Research Article

Speech Intelligibility in Children with Cochlear Implants Compared to Normal-Hearing Peers Matched for Chronological Age and Hearing Age

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Highlights

- Speech intelligibility (SI) was compared between children with CIs and NH peers
- SI was poorer in children with CIs than normal-hearing in terms of chronological age
- SI in children with CIs was the same as in NH peers matched for hearing age

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ABSTRACT

Background and Aim: Cochlear implants (CIs) can lead to the development of verbal communication in areas such as sound repertoire, speech intelligibility (SI), and conversational skills. The SI refers to the ability to make recognizable speech sounds. Children with CIs may experience poorer SI than normal-hearing (NH) children. This study aims to compare the SI between children with CIs and NH peers matched for chronological age and hearing age.

Methods: The speech samples of 40 monolingual Persian-speaking children, including 20 children with CIs and 20 NH children were used in this study. The children's SI was analyzed using three measures of the percentage of correct consonants, percentage of correct vowels, and percentage of intelligible words. One speech-language pathologist and two non-professional listeners transcribed each speech sample.

Results: The results showed no significant difference in any measures of SI between CI children and NH hearing age-matched peers, but there was a significant difference between CI children and NH chronological age-matched peers ($p<0.05$).

Conclusion: The SI in Persian-speaking children with CIs is the same as in NH hearing age-matched peers, but it was poorer compared to NH chronological age-matched peers. If the children with hearing impairments receive CIs sooner, their SI can be greater. Cochlear implantation improves SI by increasing the hearing experience.

Keywords: Speech intelligibility; percentage of correct consonants; percentage of correct vowels; percentage of intelligible words; cochlear implant; hearing age

Introduction

Cochlear implants (CIs), as the best sensory prostheses, can facilitate speech and language development in children with severe to profound hearing loss. They can develop some areas of verbal communication such as sound repertoire, speech intelligibility (SI), and conversational skills [1]. The SI is a key component of the spoken-language ability, and refers to the degree to which the desired message of the speaker is recovered by the listener [2]. It is one of the main criteria for language and speech development in children with CIs, since intelligible speaking requires the abilities ranging from sound perception to speech perception, planning and execution of utterances with linguistic knowledge, and articulation of meaningful sentences with motor skills. Thus, the ability to produce an intelligible speech is very important in the development of verbal communication in these children [3].

The SI is measured by single words, sentences, and spontaneous speech [4]. Some studies on the SI assessment of children with CIs have utilized transcription (writing down) procedures, while others have used rating scales [3-5]. There are various clinical studies to assess the SI of CI children using different study designs, types of speech stimuli, measurements, raters with different expertise level, and various materials (phonemes, syllables, imitations, and sentences) and even hierarchical scoring systems [2, 3, 6, 7]. Raters can include professional listeners (such as an experienced speech therapist or audiologist), non-professional listeners, or even the parents of implanted children. Despite the differences in the type of studies, they all have reported the benefits of CIs in improving the SI of prelingually deaf children. Similar results in previous studies have been reported after cochlear implantation and with a longer period of usage. According to them, CIs can improve the SI like the conventional hearing aids, depending on factors such as the amount of residual hearing, implant age, and duration of device use [2, 3, 6-8]. In studies conducted in Iran, results have shown lower SI in CI children compared to normal children at the same chronological and hearing ages [9, 10-12], and the positive effect of lower implant age (<6 years) on the SI [13, 14].

Several studies have produced estimates of SI in children with CIs [6-14], but there is still inadequate data to compare the speech ability of CI children and normal hearing (NH) peers matched for hearing age. The hearing age refers to the length of time a person can experience hearing after cochlear implantation. Most studies have investigated imitated speech of children, which is different from spontaneous speech [15]. Speech analysis based on spontaneous speech stimuli is still largely lacking [16]. In the present study, the continuous speech stimuli derived from picture descriptions are used, which possibly leads to different SI scores in CI and NH children. We compared the judgments of two types of raters (professional and non-professional) who measured SI by the percentage of correct consonants (PCC), percentage of correct vowels (PCV), and percentage of intelligible words (PIW). In overall, this study aimed to compare differences in SI between Persian-speaking CI children and NH peers (matched for chronological and hearing ages) and to evaluate the correlation between the three measures of SI in children with CIs.

Methods

Participants

This is a cross-sectional study. As described in our previous study [17], participants were 20 CI children selected by a convenience sampling method from Amir A'lam Hospital in Tehran, Iran and 20 NH children selected using a convenience sampling method from kindergartens in Tehran. All participants were Persian-speaking children and had no medical problems or impaired structure/function of speech organs. According to Ling test [18], the function of CI in children was normal. The type of used CI was Nucleus® Freedom ™ with Contour Advance ™ electrodes (CI24RE) which has 22 active electrodes. The CI children had a severe congenital hearing loss (Pure-tone average threshold=85 dB HL) in both ears. According to the results of Clinical Assessment of Oropharyngeal Motor Development [19], there were no problems in NH children and they had no developmental delay or hearing problems. Children in both groups were excluded from the study if they had no cooperation to participate in the tests or their speech samples could not be used for analysis. The CI children were divided into two equal subgroups of 10.

Measures of speech intelligibility

The SI assessment was performed using three measures of PCC, PCV, and PIW. The PCC shows the percentage of intended consonant sounds during a conversational sample that were expressed correctly. The PCC is calculated by dividing the total number of correctly pronounced consonants by the total number of pronounced consonants and the PCV is calculated by dividing the total number of correctly pronounced vowels by the total number of pronounced vowels. In this study, we calculated the PCC-Revised (PCC-R) and PCV-Revised (PCV-R) [20]. Finally, the PIW is obtained by dividing the total number of intelligible words by the total number of words [15, 21]. Lastly, the obtained ratios multiply by one hundred.

Assessments

In this study, we used the audio tapes of children recorded in our previous studies [17, 22]. Their continuous speech was analyzed by professional and non-professional raters. We used a collection of 18 pictures (content validity index=0.951, content validity ratio=0.944) to evoke continuous speech. From the available audio samples, 6-min samples of 40 children was selected. The orthographic transcription of speech samples was done by two native Persian-speaking listeners. They calculated the percentage of words that they could correctly understand (PIW). In addition, an speech-language pathologist transcribed the speech samples to calculate the PCC and PCV. All listeners were unacquainted with the speakers. The rating agreement was calculated for assessing the inter-rater reliability [23]. We randomly selected 20% of the speech samples and gave them to other listeners to calculate the agreement. An inter-rater agreement of 93.6% on words was reported, indicating a high agreement between raters.

Statistical analysis

To determine the normality of data distribution, Kolmogorov-Smirnov test was used whose results showed that the distribution was not normal ($p<0.05$). Hence, we used nonparametric tests for statistical analysis. The Mann-Whitney U test was conducted to detect the differences in the PCC, PCV, and PIW between the two groups of CI and NH children matched for chronological age (group I), and between CI and NH children matched for hearing age (group II). Spearman's correlation test was used to examine the correlation between the three intelligibility measures (PCC, PCV, and PIW). All analyses were performed in IBM SPSS v.17 software.

Results

In group I, CI and NH children had a same chronological age of 60-72 months (mean age=65.3±4.96 months). In group II, CI children with a mean chronological age of 107.4±11.63 months (ranged 85-123 months) had experienced hearing after implantation for 60−72 months (mean hearing age= 67.7 ± 5.61 months) similar to the hearing age of NH children (60-72 months). During the study, CI children in group I had a minimum hearing age of one year. Children had received implantation before the age of 48 months (mean= 39.5±8.23 months) in group I, and before the age of 51 months (mean=39.7±9.48 months) in group II. For more information, see Table 1. The mean values of SI measures (PCC, PCV, and PIW) are shown in Table 2. Their mean values were lower in children with CIs than NH peers in two groups. The results of Mann-Whitney U test showed that PCC ($p=0.266$), PCV ($p=0.818$), and PIW ($p=0.253$) weren't statistically different in group II, but they were statistically different between children in group I ($p<0.001$). There was a significant correlation between PCC and PIW (Spearman's Rho; $r=0.927$, $p<0.001$) as well as PCV and PIW (Spearman's Rho; $r=0.913$, $p<0.001$) in CI children in groups I and II (n=20).

Discussion

In this study, we used continuous speech of preschool Persian-speaking children for assessing their SI. Under such conditions, the benefits of CIs are evaluated. Us-

Table 1. Demographic characteristics of children in two groups (n=40)

Groups		n	Gender (F/M)	Mean±SD		
				Chronological age (months)	Hearing age (months)	Implantation age (months)
I	Children with CI (chronological age=5–6 years)	10	5/5	65.30±4.96	25.80±10.65	39.50±8.23
	Normal-hearing children (chronological/hearing age=5–6 years)	10	5/5	65.30±4.96	65.30±4.96	-
II	Children with CI (hearing age=5–6 years)	10	3/7	107.40±11.63	67.70±5.61	39.70±9.48
	Normal-hearing Children (chronological/hearing age=5–6 years)	10	3/7	67.70±5.61	67.70±5.61	-

CI; cochlear implant, F; Female, M; Male

Table 2. Results of percentage of correct consonants, percentage of correct vowels and percentage of intelligible words in two study groups

Groups		Mean±SD		
		PCC	PCV	PIW
I	Children with CI (chronological age=5–6 years)	82.71±6.36 (Range=68.51-89.70)	97.37±0.98 (Range=95.03-98.64)	78.49±5.01 (Range=67.56-85.42)
	Normal-hearing children (chronological/ hearing age=5–6 years)	99.25±0.71 (Range=97.71-100.00)	99.90±0.10 (Range=99.70-100.00)	98.86±0.65 (Range=97.83-100.00)
II	Children with CI (hearing age=5–6 years)	98.71±1.23 (Range=96.14-100.00)	99.69±0.28 (Range=99.29-100.00)	98.50±1.26 (Range=96.17-100.00)
	Normal-hearing children (chronological/ hearing age=5–6 years)	99.31±0.56 (Range=98.65-100.00)	99.71±0.21 (Range=99.50-100.00)	99.08±0.76 (Range=97.92-100.00)

PCC; percentage of correct consonants, PCV; percentage of correct vowels, PIW; percentage of intelligible words, CI; cochlear implant

ing appropriate methods for measuring SI can guide the speech-language pathologists to obtain a more complete and accurate profile of a child's communicative competence, plan intervention, monitor progress, and predict the time needed for treatment.

The signifcant difference in PCC, PCV, and PIW between the CI and NH children with the same chronological age reported in our study indicates that the NH children have clear speech, better than children with CIs, and the SI of children with CIs is significantly lower than that of NH peers because they have not received adequate auditory input during the sensitive period of language learning (when aged <2 years). In other words, they do not receive acceptable information and have no proper information processing. These children, despite improved hearing after implantation, still have lower hearing sensitivity than NH children and need direct instruction to develop the speech ability. These results are consistent with the findings of some studies with different methods of SI assessment [5, 9, 24]. The relatively high level of SI in children with CIs in group I is similar to the results of Chin and Tsai [5], who concluded that the difference in SI scores between NH and CI children decreases at the age of 5-6 years. This study supports the results of previous studies [9-12]. For example, Sohrabi et al. [11] compared SI in CI and NH children and found that the SI of CI children at the levels of vowel, consonant, and word were significantly poorer compared to NH children. The difference in the SI in our study and their study can be due to difference in chronological age of implanted children and in the type of used speech samples.

The lack of a signifcant difference in PCC, PCV, and PIW between CI and NH children with the same hearing age in our study indicates that after 60–72 months of implantation in children with CIs, their PCC, PCV, and PIW scores become almsot the same as those of NH children with a chronological age of 60–72 months. This result is consistent with the findings of Bakhshaee et al. [25] where the most of implanted children were able to achieve intelligible speech after 60 months of implantation. Receiving more auditory feedback by increasing hearing input can improve speech production ability. In other words, the SI is improved with the increase of hearing age, because children experience hearing longer. These findings are in agreement with the results of previous studies which suggested that SI continues to be improved after 5 years of CI use [1]. In Iran, the results of recent studies have shown the importance of implantation age in children with CIs [13, 14]. With the lower implantation age and greater hearing experience, a higher SI is reported.

The significant correlation between PIW, PCC, and PCV reported in our study indicates that the CI children who can pronounce consonants and vowels correctly, produce higher intelligible words. These results are in accordance with the findings of Safaiean et al. [26]. Like other study on a different population [27], a PCV higher than PCC was reported. The PCC, PCV, and PIW seem to be appropriate measures of SI. The results of this study suggest that, after 5-6 years of using CIs, the SI of children do not become different from that of NH hearing age-matched peers. Therefore, this study emphasizes the need for sooner implantation and more speech-language therapy to ensure that children achieve higher speech intelligibility. The purpose of cochlear implantations is not only to achieve the best hearing, but also to improve speech and language.

In this study, the continuous speech of children was analyzed by two professional and non-professional raters. Since in a continuous speech sample, semantic, syntactic/morphological, contextual, and supra-segmental cues are available to the listeners and reflect the real daily communication, the real percentage of the correctly pronounced words in a speech sample is a valid measure for SI. Imitating words and sentences, while saving time, do not accurately reflect the overall intelligibility and do not simulate natural speaking situations compared to continuous speech samples. Furthermore, these tasks cause lower SI than continuous speech, but the findings of Gordon-Brannan et al have shown opposite results [15]. Perhaps the higher percentage reported by the professional rater in our study (at the vowel and consonant levels) can be due to their clinical experience in working with CI children. On the other hand, a non-professional rater may not be able to correctly guess the target word that has low intelligibility and, as a result, report lower SI (at the word level). It is recommended that speech samples with different measures of SI (e.g. PCC, PCV, PIW, or speech intelligibility rating scale) and raters (professional and non-professional) should be compared with other samples in future studies. One of the strengths of this study was the comparison of CI and NH children with the same hearing age. However, the study had some limitations such as lack of control over the effect of speaking rate on the SI, small sample size, and lack of comparison with a control group using hearing aids. Future studies should address the role of these factors.

Conclusion

Speech intelligibility of children with CIs is almost similiar to that of NH hearing age-matched peers, while it is poorer compared to NH chronological age-matched peers. Therefore, it can be concluded that cochlear implantation improves speech intelligibility by increasing the hearing experience.

Ethical Considerations

Compliance with ethical guidelines

This study has an ethical approval obtained from Iran University of Medical Sciences (Code: IR.IUMS.REC.1393.9111360008).

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Authors' contributions

MT: Study design, data acquisition, data interpretation, statistical analysis, drafting the manuscript; NJ: Study design, data interpretation, drafting the manuscript; MK: statistical analysis, drafting the manuscript; YM: data interpretation; MMZ: Data acquisition.

Conflict of interest

The authors declare no conflict of interest.

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