Research Article

Acceptable Noise Level in Children with Unilateral Cochlear Implant and Bimodal Hearing

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Highlights

- Bimodal hearing can improve noise tolerance
- Bimodal hearing does not worsen the acceptable noise level

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ABSTRACT

Background and Aim: Difficulty in perception of speech in noise is one of the main complaints of hearing-impaired people. Due to profound hearing loss in cochlear implant (CI) users, they need higher signal-to-noise ratio for a better perception. Bimodal fitting is a preferred way for CI users because it prevents auditory nerve degeneration, is a complement of frequency range at the opposite ear, an is less invasive to provide binaural hearing. Acceptable noise level (ANL), as a reliable test to assess noise tolerance, has not yet been used in comparing children with bimodal hearing and CI. This study aimed to determine whether bimodal fitting can help CI children tolerate more noise.

Methods: This descriptive-analytical study was conducted on 13 children with unilateral CI and bimodal hearing. Audiometry test was performed at aided and non-aided conditions. Then, their noise tolerance was assessed by the Persian version of ANL test.

Results: Bimodal hearing resulted in statistically significant increase in ANL. The mean of ANL at unilateral CI and bimodal hearing conditions were 6.15±2.90 and 4.77±1.70, respectively.

Conclusion: Bimodal fitting lead to more noise tolerance in unilateral CI children due to the combination of binaural summation and binaural release from masking.

Keywords: Acceptable noise level; cochlear implant; hearing aid; bimodal hearing; profound hearing loss; binaural hearing

Introduction

Provision of binaural hearing in cochlear implant (CI) users can result in lots of benefits regarding localization, lateralization, and speech perception in noise. On the other hand, stimulating the auditory nerve in the opposite ear can prevent it from degeneration and auditory deprivation. Therefore, in case of surgery for the second CI, the nerve can remain applicable [1]. Based on the current evidence, the best way to provide bilateral stimulation is bimodal fitting, because the other method (i.e. bilateral cochlear implantation) is invasive and is not supported by insurance in many countries [2]. Moreover, in some countries like Iran, due to limited number of CI prosthesis, bimodal fitting is preferred. Another aspect of the bimodal hearing procedure is the difference between frequency ranges of HA and CI. Reportedly, Cis are mostly inserted into the basilar part of the cochlea; therefore, most of its hearing restoration is for the mid- and high-frequency ranges, while, hearing aids amplification method is mostly concentrated on the low- to mid-frequency ranges. Thus, the combination of them can lead to a wider range of auditory nerve stimulation [3].

Speech perception in noise is a challenging task for people with hearing loss, even for those with low hearing loss. The ability to extract signals in noisy environments depends on the coordination of many characteristics of inner ear and auditory neural pathway. Characteristics of the inner ear such as frequency specificity and temporal resolution are determinant factors; CI users with hearing loss in both ears experience many difficulties in noisy environments [4]. Most studies have reported poor speech perception in noise for individuals with severe to profound sensorineural hearing loss [4-6]. Therefore, restoration of binaural hearing by bimodal hearing using a bilateral CI is a required for those with hearing loss. It is believed that it provides binaural processing such as binaural squelch; hence, the signal can be more detectable if making two distinct streams for signal and noise be made, which can result in a better speech perception in noise [3]. However, it should be noted that low-frequency amplification, in case of bimodal hearing, may result in background noise amplification which can affect the performance of hearing-impaired people in noisy environment [7]. It necessitates more investigation on the field of bimodal hearing.

The acceptable noise level (ANL) test is a method for evaluating the noise tolerance of individuals in the presence of background noise. It was introduced by Nabelek et al. in 1991 [8]. It shows how well a person is able to put up with a continuous speech while the highest level of competitive background noise is presented. It is a valid and reliable method which is not related to factors such as age, gender and noise spectrum. In addition, it has been shown that ANL can be a good predictor of hearing aid satisfaction; people with lower ANL have better suppression in the auditory efferent system and usually are more satisfied with their hearing aids [8]. The lower ANL indicates better noise tolerance [8-13]. The Persian version of this test was validated by Ahmadi et al. using a running female-talker story with a 12-talker babble in children [12]. ANL test has been investigated just for the adults with CI [14] and it has not been yet applied for children with CI, especially for bimodal hearing. Previous studies have compared the ANL results between CI users and normal-hearing people or between adult CI and bimodal users. Since there is no ANL information for younger CI and bimodal users, this study aimed to assess the ANL of children with unilateral CI and bimodal hearing.

Methods

In this study, participants were 13 children aged 6-15 years (Mean age=8.5±2.42 years) with bilateral profound sensorineural hearing loss, who were using Cis for at least one year in their opposite ear (at least four hours a day) [15]. Most of them had same CI and hearing aids brands. In all of them, hearing aids fitting had been done by the Desired Sensation Level (DSL) method (fifth version) based on their age, and the microphones in hearing aids were Omni directional. After signing a written informed consent by the parents of children, they were asked to complete the questionnaire which surveys the age at hearing loss diagnosis, duration of hearing aids use before cochlear implantation, the age at cochlear implantation, hours of using bimodal fitting per day, and their satisfaction with it. After otoscopy and tympanometry, audiometry was conducted under four different listening conditions: a) with headphone to record unaided residual hearing thresholds in each ear, b) free field audiometry with unilateral CI, c) free field audiometry with unilateral hearing aid (HA), and d) free field audiometry with bimodal fitting. Mean hearing thresholds at each condition are reported in Table 1.

For ANL measurement, a running speech by female talker was presented at two most comfortable levels (MCL). While the running speech presented at the MCL, 12-talker babble noise was presented and the participants were asked to determine the highest background noise level (BNL) that they could put up with the story. For

calculating the ANL, the BNL was subtracted from the MCL [16]. MCL, BNL, and ANL were obtained and compared in two conditions of bimodal hearing and unilateral CI. Given that most of participants were wearing CI since the age of 4-5 years and their communication was totally dependent on CI, they refused to cooperate in ANL test with unilateral HA; hence, the results for this condition were not recorded. In order to avoid any bias and learning effect, the order of test was changed randomly.

Statistical analysis

To examine the normality in distribution of test results (MCL, BNL, and ANL), Kolmogorov-Smirnov test was applied. Paired t-test, independent t-test, one-way and two-way repeated measures ANOVA, and Bonferroni post hoc test were used to evaluate the research hypothesis and conduct pairwise comparison. Moreover, Pearson correlation test was used to evaluate the relationship between numerical variables. To control the Type I error, the $p<0.05$ was determined as the statistically significance level. Analyses were carried out in SPSS v.17 software.

Results

It was reported that 77% of parents of children were satisfied with bimodal fitting, and believed that its daily usage had beneficial impact on the performance of their children. The mean±standard deviation (SD) of time for bimodal fitting usage per day in children was 7.31±3.45 hours, and the duration of CI usage was 3.5 years which showed a significant correlation with the MCL ($r=-0.56$, $p=0.04$), indicating that with the longer use of CI, a lower intensity is needed to comfortably follow the speech. Children were using HA bilaterally for 32 months before cochlear implantation but its significant correlation was not found with BNL, MCL and ANL. Moreover, there was not any correlation between hearing thresholds and BNL, MCL, and ANL (Table 1).

The mean MCL for unilateral CI and bimodal hearing conditions were 74.08±1.85 and 73.08±2.1 dB HL, respectively, but was not significantly different ($p=0.06$, Figure 1). The mean BNL for unilateral CI and bimodal hearing conditions were 67.9±4 and 68.31±3.1 dB, respectively, but was not significantly different ($p=0.57$, Figure 1). However, there was a statistically significant difference in the ANL between unilateral CI and bimodal hearing conditions (Mean=6.15±2.9 and 4.77±1.7, respectively, $p<0.03$).

There was a statistically significant correlation between ANL score at unilateral CI condition and ANL score at bimodal hearing condition ($r=0.76$, $p<0.004$). It indicates that children with lower ANL using unilateral CI also have lower ANL for bimodal hearing (Figure 2).

Discussion

Hearing performance in a noisy environment, despite receiving sound amplification by HA or restoration by CI, is one of the main complaints of hearing-impaired people. This issue has more negative impact on children because of being in educational environments. The present study investigated the noise tolerance in children with CI compared to when HA was added to the contralateral ear and bimodal hearing was provided. Based on the results, CI users performed better than expected. Their ANL test score at unilateral CI condition was<7 which a good performance in noise [14]. Consistent with previous findings of bimodal fitting in various population with different tests, children in our

Table 1. Mean and standard deviation of hearing thresholds in unaided and aided (cochlear implant, hearing aid, and bimodal hearing) conditions

	Unaided thresholds (dB HL)		Aided Thresholds (dB HL)		
	Mean±SD				
	Implanted ear	Contralateral ear	Cochlear implant	Hearing aid	Bimodal hearing
250 Hz	91.92±11.5	79.00±9.67	22.69±6.65	40.77±7.32	21.15±10.03
500 Hz	103.85±10.6	90.76±10.20	24.61±5.94	40.77±7.56	22.69±6.33
1000 Hz	115±12.6	93.84±11.60	24.61±10.89	43.85±11.75	23.80±9.39
2000 Hz	114.60±12.8	98.46±12.40	28.07±9.02	53.46±10.07	26.53±7.74
4000 Hz	117.69±10.8	103.07±12.96	33.85±8.2	56.54±10.48	30.76±8.12

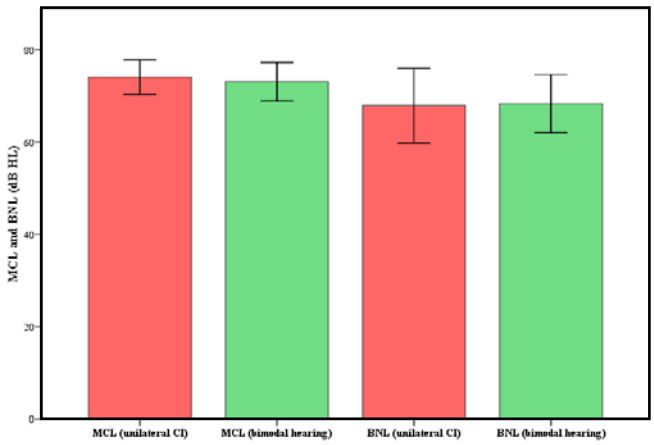

Figure 1. Mean and standard deviation of most comfortable level, background noise level, and acceptable noise level for two conditions of unilateral cochlear implant and bimodal hearing. MCL; most comfortable level, CI; cochlear implant, BNL; background noise level

study also showed good performance at bimodal hearing condition. Using HA in the opposite ear in children with unilateral CI exposed them to the much higher noise level, but resulted in significant improvement of noise perception. It suggests that binaural hearing in more important than hearing more noise. Bimodal hearing not only was not deteriorated it, but also was improved. This finding can be explained based on three important mechanisms in auditory pathway while binaural hearing is provided: binaural summation, binaural squelch, and binaural release from masking according to the results of MCL, BNL, and ANL. Bimodal hearing resulted in decreased MCL and increased BNL (both statistically non-significant), but the decreased MCL and increased BNL resulted in significant ANL. The decreased MCL is due to binaural summation and the decreased BNL is because of binaural release from masking which are two aspects of binaural hearing process restored by bimodal hearing. By activating superior olivary complex, nuclei of the lateral lemniscus, and inferior colliculus in auditory brainstem and due to interaction between inhibitory and excitatory responses and their gathering in medial geniculate body and auditory cortex, signal is developed and noise is suppressed [17].

Although it has been proved that bimodal hearing can have positive impact on speech perception in noise and can provide better signal-to-noise ratio by at least 0.4 dB even under unilateral stimulation [18], children in our study were not capable of cooperating under unilateral

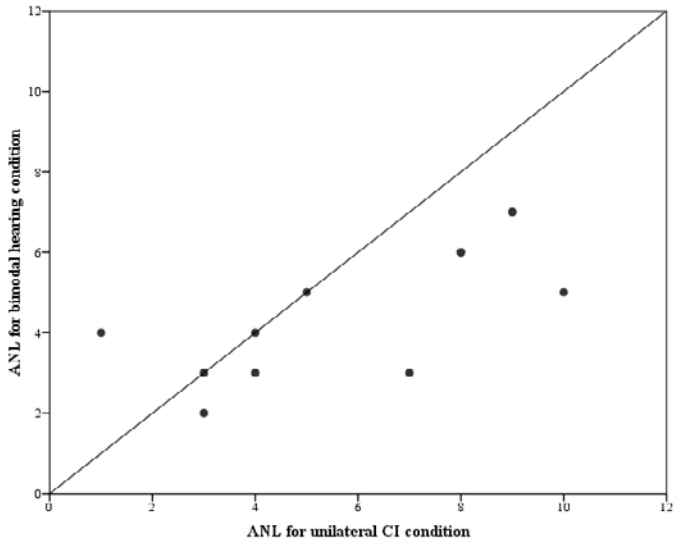

Figure 2. Scatterplot data of acceptable noise level. Acceptable noise level for unilateral cochlear implant condition is shown in horizontal axis and acceptable noise level for bimodal hearing condition is shown in vertical axis. The reference line is shown as well. ANL; acceptable noise level, CI; cochlear implant

HA use; therefore, the results were compared only at unilateral CI and bimodal hearing conditions. This may be because of the signal type in ANL test; putting up with a continuous story by unilateral HA was definitely difficult for CI users. Moreover, it has been proved that, by binaural hearing, listening effort decreases and noise tolerance improves [19]. Although 70% of participants in our study were satisfied with their HA, in most countries, HAs are not re-adjusted after cochlear implantation [20]. Therefore, it seems that more research is needed in the field of HA fitting in children with bimodal hearing. Furthermore, using the tests designed for speech in noise discrimination such as word-in-noise test along with ANL test can be helpful to have a more comprehensive insight into speech perception in noise ability of children with CI. The number of participants was low because of the COVID-19 pandemic; further studies using more participants can lead to more certain conclusions.

Conclusion

Cochlear implanted children with good hearing aid thresholds have acceptable noise level results almost similar to that of normal-hearing children. Bimodal fitting causes lower most comfortable levels and higher background noise level, leading to better acceptable noise level results. Therefore, it is suggested that bimodal hearing improves the noise tolerance in children with cochlear implant.

Ethical Considerations

Compliance with ethical guidelines

All research procedures were approved by the Research Ethics Committee of Shahid Beheshti University of Medical Sciences (Code: IR.SBMU.RETECH.REC.1398.407).

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Authors' contributions

SA: Study design, acquisition of data, interpretation of the results and drafting the manuscript; HJ: Study and revise design, interpretation of the results, statistical analysis and drafting the manuscript; HH: Acquisition of data, statistical analysis; RS: Acquisition of data.

Conflict of interest

The authors declare that there is no conflict of interest to be reported.

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