Development of Bone-conducted Ultrasonic Hearing Aid for the Profoundly Deaf

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Abstract

Ultrasounds are perceived through bone-conduction by the profoundly deaf as well as in normal-hearing subjects. A bone-conducted ultrasonic hearing aid (BCUHA), with its parameters determined by previous psychoacoustical and neurophysiological measurements, was developed for the profoundly deaf. Using BCUHA, more than 40% of profoundly deaf subjects were able to perceive sounds, and 20% were able to recognize some words.

1. Introduction

In 1991, Lenhardt et al. reported that bone-conducted ultrasound (BCU) modulated by speech sounds were discriminated [1]. This report suggested the possibility of the development of a bone-conducted ultrasonic hearing aid (BCUHA). However, after Dobie disputed Lenhardt’s results obtained from subjective psychological experiments [2], the controversy has continued. In 1998, we objectively supported Lenhardt’s argument by magnetoencephalography (MEG) [3]. We also observed activation of the auditory cortex elicited by BCU in deaf subjects as well as normal hearing subjects using MEG [3-5] and positron emission tomography (PET) [6]. Furthermore, we clarified the physiological and psychoacoustical characteristics of BCU perception: subjective pitch [5], dynamic range of loudness [5], and the optimal frequency for perception [7].

In this study, we developed a BCUHA for the profoundly deaf [8-11]. The parameters for the BCUHA were determined by the results of our former study [4, 5, 7]. Psychoacoustical test were carried out in normal hearing and deaf subjects to evaluate utility of the BCUHA.

2. Development of the bone-conducted ultrasonic hearing aid

2.1. Basic principle

Fig. 1 shows the scheme of the BCUHA. Ultrasounds are amplitude-modulated by speech or environmental sounds, which are detected by microphones, and presented to the mastoid or the sternocleidomastoid muscle by a vibrator.

2.2. Appearance and configuration

Fig. 3 illustrates the BCUHA. The configuration of BCUHA is shown in Fig. 4. Parameters of each component were determined from our previous study using psychoacoustical and neurophysiological measurements. The basic components of BCUHA are:

1. Microphone
2. Sound signal amplifier
3. Sound signal processor
4. Frequency modification unit
5. Modulation depth controller
6. Modulation depth fixation unit
7. Carrier generator (27±5 kHz)
8. DSB modulator
9. Output amplifier
10. Output limiter
11. Automatic ON/OFF controller
12. Calibration signal generator
13. Vibrator and headgear

Figure 1: BCUHA schematic
3. Psychoacoustical experiments using the bone-conducted ultrasonic hearing aid

To test the utility of the BCUHA, psychoacoustical measurements were carried out in normal hearing and deaf subjects.

3.1. Subjects

The subject volunteers were:
1. 40 normal hearing subjects
2. 37 midrange deaf subjects
3. 24 profoundly deaf subjects
   (hearing acuity (both side) > 80 dBHL)

3.2. Methods

(1) BCU tone burst (25 - 32 kHz, duration: 250 ms, rise/fall: 10 ms) were presented by BCUHA. Subjects were requested to answer whether they were able to sense sounds or not.

(2) 250 Hz, 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz tone bursts (duration: 250 ms, rise/fall: 10 ms) were presented via the BCUHA. Intensity of stimuli were set at 10 dBSL.

(3) Japanese number (ex: /ichi/ (one), /ni/ (two), /san/ (three)) were presented to subjects via the BCUHA. Subjects were requested to evaluate articulations of words into following 5 levels:

   Level 1: Clearly distinguished.
   Level 2: A little unclear, but distinguished
   Level 3: Very unclear, but distinguished
   Level 4: Not distinguished, but recognized as speech sounds
   Level 5: Not recognized as speech sounds

3.3. Results

100% of normal hearing, 89% of midrange deaf and 42% of profoundly deaf subjects were able to get sound sensation. 95% of normal hearing, 57% of midrange deaf and 21% of profoundly deaf subjects were able to discriminate frequencies correctly. Also, 95% of normal hearing, 73% of midrange deaf and 17% of profoundly deaf subjects were able to distinguish words.

5. Conclusion

There are at least 3,000,000 profoundly deaf people who cannot sense any sounds even with ordinary hearing aids. The BCUHA is the first tool to be developed anywhere in the world enabling the profoundly deaf to sense audition without surgery.

In this study, more than 40% of the profoundly deaf subjects were able to perceive some sounds when using the BCUHA. This result suggested its practicability and the importance of further developments of the BCUHA. Further, 17% of profoundly deaf subjects were able to distinguish words. Although these results were in themselves epoch-making, further improvements are essential.

5. References

[9] Nakagawa S and Imaizumi S: