

A Longitudinal Study on Language Ability Development in Children Following Cochlear Implantation

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Abstract

Audition serves as the foundation for children's language and cognitive development. Hearing impairment is prone to causing language development delay in children, which in turn affects their development in multiple aspects. Effective intervention during the sensitive period of language-related nervous system development in the preschool stage is crucial. Cochlear implantation (CI) is a key intervention technology for severe to profound sensorineural hearing loss, and early implantation, postoperative rehabilitation, and family support all influence the outcome of language recovery. This study adopts a longitudinal follow-up design to track changes in language comprehension and expression abilities of hearing-impaired children at 1 month, 3 months, 6 months, and other time points after cochlear implantation, and explores the effects of implantation age, family environmental factors (such as the amount of language stimulation and parental educational level). The study hypothesizes that the longer the time after surgery, the better the children's language abilities, and that the language abilities at 1 year and 2 years after implantation will be superior to those at 3 months or 6 months post-implantation. This study aims to reveal the trajectory of language development after surgery, provide a scientific basis for optimizing intervention strategies and formulating personalized rehabilitation plans, and thus possesses important theoretical and practical significance.

Keywords

Cochlear Implant; Hearing-impaired Children; Language Ability Development.

1. Introduction

Hearing is one of the fundamental senses for children's language development and cognitive development [1-3]. The acquisition of normal language ability relies on stable and rich auditory stimuli received from birth. Due to limited perception of auditory stimuli, children with hearing impairments often show significant delays in multiple aspects such as speech recognition, vocabulary accumulation, syntactic comprehension, and social communication. Studies have shown that untreated hearing impairment can lead to severe delays in children's receptive language and expressive language abilities, which in turn affect their cognitive, social, academic, and mental health development [4-5]. Especially in the preschool period, children's language-related nervous system is in a critical sensitive period. If effective stimulation during this period is missed, even if hearing function is restored or improved later, the language ability may still have difficulty to reaching the language ability level of their peers [6-7]. Thus, in order to improve the hearing ability and other related capacities of children with hearing impairments, cochlear implants have been developed.

Cochlear Implant (CI) is an effective intervention technology for severe to profound sensorineural hearing loss. It directly acts on the cochlear nerve through electrical stimulation, thereby bypassing the damaged auditory organs to achieve the transmission of sound signals. Over the past few decades, with advancements in technology and improvements in surgical safety, cochlear implants have been widely applied in the field of hearing intervention for infants and young children, becoming one of the key means to promote recovery of language ability recovery in hearing-impaired children [8-10].

Early implantation is considered one of the key factors in promoting language recovery. Multiple studies have shown that children who receive cochlear implants before the age of 2 achieve better results in language ability recovery than those with late implantation [11-12]. Meanwhile, systematic postoperative rehabilitation training and family support are also important factors affecting language development [13-15].

Thus, the value of this study is that it from a long-term tracking perspective, understanding the changing trends of language ability. Language development is a continuous and dynamic process. This study intends to use a longitudinal follow-up design to dynamically examine the changing trends in hearing-impaired children's language comprehension and expression abilities at multiple time points, such as 6 months after cochlear implantation.

In addition, this study will also incorporate different background factors (such as parents' educational level and family language environment) to conduct in-depth discussions on how these variables affect the long-term development of language ability. This holds significant theoretical and practical significance for optimizing cochlear implant intervention strategies and formulating personalized rehabilitation plans.

Therefore, the objectives of this study is to reveal the developmental trajectories of language abilities in children with cochlear implants at different time periods after surgery through long-term follow-up, analyze the impact of different background variables on the development of language comprehension and expression abilities, and provide a scientific basis for language rehabilitation strategies for hearing-impaired children. The hypothesis of this study is that the longer the duration after cochlear implantation, the better the language ability will be. It is anticipated that the language ability of children at six months post-implantation will be superior to that of those at first post-implantation or three months post-implantation.

This study aims to explore whether children show significant improvements in language comprehension and expression abilities at first month, 3 months, 6 months, following cochlear implantation, while also examining the role of family environmental factors in facilitating language ability improvement, as well as the positive correlation between the frequency and quality of rehabilitation interventions and the magnitude of progress in children's language development. [16-18]

2. Methods

2.1. Study Design

This was a retrospective cohort study from March in 2021 to September in 2025 of Chongqing Comprehensive Service Center for Persons with Disabilities. This study adopts a longitudinal research design to continuously monitor the developmental changes in language abilities of children with cochlear implants across different postoperative stages, with the goal of capturing long-term trends in both language comprehension and expression. By collecting data at multiple intervals, it provides a comprehensive assessment of how cochlear implantation facilitates children's language development. Data collection is structured around three key time points: 1 month after implantation (T1), representing the initial recovery stage and allowing evaluation of early language improvement; 3 months after implantation (T2),

marking a critical period of language development for assessing mid-term progress; and 6 months after implantation (T3), reflecting a relatively stable stage to examine long-term effects and the consolidation of language abilities.

2.2. Participants

Our sample included all prelingually deaf children with cochlear implants who met the following criteria between 2021 and 2025: 1) Persistent regular assessment of language comprehension and expression abilities shall be conducted in cochlear implantation programs (once every three months); 2) The rehabilitation conducted at the study site after the activation of the cochlear implant is defined as the initial rehabilitation; 3) The children and their family members have provided informed consent for the research. No exclusion criteria were established for this study.

2.3. The Assessment Method for Changes in Language Comprehension and Expression Abilities

All children regularly wore cochlear implants or hearing aids, received rehabilitation training under the guidance of qualified and trained rehabilitation physicians, and had their language comprehension and expression abilities assessed regularly by audiologists. The assessment tool was Question Bank for Hearing and Speech Rehabilitation Assessment for Deaf Children [19]. This word list adopts pictures as its primary presentation form, covering 9 items: natural sound recognition, tone recognition, monosyllabic word recognition, disyllabic word recognition, trisyllabic word recognition, short sentence recognition, speech recognition, number recognition, and selective listening. Assessments can be conducted through natural speech and the Auditory-Verbal Computer-Aided Navigation Assessment System [20]. In this study, the Auditory-Verbal Computer-Aided Navigation Assessment System was adopted for evaluation. The assessment procedure is as follows:

1) The hearing assessment encompasses monosyllabic words, disyllabic words, tones, initial consonants, final vowels (unique core concepts in Chinese), short sentences, and numbers. Conducted at baseline, 3-month, and 6-month follow-ups, the assessment involved presenting target and distractor word phrases to children, who selected the tester's read phrase. The recognition score (%) was calculated as (number of correct responses / total audiometric items) $\times$ 100%, with higher scores indicating better language comprehension.

2) The language assessment includes imitative articulation, listening attempt, communicative dialogue, intelligibility test, and picture description. Administered at the same three time points (baseline, 3-month, 6-month), it adopted the identical testing method and result calculation formula as the hearing assessment.

2.4. Medical History, Sociodemographic and Sociocultural Characteristics

The following variables cochlear implant-related were evaluated through the review of electronic medical records:

Data related to CI surgery: age at the time of surgery

Audiometric tests: conducted to assess the pure-tone average (PTA) thresholds of children with hearing impairment at frequencies of 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz. (The average value of the better ear).

The following variables related to the condition and sociocultural background of children with hearing impairment were evaluated through parent interviews and review of children's medical records:

Family bilingual environment (defined exclusively as the scenario where family members live with the child and use sign language or other languages, assessed as "present/absent");

Parental educational level (categorized into primary school, junior high school, senior high school, junior college, and undergraduate);

2.5. Statistical Analysis

Data were analyzed using SPSS 25.0 software. Statistical analysis of the data was performed using analysis of variance (ANOVA) and chi-square test.

2.6. Ethical Considerations

All parents or legal guardians were informed about and consented to this study. The design of this study and the recruitment of research participants were conducted in accordance with local ethical requirements. These children all received regular assessment under the rehabilitation process; their participation in this study did not require additional appointments, nor did it result in any loss of their regular medical care services or education.

3. Results

A total of 60 children were included in this study, all of whom underwent cochlear implant surgery between 2021 and 2025 and continuously received the same rehabilitation training. The findings related to the patients' baseline characteristics in the study sample—such as age, gender, the mean age at the first CI surgery and age at first rehabilitation—are summarized in Table 1.

Table 1. The findings related to the patients' baseline characteristics in the study sample—such as age, gender, the mean age at the first CI surgery and age at first rehabilitation

Characteristic	Value
Gender	
Female	33 (55.0)
Male	27 (45.0)
Age (years), mean (SD)	4.65 (1.6)
Age at first CI surgery (years), mean (SD) (those less than one year are counted as one year)	2.55(0.9)
Duration of receiving rehabilitation (months), mean (SD)	22.8(14.0)

Table 2. Among them, 75% of the children had parents with an educational level higher than senior high school. Other sociodemographic and sociocultural characteristics that have been previously confirmed to be associated with language development are described

Characteristic	Value
Parental education, n (%)	
Primary school	4 (6.7)
Junior high school	11 (18.3)
Senior high school	20(33.3)
Junior college	3(5.0)
Undergraduate	22(36.7)
Language Environment, n (%)	
Mandarin	13(21.7)
Dialect	39(65.0)
Bilingual (Mandarin + Dialect)	8(13.3)

Among them, 75% of the children had parents with an educational level higher than senior high school. Other sociodemographic and sociocultural characteristics that have been

previously confirmed to be associated with language development are described in detail in Table 2.

Regarding children's performance, pure-tone audiometry results, the medians and interquartile ranges of auditory and speech ability scores across different hearing ages (i.e., the duration of cochlear implant use), the ranges of cases where evaluation was not feasible due to the children being too young or having an excessively short rehabilitation period in the initial hearing and language assessment can be referenced in Table 3/4/5

Table 3. First post-implantation measurement data

Characteristic	Value
Pure-tone audiometry results (dB), mean (SD)	36.1(5.1)
Auditory ability score,mean(SD)	
Monosyllables	23(24.0)
Disyllables	37.3(27.7)
Trisyllables	26.4(21.2)
Short sentences	22.9(21.7)
Numbers	30(30.6)
Tones	25.1(21.5)
Initial consonants	31.9(23.8)
Final vowels	34.9(26.6)
Average speech recognition score,mean(SD)	28.9(23.8)
Hearing level,mean(SD)	1.3(0.5)
Language ability score,mean(SD)	
Listening and identifying pictures	1.2(1.0)
Describing pictures	1(0.9)
Imitating sentence length	1(0.8)
Communicative dialogue	0.7(0.6)
Speech intelligibility	0.8(0.7)
Language proficiency level,mean(SD)	0.9(0.7)
Average language age level,mean(SD)	1.2(0.6)

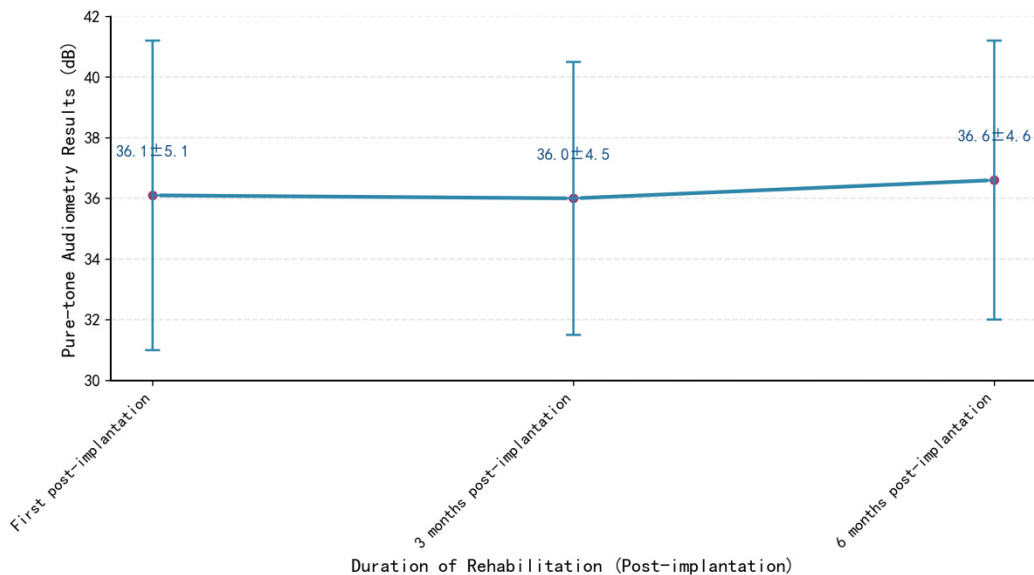
Table 4. Six months post-implantation rehabilitation follow-up data

Characteristic	Value
Pure-tone audiometry results (dB), mean(SD)	36(4.5)
Auditory ability score,mean(SD)	
Monosyllables	67(19.0)
Disyllables	77.8(15.2)
Trisyllables	62.8(24.0)
Short sentences	64.2(23.4)
Numbers	85(13.8)
Tones	57(14.3)
Initial consonants	62.4(15.9)
Final vowels	73.1(17.1)
Average speech recognition score,mean(SD)	68.7(16.8)
Hearing level,mean(SD)	2.1(0.9)
Language ability score,mean(SD)	
Listening and identifying pictures	1.9(0.9)
Describing pictures	1.5(0.8)
Imitating sentence length	1.7(0.7)
Communicative dialogue	1.3(0.7)
Speech intelligibility	1.6(0.8)
Language proficiency level,mean(SD)	1.6(0.7)
Average language age level,mean(SD)	1.6(0.7)

Table 5. Six months post-implantation rehabilitation follow-up data

Characteristic	Value
Pure-tone audiometry results (dB), mean (SD)	36.6(4.6)
Auditory ability score,mean(SD)	
Monosyllables	80.7(16.6)
Disyllables	87(14.2)
Trisyllables	79(21.1)
Short sentences	79.1(20.2)
Numbers	89.2(14.9)
Tones	76.4(15.8)
Initial consonants	77.1(13.5)
Final vowels	84.6(13.7)
Average speech recognition score,mean(SD)	81.7(14.8)
Hearing level,mean(SD)	3.1(0.9)
Language ability score,mean(SD)	
Listening and identifying pictures	2.5(0.7)
Describing pictures	2.3(0.7)
Imitating sentence length	2.3(0.8)
Communicative dialogue	1.7(0.7)
Speech intelligibility	2(0.8)
Language proficiency level,mean(SD)	2.2(0.6)
Average language age level,mean(SD)	2.2(0.8)

The relevant graph plotted based on the above data is as follows.

**Figure 1.** Changes in Pure-tone Audiometry Results with Different Durations of Post-implantation on Rehabilitation

It can be observed that with the extension of post-implantation rehabilitation duration, the pure-tone audiometry results of the subjects showed a gradual upward trend, while the standard deviation gradually decreased, indicating that the stability of auditory function was continuously improving. This suggests that long-term rehabilitation intervention after

cochlear implantation is beneficial for the optimization of patients' auditory function, and the individual differences in auditory function tend to narrow as the rehabilitation duration increases.

Table 6. Nonparametric Test Results

Indicator	Time Point	Mean± Standard Deviation	Median (P25, P75)	Minimum–Maximum	Paired Comparisons	Z-value	P-value
Pure-tone audiometry results	Initial	36.08±5.05	35.00(30.00,40.00)	30-45	—	—	—
	Three-month	36.00±4.49	35.00(35.00,40.00)	30-45	Three-month vs Initial	-0.185	0.854
	Six-month	36.58±4.56	35.00(35.00,40.00)	30-45	Six-month vs Initial	-1.513	0.13
					Six-month vs Three-month	-1.29	0.197
Average speech recognition score	Initial	28.90±23.82	28.75(0.00,31.50)	0.00-84.63	—	—	—
	Three-month	68.67±16.76	68.13(61.06,85.72)	27.75-93.50	Three-month vs Initial	-6.729	<0.001
	Six-month	81.66±14.78	87.06(68.75,91.75)	38.88-96.00	Six-month vs Initial	-6.736	<0.001
					Six-month vs Three-month	-5.427	<0.001
Hearing level	Initial	0.93±0.73	1.00(0.00,1.00)	0-3	—	—	—
	Three-month	2.10±0.88	2.00(1.25,3.00)	0-4	Three-month vs Initial	-6.534	<0.001
	Six-month	3.07±0.90	3.00(2.00,4.00)	1-4	Six-month vs Initial	-6.752	<0.001
					Six-month vs Three-month	-5.436	<0.001
Language proficiency level	Initial	0.93±0.72	1.00(0.40,1.20)	0.00-3.00	—	—	—
	Three-month	1.60±0.67	1.40(1.00,2.00)	1.0-3.8	Three-month vs Initial	-5.89	<0.001
	Six-month	2.17±0.62	2.00(2.00,2.65)	0.8-4.0	Six-month vs Initial	-6.691	<0.001
					Six-month vs Three-month	-5.262	<0.001
Average language age level	Initial	0.90±0.73	1.00(0.13,1.00)	0.0-3.0	—	—	—
	Three-month	1.55±0.75	1.00(1.00,2.00)	1-4	Three-month vs Initial	-5.329	<0.001
	Six-month	2.18±0.79	2.00(2.00,3.00)	0.5-4.0	Six-month vs Initial	-6.44	<0.001
					Six-month vs Three-month	-5.862	<0.001

The study results demonstrated that during the observation period, patients' pure-tone thresholds remained stable, while their speech recognition ability, hearing grade, language grade, and average language age level showed significant and sustained improvements.

Specifically, the pure-tone threshold measurements at the three time points were 36.08±5.05 dB HL, 36.00±4.49 dB HL, and 36.58±4.56 dB HL, respectively. Pairwise comparisons between time points revealed no statistically significant differences (3-month vs. Baseline: Z=-0.185, p=0.854; 6-month vs. Baseline: Z=-1.513, p=0.130; 6-month vs. 3-month: Z=-1.290, p=0.197).

In contrast, the average speech recognition score significantly increased from 28.90±23.82% at baseline to 68.67±16.76% at 3-month follow-up, and further to 81.66±14.78% at 6-month follow-up. The improvements between all time points were statistically significant (3-month vs. Baseline: Z=-6.729, p<0.001; 6-month vs. Baseline: Z=-6.736, p<0.001; 6-month vs. 3-month: Z=-5.427, p<0.001).

Hearing grade assessments also showed substantial progress, rising from 0.93±0.73 at baseline to 2.10±0.88 at 3 months and 3.07±0.90 at 6 months (3-month vs. Baseline: Z=-6.534, p<0.001; 6-month vs. Baseline: Z=-6.752, p<0.001; 6-month vs. 3-month: Z=-5.436, p<0.001).

Regarding language function, the language grade improved from 0.93±0.72 at baseline to 1.60±0.67 at 3 months and 2.17±0.62 at 6 months (3-month vs. Baseline: Z=-5.890, p<0.001;

6-month vs. Baseline: $Z=-6.691$, $p<0.001$; 6-month vs. 3-month: $Z=-5.262$, $p<0.001$). Similarly, the average language age level increased from 0.90 ± 0.73 at baseline to 1.55 ± 0.75 at 3 months, ultimately reaching 2.18 ± 0.79 at 6 months (3-month vs. Baseline: $Z=-5.329$, $p<0.001$; 6-month vs. Baseline: $Z=-6.440$, $p<0.001$; 6-month vs. 3-month: $Z=-5.862$, $p<0.001$).

These consistent findings indicate that while patients' baseline hearing levels remained stable over the 6-month period, their auditory processing capabilities and language functions were significantly enhanced during the intervention. This provides robust evidence for the effectiveness of the relevant rehabilitation measures.

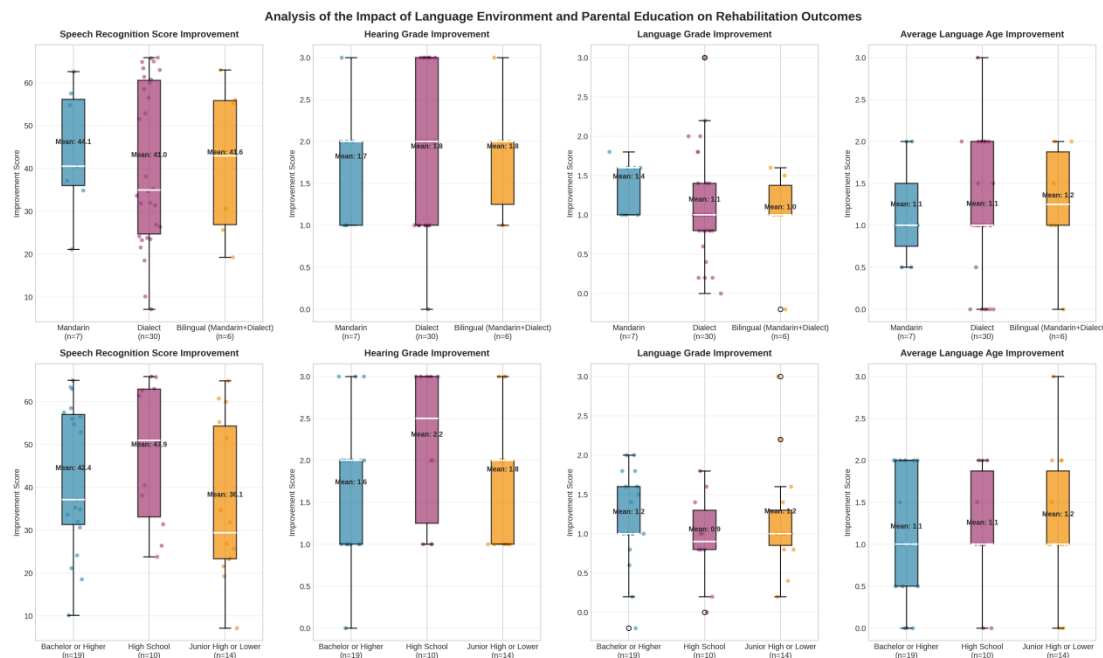


Figure 2. Association between sociodemographic and sociocultural characteristics.

Through statistical testing (Kruskal-Wallis H test) and visual analysis, no significant effects of language environment and parental highest educational attainment on rehabilitation outcomes were identified (all p-values > 0.05).

4. Discussion

The research results indicated that during the long-term rehabilitation of hearing-impaired children after cochlear implantation, rehabilitation outcomes varied across different time points. With prolonged rehabilitation intervention, the children's hearing and language abilities showed an overall upward trend, which aligns with the core principles of neuroplasticity in pediatric auditory development. Long-term intervention facilitates the establishment of stable neural pathways between the auditory periphery and brain language processing centers, underscoring the necessity of sustained, systematic rehabilitation and providing empirical support for clinical guidelines emphasizing long-term follow-up and personalized plans. In contrast, no significant correlation was found between rehabilitation outcomes and the home language environment or parental educational attainment, contradicting some previous studies. This discrepancy may be attributed to the standardized, uniform rehabilitation services provided by the involved disability service center, which offset potential family-related impacts, and the homogeneity of the single-center sample. This finding suggests that standardized professional rehabilitation services may play a more

critical role than family background, offering implications for equitable rehabilitation resource popularization in China, especially for children from disadvantaged families. As a report on pediatric cochlear implantation outcomes at a Chinese disability service center, this study included patients regardless of etiology or comorbidities, enhancing generalizability to broader clinical populations and filling the gap in real-world (rather than highly selected cohort) research. However, it has limitations: subjective bias from scale-based assessments, a relatively small sample size, and a short 6-month follow-up. Future research could explore interactions between rehabilitation intensity, neurodevelopmental individual differences, and family support, integrate digital health technologies to optimize services, and ultimately promote the comprehensive development and social integration of hearing-impaired children.

5. Conclusion

Consistent with the pre-research expectations, the hearing and language levels of children after cochlear implantation are proportional to the duration of rehabilitation intervention.

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