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Development of a Bone-conducted Ultrasonic Hearing Aid (BCUHA) for the Profoundly Deaf: Evaluation of Sound Quality using Semantic Differential Method

重度難聴者のための骨導超音波補聴器の開発：SD 法による音質評価

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1. Introduction

Bone-conducted ultrasound (BCU) can be experienced as sound even by the severely hearing-impaired. We have developed a BCU hearing aid (BCUHA) for the profoundly deaf,[1] Remarkable results have already been achieved; enabling 42 percent of the profoundly deaf trial subjects to perceive some sort of sound, and 30% of them to recognize simple words. These results suggested its practicability, however, there is room for improvement in terms of articulation and sound quality.

In the BCUHA, ultrasonic sinusoids with a frequency of about 30 kHz are amplitude-modulated by speech and presented to the mastoid by a vibrator. As a method of amplitude modulation (AM), double-sideband with transmitted carrier (DSB-TC) modulation has been used. Generally, two sounds are perceived by the BCUHA: one is a high-pitched tone due to the ultrasonic carrier, with a pitch corresponding to a 8–16 kHz air-conducted (AC) sinusoid, and the other is the envelope of the modulated signal.[2] This high-pitched tone due to the ultrasonic carrier appears to be a key factor in the degradation of the articulation and sound quality.

In the previous study, we proposed new AM methods to reduce the high-pitched tone. The evaluation tests showed that newly installed transposed modulation (TM) has some advantages in terms of the subjective auditory impression over the other AM methods.[3] However, in the previous study, the subjective auditory impression of the sound was investigated by using a questionnaire which was conducted to assess the quality of speech sounds.[4] Therefore, results of the questionnaire reflect integrated evaluations of speech perception rather than sound quality. In this study, sound quality of BCUHA with three types of AM methods [DSB-TC, TM, and Double sideband with suppressed carrier (DSB-SC)] was examined using the semantic differential (SD) and a factor analysis.

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2. Methods

2.1 Three types of amplitude modulation

Tested three AM methods are expressed as follows, where A, $s(t)$, $fc(t)$, and m represent a constant, the modulator signal (speech), a carrier signal, and the modulation depth, respectively.

I) DSB-TC $$f(t) = A(1 + m \times s(t)) \times fc(t) \qquad (1)$$

In this method, the envelope of the modulated signal corresponds to the modulator. On the other hand, it is accompanied by a strong high-pitched tone, especially when the modulation depth is low.

II) DSB-SC $$f(t) = A(m \times s(t)) \times fc(t) \qquad (2)$$

Since the peak of power at the carrier frequency is suppressed, this method has the advantages of the reduction of the high-pitched tone. However, the envelope of the modulated signal does not correspond to the modulator signal. The pitch accompanied by the envelope is almost twice as high as that of the modulator signal,[2] and contain some distortion.

III) TM[5] $$f(t) = A(m \times s_{tp}(t)) \times fc(t) \qquad (3)$$

Here $s_{tp}(t)$ represents a half-wave-rectified and low-pass-filtered modulator signal. In this study, the modulator signal was low-pass filtered at 8 kHz. Since the peak of power at the carrier frequency is suppressed, the high-pitched tone due to the carrier is reduced. Furthermore, the intervals between peaks of the envelope of the modulated signal are the same as the intervals between the peaks of the modulator signal, thus; the pitch due to the envelope is expected to be similar to that of the modulator signal. On the other hand, it is thought that transposed BCU speech essentially contains some distortion because of the rectification process.

2.2 Evaluation of sound quality

28 Japanese normal-hearing adults (21-41 years, mean 24.2 ± 4.9) participated. First, word intelligibility for 4-mora Japanese words were

investigated using the three types of BCU speech with the three AM methods and AC speech. For all stimuli, the carrier signal $f_c(t)$ was a 30-kHz sinusoid, and the modulation depth m was adjusted for each word to avoid over-modulation.

After each session of the word intelligibility test, the subjective impression of the sound was examined using the SD method. 12 pairs of adjective scales, same as the former study[6] (see Fig. 1), were selected and evaluated on the seven-point scale. A factor analysis of the adjective scales were conducted.

3. Results

The mean intelligibility scores were 45.1% for DSB-TC speech, 18.9% for DSB-SC speech, 48.2% for TM speech, and 93.4% for AC speech. All types of BCU speech have lower intelligibility than AC speech ($p < 0.001$), and DSB-TC speech and TM speech have higher intelligibility than DSB-SC speech ($p < 0.001$).

Profiles of each stimulus type obtained in the SD test are shown in Fig. 1. By the factor analysis, three factors were extracted and interrupted as a "metallic" factor, an "esthetic" factor, and a "powerfulness" factor. Scatter diagram and averages of each factor score for three BCU and AC sounds are shown in Fig. 2 and 3, respectively. One-way ANOVA showed an effect of the stimulus type on all factor scores ($p < 0.001$). A post-hoc test (Tukey's HSD) revealed that each BCU stimulus has a higher metallic factor score ($p < 0.001$) and lower esthetic factor score ($p < 0.001$) than the AC stimulus. Additionally, the esthetic factor score of the DSB-SC stimulus is lower than those of the DSB-TC and TM stimuli ($p < 0.001$). In terms of the powerfulness factor scores, the AC stimulus is higher than the DSB-TC and DSB-SC stimuli ($p < 0.001$) and the TM stimulus is higher than the DSB-TC stimulus ($p < 0.05$), while no significant difference was observed between AC and TM stimuli.

4. Conclusion

Generally, the TM speech is closer than other AM methods to AC speech in terms of the sound quality. In particular, the TM speech had higher powerfulness factor score than DSB-TC and DSB-SC, and higher esthetic factor score than DSB-SC. The current results indicate that the TM has some advantages in sound quality over the other AM methods, and provide useful information for further development of the BCUHA.

Acknowledgment

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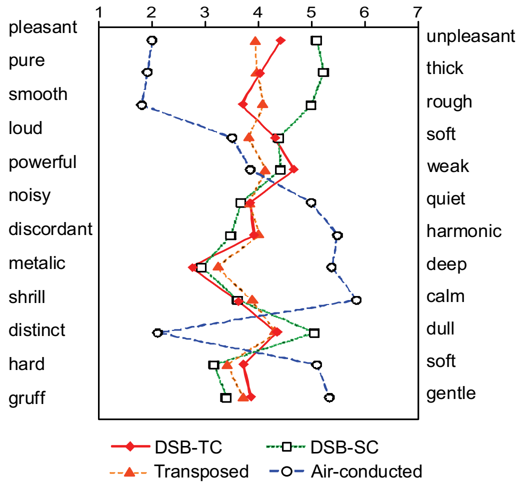

Fig. 1. Profiles of three types of BCU and AC sounds

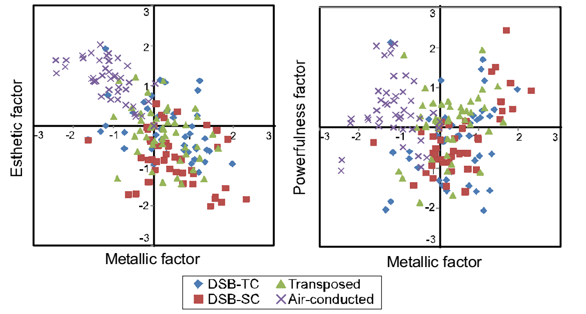

Fig. 2. Scatter diagram of factor scores for three BCU and AC sounds.

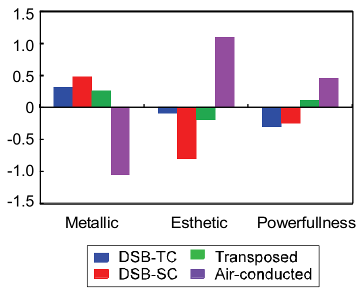

Fig. 3. Averaged factor scores for each stimulus.

References

1. S. Nakagawa et al.: Trans. Jpn. Soc. Med. Biol. Eng. **44** (2006) 184.
2. K. Fujimoto, and S. Nakagawa: Hear. Res. **204** (2005) 210.
3. S. Nakagawa et al.: Jpn. J. Appl. Phys. **51** (2012) 07GF22.
4. M. Okamoto, et al.: The research report of 2001 health labor sciences research grant H11-sensory organ-004 (2002) [in Japanese].
5. L. R. Bernstein, and C. Trahiotis: J. Acoust. Soc. Am. **112**(2002) 1026.
6. S. Namba et al.: J. Acoust. Soc. Jpn. (E), **13** (1992) 229–232.