient evironments. For example, in noisy environments, speech level and pitch increase[1)]. Thus, we are able to control our utterance by AF, to keep reliable speech communication.

On the other hand, we perceive our own voice as both air-conducted and bone-conducted sounds[2)]. It is known that bone conduction causes the "occlusion effect (OE)," in which low-frequency loudness is perceived to be larger than original intensity when the ear canal is occluded [3)]. OE also occurs in bone-conducted sound included in one's own voice; the speaker perceives his/her own voice lower and muffled by OE when the ear canal is occluded. Therefore it is thought that OE has some effects on AF. Although there have been several studies on the effects of hearing protection devices (HPDs), such as earplugs and ear muffs, on speech production, few have evaluated components transmitted via bone-conduction pathways.

In this study, effects of wearing earplugs on one's voice were evaluated by measuring both air-conducted and bone-conducted components. Air-conducted speech, ear canal sound pressure (ECSP), and head vibration were measured, and intensity, frequency, and speech rate were evaluated in each measurement.

2. Experiments

Seven participants (four men and three women, aged 21-24 years) with no history of hearing function deficits participated in the experiments. All measurements were performed in an anechoic room in which silence was kept. A headset microphone (TH53, SHURE) was used to measure air-conducted speech. The headset microphone was set 15-mm apart from the mouth. A probe tube microphone (ER-7C, Etymotic) inserted into participants' ear canal and an accelerometer (352A24, PCB) attached to participants' mastoid process of the temporal bone were used to measure ECSP and head vibration during speech with (referred to as occluded) and without (referred to as open) earplugs, respectively (Hereafter recorded data by the headset microphone, probe tube microphone, and accelerometer are referred to as mic, ECSP, and acc, respectively). The probe tube microphone was inserted into the ear canal with its tip extending approximately 20-mm from the tragus. The accelerometer was fixed with a steel-spring headband to which a self-made jig was attached (Figs. 1 and 2). Under the occluded condition, the ear canal was occluded by wearing earplugs (ear tips for an otoacoustic emission measurement (ER10D-KIT, Etymotic) with self-made jigs).

Participants were instructed to read aloud sentences presented in a display placed 1-m in front of the subject. The participants were also instructed to speak naturally as if communicating with the listener in the position where the display was located. The spoken sentences were the first part of the novel 'Botchan' (/Oyayuzuri no muteppoude… tonde

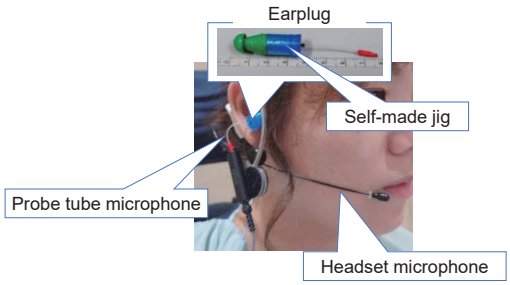

Fig. 1 Setup of the headset microphone and probe tube microphone (under the occluded condition).

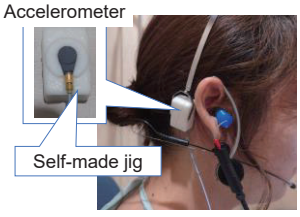

Fig. 2 Setup of the accelerometer (under the occluded condition).

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Recorded data were analyzed by Praat, and mean pitch, first, second and third formant frequency (F1, F2, F3), intensity and speech rate (number of mora per second) were evaluated.

3. Results

Tables. I and II show averages and standard deviations of each evaluated item, respectively. In all measurements, no differences in pitch between open and occluded conditions. However, F1, F2 and F3 were increased by wearing earplugs. Also, the intensity and speech rate were increased.

We conducted a paired t-test for all evaluated items and found significant differences between the open and occluded conditions. There were significant increases in the F1, F2, and intensity in the ECSP (F1: $p = 0.0235$, F2: $p = 0.0417$, intensity: $p = 0.0002$).

4. Discussion

In all the measurements, there were no differences in the pitch between the open and occluded conditions. The current results agree with a result of air-conducted speech obtained in former study[4].

Table I. Averages of each evaluation under the open condition (Mean ± S.D.)

	Mic	ECSP	Acc
Pitch [Hz]	171.21 ± 56.38	170.22 ± 56.06	179.22 ± 51.05
F1 [Hz]	770.56 ± 36.05	922.88 ± 122.92	951.06 ± 85.17
F2 [Hz]	1892.93 ± 69.40	2028.10 ± 72.54	1710.92 ± 41.47
F3 [Hz]	3023.07 ± 97.71	3016.70 ± 60.74	2679.17 ± 120.55
Intensity [dB a.u.]	34.16 ± 2.57	40.06 ± 2.31	52.50 ± 2.35
Speech rate [mora/s]	7.67 ± 1.06		

Table II. Averages of each evaluation under the occluded condition (Mean ± S.D.)

	Mic	ECSP	Acc
Pitch [Hz]	171.48 ± 60.18	170.44 ± 61.24	183.25 ± 52.55
F1 [Hz]	757.08 ± 48.83	678.02 ± 87.13	945.20 ± 88.01
F2 [Hz]	1887.19 ± 81.65	1862.59 ± 146.49	1688.72 ± 71.28
F3 [Hz]	2995.95 ± 115.30	3174.65 ± 185.29	2615.97 ± 133.18
Intensity [dB a.u.]	35.04 ± 2.91	52.38 ± 3.99	52.90 ± 3.31
Speech rate [mora/s]	8.14 ± 1.34		

It was reported that the formant frequency altered with "perturbed" feedback and the direction of variation were opposite of the perturbation[5]. According to the former study, it is expected that F1 and F2 become higher when wearing earplugs because the low-frequency sounds are enhanced by the OE. However, in the current study, F1, F2, and F3 were decreased by the occlusion. It is difficult to conclude mechanisms of these differences, but F1 and F2 estimated in ECSP showed especially larger variation. Enhanced low-frequency components in BC pathways may cause this discrepancy.

In the former study, the participants spoke short English words, but in this study, the participants spoke longer sentences, and this difference may have caused the difference between these studies.

The intensity increased in this study, corresponding to a former study[4]. In silent environments, the utterance intensity is thought to be increased by wearing earplugs to compensate for the reduction in air-conducted speech perceived by the speakers themselves.

No significant differences were observed in speech rate. Therefore, wearing earplugs does not affect on speech speed.

5. Conclusion

Effects of wearing earplugs on perception of one's own voice were investigated. We measured air-conducted speech, ECSP, and head vibration during utterance with wearing earplugs. The results showed that formant frequencies decreased and speech level increased, although pitch did not show significant changes. It is considered that enhancement of perception of low-frequency sounds by the occlusion effect affected these results. On the other hand, changes of the pitch and intensity were not large because the experiment was conducted in a silent condition. Further experiments under noisy environments may be needed to observe clearer change of speech production.

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