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Rihana Raichand
M.Sc. Audiology (Student), Department of Speech and Hearing, Sri Aurobindo University Indore, Madhya Pradesh, India

Tejesvani
M.Sc. Audiology (Student), Department of Speech and Hearing, Sri Aurobindo University Indore, Madhya Pradesh, India

Srabanti Khemka
Associate Professor, Department of Speech and Hearing, Sri Aurobindo University Indore, Madhya Pradesh, India

Himadri Bhagat
Audiologist and Speech Language Pathologist, NRHM-RBSK Programme, SGPGI Lucknow Uttar Pradesh, India

Correspondence
Rihana Raichand
M.Sc. Audiology (Student), Department of Speech and Hearing, Sri Aurobindo University Indore, Madhya Pradesh, India

Evaluating word identification in noise and speech - language outcomes in school aged children using unilateral cochlear implant vs bimodal auditory stimulation

Rihana Raichand, Tejesvani, Srabanti Khemka and Himadri Bhagat

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Abstract

Background: Word identification in noise, a core aspect of speech perception, requires matching spoken sounds to mental lexical representations. Children with hearing impairments often face challenges in noisy environments due to reduced spectral resolution and limited auditory input. Bimodal auditory stimulation can enhance perception by providing acoustic cues and supporting binaural processing. Understanding how different auditory modes influence word recognition in noise and associated speech - language outcomes is vital for guiding effective interventions. The study evaluated word identification in noise and associated speech–language outcomes in two school aged children using unilateral cochlear implant versus bimodal auditory stimulation.

Method: A comparative case study design was employed with two pediatric CI recipients: S1, a 7-year-old using bimodal stimulation, and S2, an 8-year-old with unilateral CI. Word identification in noise was assessed using the Hindi Word Identification in Noise Test for Children (HWINT-C) at +5 dB and +7 dB SNR with bisyllabic and monosyllabic words. Speech and language abilities, were evaluated using the Integrated Scales of Development (ISD) and the Speech Intelligibility Rating (SIR) scale.

Results: S1 outperformed S2 across all word types and SNR in HWINT-C. ISD scores indicated higher developmental age-equivalents for S1 in audition, receptive and expressive language, speech, and cognition, while social development was comparable. SIR reflected more intelligible speech for S1than S2.

Conclusion: Bimodal stimulation improves word recognition in noise, reduces cognitive load, and enhances phonological processing, supporting better language and cognitive outcomes, emphasizing the need to optimize auditory input for children with cochlear implants.

Keywords:

Introduction

Speech perception is a complex cognitive-linguistic skill that involves the transformation of acoustic sound waves into linguistic units-phonemes, syllables, and words-which are subsequently integrated into higher-order language structures (Holt & Lotto, 2008). A particularly important but challenging dimension of speech perception is word identification in noise. It refers to the ability to match the auditory form of a spoken word to its stored lexical representation in long-term memory (Rönnberg *et al*., 2010; Rvachew & Lapré, 2018) [13, 14]. Successful word identification forms the foundation for spoken language development, learning, and effective communication (Clark, 2009; MacWhinney, 2005).

Children are frequently exposed to noisy and reverberant environments such as classrooms and playgrounds, where background noise negatively affects speech perception. Research shows that noise reduces speech intelligibility and increases listening effort, leading to greater cognitive load and fatigue (Buss, 2014; Calandruccio, 2010). Compared with adults, children experience greater difficulty recognizing speech in noisy environments, primarily due to immature central auditory processing rather than peripheral hearing limitations (Crandell, 1993; Baker *et al*., 2014) [5]. They also struggle to segregate target speech from competing noise and to selectively attend to relevant auditory information (Hall *et al*., 2002;

Wightman, 2005) [7]. Both typically developing children and those with hearing loss face challenges in academic performance and incidental learning under noisy conditions (Kirk, 2005; Litovsky, 2012). The American Speech-Language-Hearing Association (1995) and American National Standards Institute (2010) recommend classroom signal-to-noise ratios of at least +15 dB and ambient noise levels below 35 dBA to support optimal learning. Nevertheless, many classrooms do not meet these acoustic standards, disadvantaging students, particularly those with hearing impairment.

Speech perception underpins children's language acquisition, communication competence, and broader cognitive development. It encompasses auditory processing, phonemic awareness, lexical access, and the interpretation of spoken sound patterns, all of which support the development of effective communication skills (McRoberts, 2008). Precise speech perception is therefore a prerequisite for spoken language growth. Children with hearing impairment often receive degraded or inconsistent auditory input, which can delay their linguistic development. Evidence indicates that children with hearing impairment who exhibit stronger speech perception abilities demonstrate more advanced spoken language outcomes on standardized measures (Sedey *et al*., 2003; Jerger *et al*., 2007).

Children who use cochlear implants (CIs) show substantial variability in developmental outcomes. Many demonstrate significant improvements in speech perception, listening skills, expressive language, speech intelligibility, and overall communication, particularly with early implantation and consistent intervention (Geers, 2002; Nicholas & Geers, 2007). However, although CIs provide auditory access through direct stimulation of the auditory nerve, limited spectral resolution compared to typical hearing makes speech-in-noise perception persistently challenging (Fu & Nogaki, 2005). Research indicates less robust phonemic category development (Geers & Hayes, 2011; Johnson & Goswami, 2010), [9] alongside broader language vulnerabilities, including grammatical difficulties (Niparko *et al*., 2010) and slower vocabulary growth (Brinton & Goswami, 2009). The type of auditory input plays a critical role in shaping developmental outcomes for children with hearing loss. Unilateral cochlear implantation delivers electrical stimulation to a single ear, limiting access to binaural advantages such as sound localization, binaural squelch, and improved speech perception in noisy environments (Litovsky *et al*., 2006; Gordon *et al*., 2011). In contrast, bimodal stimulation—using a cochlear implant in one ear and a contralateral hearing aid—provides complementary electrical and acoustic signals. This arrangement preserves low-frequency acoustic information, which contributes to improved pitch perception, prosodic processing, and speech understanding in adverse listening conditions (Ching *et al*., 2007) [3].

Despite advances in cochlear implantation and early intervention, children with hearing loss continue to experience difficulties in speech perception, particularly in noisy environments, which can limit language development, communication, and academic outcomes. Variability in outcomes is influenced by factors such as type of auditory stimulation (unilateral vs. bimodal), residual hearing, and classroom acoustics. Given the critical role of accurate speech perception in language acquisition and learning, there is a need to examine how different modes of auditory input impact speech perception, word recognition in noise, and language development. The present study aims to investigate the relationship between word identification in noise and speech and language outcomes in children.

Methods

The present study followed a comparative case study design to assess and compare word identification in noise and associated speech–language outcomes in paediatric cochlear implant users with bimodal and unilateral stimulation.

Participant

Two pediatric cochlear implant recipients, S1 and S2, were included in this study. S1, a 7-year-old girl with 2.9 years of implant age, presented with severe-to-profound hearing loss in the right ear and moderately-severe to severe loss in the left, using bimodal amplification with a right-ear cochlear implant (Nucleus-8 processor using ACE coding strategy) and a left-ear programmable hearing aid (GN Resound Nexia-8). Radiological evaluation revealed normal morphology of the bony cochlea with no evidence of structural abnormality. S2, an 8-year-old girl with of implant age of 3 years, had bilateral severe-to-profound sensorineural hearing loss and received unilateral stimulation using cochlear implant (CP802 processor using the ACE coding strategy) in the right-ear. Radiological imaging indicated mild partial hypoplasia of the cochlear apex bilaterally with a normal basal turn, consistent with Type II incomplete partition.

Procedure

A detailed case history was taken to document demographic information (age and gender) medical and developmental history. Word identification in noise was assessed using the Hindi Word Identification in Noise Test for Children (HWINT-C) (Bhagat and Khemka, 2026) [2]. The test consists of 2 lists (list A: A1, A2 and list B: B1, B2) comprising of 20 bisyllabic and 20 monosyllabic words presented at +5 and +7dB SNR. Testing was carried out in a well-lighted audiometric room with permissible noise limits according to ANSI specification [ANSI/ASA S3.1-1999 (R2018)]. Participants were comfortably seated on a chair, with calibrated loudspeakers placed at 1-meter distance and 0- degree azimuth. HWINT-C was presented diotically through calibrated loudspeakers at presentation level of 65dBSPL. The pattern of presentation was ordered as list A1 (bisyllabic words at +5dBSNR),list B1 (monosyllabic words at +5dBSNR) followed by list A2 (bisyllabic words at +7dBSNR) and List B2 (monosyllabic words at +7dBSNR). Correct score was considered only for whole-word repetition.

Speech, language abilities were evaluated using Integrated Scales of Development (ISD) that assessed the domains of audition, receptive language, expressive language, speech, cognition, pragmatics and the Speech Intelligibility Rating (SIR) Scale developed (AYJNISHD, Mumbai).

Results

Written consent was taken from the primary caregivers for participation in the study after explaining the procedure. Developmental history obtained from parents revealed age-appropriate motor, social, and behavioural milestones in both participants. Psychological evaluation reports indicated average intellectual functioning whereas Radiological

findings demonstrated cochlear malformations in both participants.
Results obtained from Hindi Word Identification in Noise Test (HWINT-C) are presented in Table 1.

Table 1: Results of HWINT-C for S1 and S2

Test List	Word Type	SNR Level	S1	S2
A1	Bisyllabic	+5dB	40%	10%
A2	Bisyllabic	+7dB	50%	20%
B1	Monosyllabic	+5dB	35%	5%
B2	Monosyllabic	+7dB	55%	15%

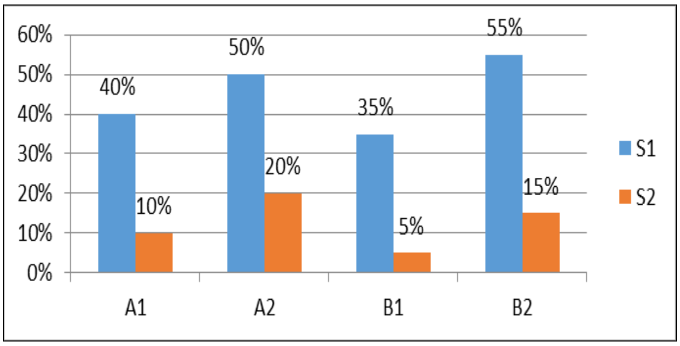

Fig 1: Percentage scores of HWINT-C lists

The results presents speech perception performance of the two participants (S1 and S2) across different word types and signal-to-noise ratio (SNR) levels. Participant S1 consistently outperformed S2 across all conditions. For bisyllabic words, S1 achieved 40% and 50% correct at +5 dB and +7 dB SNR, respectively, whereas S2 scored substantially lower, with 10% and 20% correct. For monosyllabic words, S1 scored 35% and 55% at +5 dB and +7 dB SNR, while S2 achieved only 5% and 15% revealing a widened difference in monosyllabic words. Overall, both participants showed improved performance at the higher SNR (+7 dB), with S1 demonstrating greater benefit and higher baseline accuracy than S2.
Result of Integrated Scale of Developmental (ISD) for S1 and S2 is represented in Table 2.

Table 2: Result of ISD for S1 and S2

Subscale	S1	S2
Audition	31-36 months	25-30 months
Receptive language	37-42 months	31-36 months
Expressive language	31-36 months	25-30 months
Speech	25-30 months	19-24 months
Cognition	43-48 months	25-30 months
Social	37-42 months	37-42 months

The results summarizes developmental age-equivalent scores across various subscales of ISD for participants S1 and S2. S1 demonstrated higher performance than S2 in most domains, particularly in cognition (43–48 months vs. 25–30 months) and receptive language (37–42 months vs. 31–36 months). In audition and expressive language, S1 scored 31–36 months, compared to 25–30 months for S2. For speech, S1 achieved 25–30 months, while S2 scored 19–24 months. Both participants exhibited similar social development (37–42 months). Overall, these results indicate that S1 had more advanced auditory, language, and cognitive skills, whereas social abilities were comparable between the two children.

The Speech Intelligibility Rating (SIR) scores for the participants obtained showed that Participant S1 received a Grade 2 rating, indicating speech that is generally understandable with little effort. Participant S2 was rated Grade 3, reflecting speech that is understandable but requires concentration and effort from the listener.

Discussion

The present comparative case study examined word identification in noise and its relationship with speech–language outcomes in two pediatric cochlear implant users with different modes of auditory stimulation. In the present study the participant with bimodal amplification consistently achieved higher scores across both bisyllabic and monosyllabic words at +5 dB and +7 dB SNR that indicated an advantage in adverse listening conditions. However, improvement at +7 dB SNR for both participants supports the fact that increased audibility enhances speech recognition performance in children with hearing impairment (Buss, 2014). Participant with unilateral cochlear implantation scored poorly particularly for monosyllabic words, suggesting more challenges to limited contextual and phonological cues. Monosyllabic words provide fewer acoustic-phonetic redundancies, making them more challenging in noise, especially for unilateral cochlear implant recipients exhibiting a reduced spectral resolution (Fu & Nogaki, 2005). However, better performance for bisyllabic words as viewed in the present study may be attributed to greater acoustic redundancy and longer duration, which provides additional phonetic and temporal cues for identification (Nittrouer & Boothroyd, 1990).
The better performance of bimodal stimulation in the present study may be attributed. to binaural advantages such as improved sound localization and binaural squelch, which enhance speech perception in noise (Litovsky *et al*., 2006; Gordon *et al*., 2011). Additionally, bimodal users retain access to low-frequency acoustic information through the hearing aid, contributing to better pitch perception and prosodic cues (Ching *et al*., 2007) [3]. These low-frequency cues are particularly important for segregating speech from background noise and for lexical access. In contrast, the unilateral cochlear implant user relied solely on electrical input that provides limited spectral detail and reduced temporal fine-structure information, making speech discrimination in noise more difficult. Previous studies have similarly reported improved speech perception scores when a hearing aid is used along with a cochlear implant (Nilakantan *et al*., 2018; Das *et al*., 2018).
The present study highlights a strong association between speech perception abilities and speech and language outcomes. Higher receptive language, expressive language, and cognitive scores of the bimodal user in the present study supports the established view that more auditory input facilitates improved speech perception that enables more efficient linguistic encoding and phonological representation (Sedey *et al*., 2003; Jerger *et al*., 2007). Additionally, limited spectral resolution in unilateral cochlear implant recipient can affect the precision of phonemic category formation, which is critical for vocabulary growth and morphological development leading to expressive language delays. (Geers & Hayes, 2011; Johnson & Goswami, 2010; Aslan *et al*., 2023) [9]. Furthermore, cognitive performance differences observed between the participants may be linked to auditory access. Stronger auditory perception has been

associated with reduced cognitive load in children with cochlear implants (Kronenberger *et al*., 2013).

Conclusion

The current case study findings explain the relationship between word identification and speech and language outcomes in children using unilateral cochlear implant and bimodal auditory stimulation. Efficient speech perception reduces cognitive load, supports accurate phonological encoding, and facilitates language learning. Conversely, persistent difficulty in speech-in-noise conditions may constrain linguistic and cognitive development, underscoring the importance of optimizing auditory input and listening environments for children with cochlear implants.

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