# Word Intelligibility of Bone Conductive Sound When Wearing Ear Plugs

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***Abstract*—In this study, we measured and compared the word intelligibility of air conductive and bone conductive sound when wearing ear plugs in both ears by speech audiometry. The correct responses of word intelligibility of bone conductive sound tended to be better than those of sound heard through air conduction even in a high signal-to-noise environment. This effect was only elicited when ear plugs were used in both ears.**

***Keywords—word intelligibility; bone conduction; speech audiometry; ear plug***

## I. INTRODUCTION

We believe that the perception of bone conduction headphones being inferior to general air conduction headphones in terms of sound quality and volume [1] is a result of vibration damping by skin as well as a declination of signal-to-noise ratio (S/N) caused by hearing air conductive sound when bone conductive sound is heard. Therefore, we focused on word intelligibility, which is easily affected by S/N decline. Through experiments, we compared the word intelligibility of air conductive sound and bone conductive sound when wearing ear plugs in both ears.

## II. SPEECH AUDIOMETRY

Actuators used in bone conduction headphones can be classified into three types: piezoelectric, electromagnetic, and giant magnetostrictive. In principle, actuators used in giant magnetostrictive bone conduction have a high driving force and relatively flat frequency response [2]. However, commercially available bone conduction headphones of the giant magnetostrictive type are considered inferior to general air conduction headphones, as mentioned previously [1]. Therefore, we compared giant magnetostrictive bone conduction headphones with general air conduction headphones and considered the word intelligibility of bone conductive sound when wearing ear plugs in both ears. In the following subsections, we describe the word speech for examinations that we used in experiments. Then, we describe the experimental procedure.

### *A. Word Speech Data for Examinations*

We used the familiarity-controlled word lists 2007 (FW07) [3] for the word speech data for examinations. Table I presents a part of the list of low familiarity rank data of FW07, which means that the familiarity degree is the lowest, that we used in the experiments. The list consists of 20 words constructed by 4 moras. Sound pressure correction was applied to reduce differences in the average word intelligibility between lists. We determined individual differences according to the word familiarity.

### *B. Experimental Procedure*

The subjects of the experiment were five Japanese men with no hearing loss (A–E, 20–24 years old). The subjects first heard a 1 kHz sine wave using a set of headphones. Then, they regulated the volume of the headphones and determined a minimum audible value, and this sound pressure was taken as the 0 dB reference. Next, we output words whose relative sound pressure was +20 dB from the list one by one while the subjects wore the headphones. The subjects wrote down the words they heard on an answer sheet in katakana. The experiments were performed in a soundproof room (the background noise was less than the measurement range of the sound-level meter) for both the air conduction and bone conduction headphones. However, in experiments using the bone conduction headphones, subjects wore bone conduction actuators on mastoids, which are behind auricles. This is commonly used in bone conduction audiometry and different from using the zygomatic process, which is in front of auricles, to prevent the wraparound of air conductive sounds. Fig.1 shows the location where the bone conduction actuators of the bone conduction headphones (TEAC HP-F200) were worn.

Examinations of word intelligibility were performed for the following conditions:

I: Air conduction headphones (Audio-Technica ATH-WS70)

II: Bone conduction headphones (TEAC HP-F200)

III: Bone conduction headphones (TEAC HP-F200) + ear plugs (BEESAFE BSEP01SN)

We performed the experiments using data of 20 lists, consisting of 10 sets of 2 lists each, on different days. To prevent any influence of the order of data, the order for the first half (list 1–10) was Condition I, III, and II and for the latter half (list 11–20) was Condition II, III, and I.

TABLE I. EXAMPLES OF FAMILIARITY-CONTROLLED WORD LISTS FOR SPEECH AUDIOMETRY

| No | List 1 | List 2 | List 3 | List 4 | List 5 |
|---|---|---|---|---|---|
| 1 | アカガネ | コロモデ | アダナミ | ジキミヤ | タマダレ |
| 2 | ワラバイ | オオトシ | カシャガタ | ニチアン | カワダチ |
| 3 | ラシャメン | モノノグ | トシバイ | キリハク | ゲンパイ |
| 4 | ザイカタ | ヘンモク | ノリサク | アライシュ | ジンガネ |
| 5 | カワヨド | ヒコバエ | モンガラ | ハナミゾ | ザッパク |
| 6 | タカドノ | ロンキツ | チンポン | イリガワ | ガラユキ |
| 7 | ドカヒン | チンメン | テンポン | ナガシオ | ワザクレ |
| 8 | ソマヤマ | ビンゼン | ケンウン | シワバラ | サスマタ |
| 9 | サトバラ | ブンコン | ザイゾク | リンバツ | ヤブハラ |
| 10 | モロハク | リンポン | ランコン | ライバン | チュウニン |
| 11 | ボンコツ | ヨワミソ | シタバエ | タカヒモ | ラクタイ |
| 12 | ナマヨイ | アリギレ | マキワラ | マジライ | ボウサゲ |
| 13 | オシタジ | イタゴト | バンガタ | エンパツ | ツバモト |
| 14 | イドガエ | トキギヌ | ワカトウ | センニク | モクヤク |
| 15 | コワイイ | ジョサイヤ | ヒラジロ | ボンブン | ニンガイ |
| 16 | チヨロズ | ホリワリ | ナカシオ | ゼンキン | チョウダツ |
| 17 | ミミガネ | シモタヤ | レンシツ | ジュンイツ | ウラモリ |
| 18 | シラハリ | タキノミ | ダイリキ | ブンウン | オハヅケ |
| 19 | トキワズ | マチハン | オニガミ | ヒンプン | リンバン |
| 20 | ヒザカブ | カイボリ | ハコミヤ | ガンザン | レンルイ |

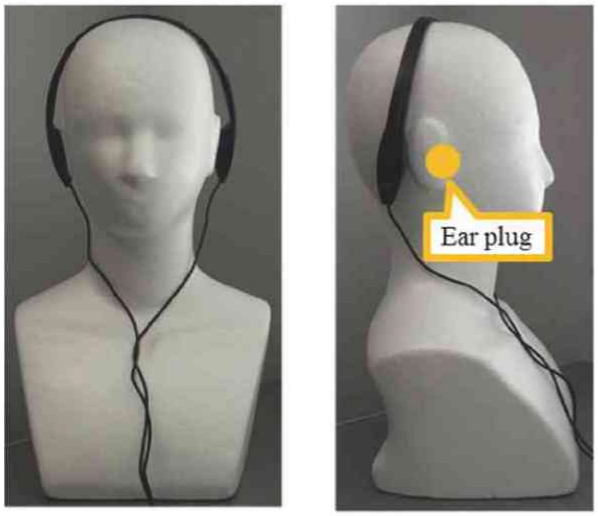


Fig. 1. Location where the bone conduction actuators were worn.

## III. RESULTS

Fig.2 shows the average of mora accuracy and the standard deviation in Condition I, II, and III for all subjects (20 words per 1 list, 80 moras). The measurement was done once for each subject. The results show individual differences, but in Condition III, the word intelligibility is higher than in other conditions for all subjects. Table II lists the percentage of average mora accuracy of all subjects for the first half (list 1–10), the latter half (list 11–20), and the whole set (list 1–20). The first and the latter halves show slight differences, and the results for the whole set were obtained by averaging after replacing the first half with the latter half to offset the influence of the procedure.

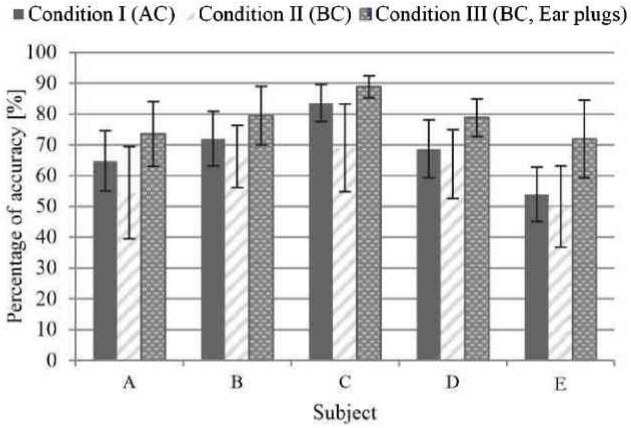


Fig. 2. Average mora accuracy and SD.

TABLE II. AVERAGE MORA ACCURACY OF FIVE MALE SUBJECTS [%]

| | **List 1–10** | **List 11–20** | **List 1–20** |
|---|---|---|---|
| Condition I | 67.8 | 69.4 | 68.6 |
| Condition II | 62.2 | 59.2 | 60.7 |
| Condition III | 77.9 | 79.2 | 78.5 |

## IV. SUMMARY

To investigate the perception that bone conduction headphones are inferior to general air conduction headphones in terms of sound quality and volume, we compared the word intelligibility of air conductive sound and bone conductive sound when wearing ear plugs in both ears by experiment. The correct responses of word intelligibility of bone conductive sound were found to be better than those of the sound heard through air conduction even in a high S/N environment. This effect was only observed when ear plugs were used in both ears. This shows that wearing ear plugs is effective in improving the word intelligibility of bone conductive sound.

The reason for this effect is thought to be the changes in resonance characteristics of the ear canal when wearing ear plugs, which affects the air conductive sound in the ear canal when using bone conduction headphones. In future, we plan to further clarify this effect by carrying out a more detailed experiment.

## REFERENCES


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