International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Auditory Perception Outcomes in Early and Late Cochlear Implanted Children: A Comparative Study with Normal-Hearing Peers

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Abstract

Auditory perception plays a crucial role in the development of spoken language, literacy skills, and social communication in children. Those with severe-to-profound prelingual hearing loss often experience delays in auditory and language development due to reduced auditory input during early periods of neural plasticity. Cochlear implantation is widely recognized as an effective intervention because it directly stimulates the auditory nerve and enables access to meaningful sound. Research consistently shows that implantation at an early age—especially before the age of three—supports better auditory and language outcomes by taking advantage of key periods of neural development. The present study aimed to compare auditory perception outcomes among early-implanted (EI) - (1–3 years), late-implanted (LI) - (3–5 years), and normal-hearing (NH) Hindi-speaking children, aged 6–7 years using the Revised Categories of Auditory Perception (R-CAP) scale. A total of 60 participants were equally divided across three groups with gender parity and had received at least two years of auditory-verbal therapy. Results demonstrated that normal-hearing children achieved a ceiling score (Mean = 12.00), followed by early-implanted children (Mean = 11.65), and late-implanted children (Mean = 10.45). Statistical analysis (Levene's Test, $p < 0.05$) revealed significant intergroup variability, particularly highlighting the perceptual disadvantage among late-implanted children. Gender-wise comparisons showed no significant differences ($p > 0.05$) across groups, indicating that auditory outcomes are primarily governed by age at implantation and auditory exposure rather than biological sex. The findings support earlier evidence demonstrating the advantages of early auditory access and further underscore the effectiveness of structured auditory-verbal rehabilitation programs for pediatric cochlear implant users in the Indian context. This study contributes to establishing R-CAP performance benchmarks for native Hindi-speaking children and underscores the need for early identification, timely cochlear implantation, and culturally relevant rehabilitative strategies.

Introduction:

Auditory perception forms the foundation of spoken language development, literacy, and social communication. In children with severe-to-profound hearing loss, the absence of adequate auditory input during critical developmental periods leads to delays not only in speech and language acquisition but also in cognitive, emotional, and social domains (Nicholas & Geers, 2006). Cochlear implantation has emerged as the most effective intervention for children deriving limited benefit from conventional

amplification devices, as it directly stimulates the auditory nerve, bypassing damaged cochlear hair cells and providing access to sound (Olusany, Neumann, & Saunders, 2014).

A substantial body of research has established that the age at implantation plays a decisive role in determining post-implantation auditory and communication outcomes. Early implantation, particularly before the age of three years, takes advantage of heightened neural plasticity and supports more age-appropriate auditory and language development (Davidson, Geers, Blamey, Tobey & Brenner 2011). Neurophysiological studies have confirmed this critical window, showing that auditory cortical responses are more typical when stimulation occurs within the first few years of life. In contrast, extended auditory deprivation results in atypical cortical reorganization, which negatively affects speech perception and language processing (Sharma, Dorman, & Spahr 2002). Clinically, children implanted before 12 months of age demonstrate faster progress in receptive and expressive language skills than those implanted later, highlighting the advantage of very early auditory access (Rambold 2016). Conversely, late implantation is often associated with poorer perceptual accuracy, slower language acquisition, and greater difficulty in complex listening environments, reflecting the long-term effects of auditory deprivation (Nittrouer Caldwell-Tarr, & Lowenstein, 2013).

The assessment of auditory perception in paediatric cochlear implant users has been standardized using instruments such as the Revised Categories of Auditory Perception (R-CAP) scale (Archbold, Lutman, & Marshall, 1995), which measures listening abilities across progressively complex levels, from sound detection to open-set speech understanding. Research consistently demonstrates that children implanted at an earlier age achieve higher R-CAP levels, often approaching the performance of their normal-hearing peers. In contrast, late-implanted children tend to show delays, particularly in open-set speech perception and real-world communication scenarios Ruffin, Kronenberger, Colson, Henning, & Pisoni 2013) . Longitudinal studies have also revealed that earlier-implanted children not only achieve superior auditory perception outcomes more rapidly but also maintain these advantages over time, especially in sentence recognition and listening in quiet environments (Dunn, Walker, Oleson, Kenworthy, Van Voorst, Tomblin & Kirk 2014).

Despite these advancements, differences persist between cochlear implant users and normal-hearing children. Even among early-implanted children, limitations remain in higher-order auditory skills such as listening in noise, following rapid speech, or degraded auditory signals (Peng, Tomblin, & Turner, 2008). Furthermore, auditory experience in naturalistic and linguistically rich environments has been shown to influence outcomes significantly. Children who receive consistent device use and rich linguistic input perform better than those with restricted auditory opportunities (Houston & Neurotology 2010). Additionally, factors such as the quality of auditory-verbal rehabilitation, the degree of family involvement, and the linguistic and socioeconomic environment substantially influence auditory and language development (Ching, Day, Seeto, Dillon, Marnane & Street 2013).

Arya, Nandurkar, Shah & Verma 2019) who compared speech perception skills in Hindi-speaking children with pre-lingual severe to profound hearing loss using hearing aids and cochlear implants, found that cochlear implantation led to improved outcomes. Additionally, the negligible gender differences suggest that equitable access to early intervention and rehabilitation in the Indian pediatric population can minimize potential disparities in auditory development. This is supported by the work of Prakash, Lakshmi, & Sreedhar, (2023), which validated the Little EARS questionnaire in Hindi and emphasized the importance of culturally sensitive assessment tools in the Indian context.

Gender-based comparisons in auditory perception and language outcomes among cochlear-implanted children have gained attention in recent years, as subtle biological, environmental, and sociocultural factors may influence auditory and linguistic development. Studies have shown that female children often exhibit marginally better auditory and speech outcomes following cochlear implantation, possibly due to early maturation of auditory-linguistic pathways and greater engagement in verbal interactions during early development (Geers & Sedey, 2011; Tobey et al., 2011). However, findings remain inconsistent across populations, warranting context-specific exploration.

Need for the Study:

Although several studies have examined categorical auditory perception outcomes following cochlear implantation, a significant gap remains in systematically comparing early- and late-implanted children with age-matched normal-hearing peers using standardized perception measures such as the Revised Categories of Auditory Perception (R-CAP) scale, particularly within the Indian linguistic context. Most existing research has primarily focused on Western populations or emphasized language development outcomes rather than specifically quantifying auditory perception differences across implantation age groups. Furthermore, there is a paucity of longitudinal and comparative data on native Hindi-speaking children, who may differ in auditory-linguistic exposure, access to rehabilitation, and socio-cultural experiences that influence auditory development.

The present study aims to address these gaps by systematically comparing auditory perception performance among three groups of children—early-implanted, late-implanted, and normal-hearing—using the R-CAP scale. This approach enables assessment across progressive auditory milestones and facilitates benchmarking cochlear implant outcomes against normative hearing standards. In doing so, the study seeks to provide context-specific insights that can guide optimal implantation timing, rehabilitation strategies, and parental counselling within the Indian paediatric population.

In the Indian context, gender differences may be further amplified by sociocultural factors such as unequal access to early intervention services, variations in parental involvement, and educational opportunities. Therefore, including gender as a variable of comparison in auditory perception research is essential to understand whether these disparities influence rehabilitation outcomes and to promote equitable intervention strategies for both boys and girls with cochlear implants (Selvavinayagam & Subramaniam (2022).

The main aim of the current study is to compare the auditory perceptual abilities in early and late implanted children compare to the age and gender matched normal children.

Objectives of the Study:

1. To compare auditory perception skills among early-implanted (1–3 years), late-implanted (3–5 years), and normal-hearing groups of children.
2. To determine whether early implantation provides a statistically significant advantage over late implantation in auditory perception outcomes.
3. To establish baseline R-CAP performance benchmarks for normal-hearing and cochlear-implanted children in the Indian context and to see if there are any gender differences.

Hypotheses (H_0):

1. There is no significant difference in auditory perception skills among early-implanted, late-implanted

, and normal-hearing children as measured by the Revised Categories of Auditory Perception (R-CAP) scale.
2. Children who undergo early cochlear implantation (before 3 years of age) do not differ significantly in auditory perception scores from those implanted after 3 years of age.
3. There is no significant difference in auditory perception outcomes between male and female cochlear-implanted children as measured by the R-CAP scale.

Participants

The present study included a total of 60 children aged 6 to 7 years, evenly divided into three groups of 20 participants each, with an equal number of males and females in each group. Group I (EI) comprised children who received early cochlear implants between 1 and 3 years of age; Group II (LI) consisted of children who underwent late cochlear implantation between 3 and 5 years, and Group III (NH) included age- and gender-matched children with normal hearing, serving as the control group. Participants were selected using purposive sampling to ensure balanced representation across groups. Additionally, all children in the implanted groups had completed a minimum of two years of auditory-verbal therapy post-implantation, ensuring a standardized level of rehabilitation exposure.

Inclusion criteria for the study required that children in Groups I and II be native Hindi speakers, aged 6–7 years, and diagnosed with profound prelingual deafness prior to implantation. Children in Group I had received early implantation (EI; below the age of 3 years), while those in Group II had late implantation (LI; 3-6 years). The control group consisted of children with normal hearing (NH; Group III) who were native Hindi speakers with normal hearing and no associated speech, language, or developmental abnormalities.

Auditory perception abilities were measured using the Revised Categories of Auditory Perception (R-CAP) Scale, which ranges from Level 0 (no awareness of environmental sounds) to Level 12 (complex open-set speech recognition). A cross-sectional, observational design was employed to examine language outcomes in children with unilateral cochlear implants. Initially, participants were screened using the WHO Disability Ten Test to exclude individuals with co-existing conditions such as speech and language disorders, hearing impairments, neurological issues, or psychological deficits, ensuring that all participants were free from confounding conditions except for hearing impairment and associated speech and language problems in the implanted groups.

Each child was evaluated using the receptive and expressive components of the R-CAP. The receptive component assessed the child's ability to understand spoken language through non-verbal responses, such as pointing or selecting items, while the expressive component evaluated verbal responses, including sentence repetition, object naming, and scene description. Assessments were conducted individually in quiet, distraction-free environments with age-appropriate instructions to maintain consistency and reliability. Responses were scored according to standardized criteria, allowing for the identification of subtle auditory or expressive language difficulties.

Data were recorded, converted into percentages where appropriate, and organized for statistical analysis using SPSS software. Both descriptive and inferential statistics were applied to examine differences across groups. The results focus on auditory comprehension outcomes among the three groups, comparing children with early and late cochlear implantation to age-matched normal-hearing controls.

Auditory Comprehension:

The table 1 summarizes the descriptive statistics of the three groups in terms of their auditory performance levels. Group 1 (n = 20) shows a mean score of 11.65 with a standard deviation of 0.49, indicating that most of the participants scored closely around 11 or 12, with a narrow spread of scores. Group 2 (n = 20) has a lower mean score of 10.45 and a relatively higher standard deviation of 0.51, suggesting that this group performed less well overall and also displayed greater variability in scores, ranging between 10 and 12. In contrast, Group 3 (n = 20) achieved a consistent mean score of 12.00 with no variation (SD = 0.00), meaning that all participants in this group scored the maximum level (12) on the auditory perceptual skills. This clearly indicates that Group 3 consistently outperformed the other groups, while Group 2 lagged behind, with Group 1 falling in between.

Table-I: Mean and Standard Deviation of Revised-CAP Scores Across Groups

Group	Sample Size (n)	Mean CAP Score	Standard Deviation (SD)
Group I	20	11.6	0.49
Group II	20	10.5	0.51
Group III	20	12.0	0.00

Test of Homogeneity of Variances (Levene's Test)

Levene's test showed a significant result ($F = 4.27$, $p < .018$), confirming that the group variances were not equal.

Table-II: Significance values of Revised-CAP Scores Across Groups

Test	Levene Statistic (F)	df1	df2	Sig. (p-value)
Levene's Test for CAP Scores	4.27	2	57	0.018*

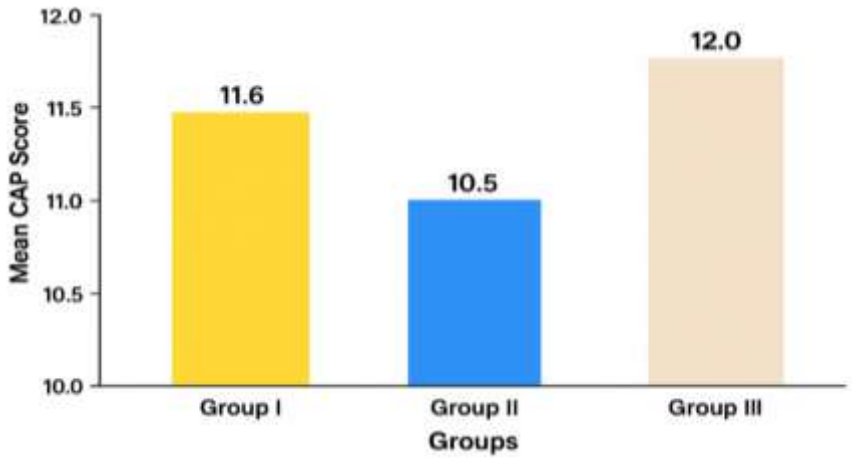

Figure I: Distribution of Mean Auditory Comprehension Levels Across EI, LI, and NH Children.

The bar graph illustrates the mean scores of three groups along with their standard deviations.

Gender-wise Comparison of Mean CAP Scores Across Groups:

The histogram illustrates (Fig. 2) the mean Categories of Auditory Performance (CAP) scores of male and female children across three study groups - The participants were divided into three groups based on their hearing status and age at implantation. Group I (Early Implanted – EI-CI) included children who received cochlear implants between 1 to 3 years of age. Group II (Late Implanted – LI-CI) comprised children who underwent cochlear implantation between 3 to 5 years of age. Group III (Normal Hearing – NH) consisted of age- and gender-matched children with normal hearing who served as the control group. The blue bars represent male participants, while the pink bars represent female participants.

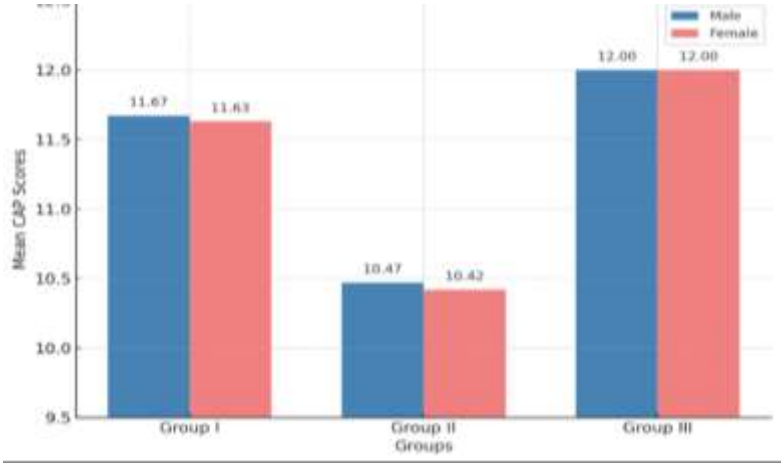

Figure II: Gender-wise mean CAP scores across groups

In Group I, both males (Mean = 11.67) and females (Mean = 11.63) demonstrated almost identical auditory performance, indicating that gender does not significantly influence CAP outcomes among early-implanted children. Similarly, in Group II, male (Mean = 10.47) and female (Mean = 10.42) participants showed comparable scores, suggesting minimal variation in auditory perception between genders even when implantation was performed later. In Group III, both males and females achieved the maximum possible CAP score (Mean = 12.00), reflecting the expected ceiling performance of children with normal hearing.

Overall, the histogram highlights that gender differences in CAP performance are negligible across all groups. Statistical analysis using independent sample t-tests further supports this observation, showing no significant difference ($p > 0.05$) between male and female participants within each group. This indicates that auditory performance following cochlear implantation is primarily influenced by factors such as age at implantation and auditory experience, rather than gender.

Table-III: Mean and Standard Deviation of Revised-CAP Scores Across Gender Groups

Group	Gender	N	Mean	SD	Std. Error of Mean
Group I (Early CI)	Male	10	11.67	0.49	0.15
	Female	10	11.63	0.51	0.16
Group II (Late CI)	Male	10	10.47	0.56	0.18
	Female	10	10.42	0.53	0.17
Group III (Normal Hearing)	Male	10	12.00	0.00	0.00

	Female	10	12.00	0.00	0.00

Table-IV: Significance values of Revised-CAP Scores, Gender Comparison within Groups)

Group	Levene's Test for Equality of Variances (F)	Sig.	T	Df	Sig.(2-tailed)	Mean Difference	Std. Error Difference
Group I	0.12	0.72	0.17	18	0.86	0.04	0.23
Group II	0.142	0.710	0.21	18	0.835	0.05	0.24
Group III	-	-	-	-	-	0.00	0.00

The gender-wise analysis of CAP scores shows that male and female children across all groups - early CI, late CI, and normal hearing-have nearly identical mean scores. Group I and II exhibited minimal differences between genders, while Group III reached the maximum score for both males and females. Independent t-tests confirmed no significant gender differences within any group ($p > 0.05$). Overall, the findings indicate that CAP outcomes are largely unaffected by gender, with auditory performance being more influenced by factors such as age at implantation and auditory experience.

Discussion

Auditory Perception Across Study Groups

The present study assessed auditory perception in children with early and late cochlear implantation, compared to age-matched normal-hearing peers, utilizing the Revised Categories of Auditory Perception (R-CAP) scale. The results revealed that children with normal hearing (Group III) achieved the maximum CAP score, early-implanted children (Group I) had a high mean score, and late-implanted children (Group II) exhibited a slightly lower mean score with greater variability. Since a statistically significant difference was observed among the three groups (early-implanted, late-implanted, and normal-hearing children), the null hypothesis (H_{01}) is rejected. This indicates that auditory perception skills differ significantly across the groups, with early implantation yielding better outcomes. These findings align with previous research indicating that earlier cochlear implantation is associated with better auditory outcomes. For instance, a systematic review (Wu, Sbeih, Anne, Cohen, Schwartz, Liu & Appachi, 2023), found that children implanted before 12 months of age demonstrated improved auditory outcomes compared to those implanted later. Similarly, Mancini & Giallini (2016), reported that early implantation in Hindi-speaking children led to better auditory comprehension skills.

Implications of Early vs. Late Cochlear Implantation

The observed differences between early- and late-implanted children underscore the importance of early intervention. Children implanted before the age of 3 years demonstrated superior auditory perceptual skills, emphasizing that timely access to cochlear implants and structured auditory-verbal therapy enhances auditory pathway development. These findings are supported by Robbins Koch, Osberger, Zimmerman-Phillips and Kishon-Rabin (2004), who concluded that children who undergo implantation at a younger age acquire auditory skills nearer to those of their peers with normal hearing. Furthermore, Abdelhamid & Fadel (2024), found that children who received cochlear implants before a real delay in spoken language development were more able to achieve age-appropriate spoken language. The results showed that early-implanted children performed better than late-implanted peers, and the difference was

statistically significant. Hence, the null hypothesis (H_{02}) is rejected, confirming that age at implantation significantly affects auditory perception outcomes.

Gender-wise Comparison of CAP Scores

The gender-wise analysis revealed negligible differences in CAP outcomes between male and female participants across all three groups. In early-implanted children (Group I), males had almost identical scores. Similarly, late-implanted children (Group II) showed minimal differences between genders). Both male and female participants in Group III achieved the maximum score. Independent sample t-tests confirmed that these differences were not statistically significant ($p > 0.05$). These results are consistent with studies suggesting that gender does not significantly influence auditory perception following cochlear implantation. No significant difference was found in CAP scores between male and female cochlear-implanted children. Therefore, the null hypothesis (H_{03}) is accepted, indicating that gender does not influence auditory perception performance. This is in agreement with the study by Sundaresan (2021) who found no significant gender differences in speech perception among children with cochlear implants. Additionally, Prakash et. al (2023) reported that gender identification of voices did not differ significantly between male and female cochlear implant users.

Summary:

The present study examined auditory perception outcomes in children with early and late cochlear implantation compared to age-matched normal-hearing peers using the Revised Categories of Auditory Perception (R-CAP) scale. Results indicated that early-implanted children demonstrated superior auditory performance compared to late-implanted peers, while normal-hearing children consistently achieved maximum CAP scores. Gender-wise analysis revealed negligible differences, suggesting that auditory outcomes are primarily influenced by age at implantation and structured rehabilitation rather than gender. These findings provide context-specific insights into auditory development among Hindi-speaking children in India.

Conclusion:

Early cochlear implantation significantly enhances auditory perception outcomes in children with profound prelingual hearing loss, supporting the importance of timely intervention. Late implantation, while beneficial, results in comparatively lower auditory performance and greater variability. Gender does not appear to be a determining factor in CAP outcomes, highlighting that structured rehabilitation and auditory exposure are the key contributors to auditory development. Overall, the study reinforces the critical role of early diagnosis, intervention, and consistent post-implant therapy in optimizing auditory skills.

Limitations

This study has several limitations. First, the cross-sectional design limits the ability to establish causality between implantation age and auditory outcomes. Second, the sample size of 60 participants, though balanced, may not fully represent the diversity of the pediatric population across India. Third, the study focused only on unilateral cochlear implantation and Hindi-speaking children, which may limit generalizability to other linguistic and cultural populations. Finally, socio-environmental variables such as socioeconomic status, home auditory exposure and parental involvement were not quantified, which

could influence auditory development.

Clinical Implications

The findings have significant clinical implications for pediatric cochlear implantation programs. They underscore the necessity of early identification of hearing loss and prompt surgical intervention, ideally before three years of age, to maximize auditory perception outcomes. Structured auditory-verbal therapy post-implantation is essential to achieve performance levels comparable to normal-hearing peers. Additionally, gender should not influence access to cochlear implantation or rehabilitation services, promoting equitable intervention practices across the pediatric population.

Future Directions

Future research should adopt longitudinal designs to monitor auditory perception development over time and assess the long-term impact of early versus late implantation. Studies with larger and more diverse samples, including children from different linguistic and cultural backgrounds, are needed to enhance generalizability. Incorporating measures of SES, environmental factors, parental involvement, and quality of auditory-verbal therapy can provide a more comprehensive understanding of factors influencing auditory outcomes. Finally, exploring bilateral implantation and its effects on complex auditory tasks could offer further insights into optimizing cochlear implant rehabilitation strategies.

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