EVALUATING THE LEVEL DEPENDENT SPEECH IDENTIFICATION PERFORMANCE IN PAEDIATRIC COCHLEAR IMPLANT RECIPIENTS

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CERTIFICATE

This is to certify that this dissertation entitled **"Evaluating the level dependent speech identification performance in paediatric cochlear implant recipients"** is a bonafide work submitted as part of fulfilment of the degree of Master of Science **Audiology** of the student with Registration Number **P01II24S023042**. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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CERTIFICATE

This is to certify that this dissertation entitled " **Evaluating the level dependent speech identification performance in paediatric cochlear implant recipients** " has been prepared under my supervision and guidance. It is also being certified that this dissertation has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled **"Evaluating the relationship between speech perception tests and functional outcome measures in pediatric cochlear implant recipients"** is the result of my own study under the guidance of Dr. Jawahar Antony P., Assistant Professor of Audiology, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other university for the award of any other Diploma or Degree.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Speech perception assessment in paediatric cochlear implant (CI) users is conventionally performed at conversational intensity levels under controlled listening conditions. However, listening in everyday environments occurs under variable-intensity conditions, and conventional speech perception measures may not adequately reflect real-world functional listening abilities. The present study investigated the relationship between speech perception performance across different presentation intensity levels and functional listening outcomes in paediatric cochlear implant users. A cross-sectional within-subject design was employed. Twenty-two unilateral paediatric cochlear implant users aged 5-8 years (M=6.28, SD=0.65) participated in the study. Open-set Kannada bi-syllabic word identification testing was carried out in a sound-field at 30 dB HL, 45 dB HL, and 60 dB HL presentation levels. Functional listening ability was assessed using the Functional Listening Index–Paediatric (FLI-P). Parametric statistical analyses, including one-way repeated-measures analysis of variance, Bonferroni post hoc comparisons, and Pearson's correlations, were performed. Speech perception performance improved markedly with increasing presentation intensity. The maximum speech perception performance was observed at 60 dB HL, while the minimum was at 30 dB HL. There were significant differences among the three presentation levels ($p < .001$). Speech perception scores showed significant positive correlations with FLI-P test performance across all intensity levels. The highest correlation co-efficient were observed at 45 dB HL ($r = .845$, $p < .001$) followed by at 60 dB HL ($r = .735$, $p < .001$), and 30 dB HL ($r = .51$, $p = .016$). Thus, the speech perception testing at conversational level appears to be the most clinically meaningful and sufficient measure of auditory function to represent the real life listening abilities in paediatric cochlear implant recipients.

Keywords: cochlear implants, speech perception, functional listening, paediatric audiology, FLI-P, presentation intensity, auditory outcomes

CHAPTER I

INTRODUCTION

Speech perception is the major aspect of auditory communication and contributes to the development of speech, language, cognition, and social interaction during early childhood (Stelmachowicz et al., 2004; Tyler et al., 2000). With continuous exposure to speech, children learn to utilise the ability to extract and integrate spectral, temporal, and intensity-related acoustic cues that support phonological development, lexical improvement, and advance linguistic processing (Peng et al., 2008; Smiljanic & Gilbert, 2017). Access to auditory input during the developmental period is therefore essential for the establishment of efficient spoken language systems.

Children with profound sensorineural hearing loss often have difficulty accessing auditory information, which negatively influences the acquisition of speech perception and language abilities (Moeller et al., 2007; Nittrouer & Burton, 2005). Cochlear implants (CIs) restore auditory information processing by providing direct electrical stimulation to the auditory nerve, thereby supporting the perception of speech, language, and environmental sounds necessary for communication (Sharma et al., 2020). Although improvements in listening performance have been reported following cochlear implantation, clinical outcomes in pediatric CI users remain highly variable. They are influenced by multiple factors, including age at implantation, duration of auditory deprivation, device programming, consistency of rehabilitation, and environmental auditory exposure (Davidson et al., 2011; Tyler et al., 2000).

Traditionally, clinical assessment of cochlear implant outcomes relies predominantly on speech perception testing conducted under controlled listening conditions at conversational presentation levels, typically 40–45 dB HL (Elsayed, 2022). While these assessments provide valuable information on listening performance under ideal acoustic conditions, they may not sufficiently reflect auditory functioning in real-world communication environments. Every day, listening occurs across a broad range of variable-intensity conditions, including low-intensity conversational exchanges, moderate conversational speech, and high-intensity listening in adverse listening environments such as classrooms and playgrounds (Peng et al., 2008).

Exposure to speech sounds across multiple intensity levels is vital for listening, learning, and language development (Wolfe et al., 2015). Soft speech signals, such as whispered speech or distant conversational speech, offer opportunities for incidental learning in natural communication environments. Children acquire vocabulary and language through passive exposure to surrounding communication rather than through direct instruction in a controlled setup (Tyler et al., 2000). Additionally, the ability to perceive low-intensity speech signals is important for learning and supports natural language acquisition during early childhood (Moeller et al., 2007). Assessment of speech perception across presentation levels provides valuable information on whether children using cochlear implants have adequate listening availability to support incidental learning and, in turn, lead to effective communication. Children with hearing loss showed reduced ability to detect low-level speech signals due to decreased thresholds, sensory loss, and reduced processing ability; as a result, these children may miss important linguistic cues in everyday listening environments (Wolfe et al., 2015).

In addition, high-level speech may also affect listening challenges for cochlear implant users. Studies have reported that excessively loud signals may lead to distortion or discomfort due to the limited electrical dynamic range of cochlear implant stimulation (Khater et al., 2015). This may affect speech clarity and listening comfort when speech signals are presented at higher intensity levels. Consequently, both low-level and high-level speech perception may affect the overall listening experience of children using cochlear implants (Wolfe et al., 2015).

The ability to detect soft speech or distant conversational speech allows children to gather vital linguistic information from environmental communication contexts. Such listening opportunities are important for vocabulary development, grammatical learning, and conversational understanding of communication in different situations (Moeller et al., 2007). Higher presentation levels may become important in noisy environments or in varying communication settings. In these situations, adequate audibility of speech signals enables children to distinguish speech from challenging environmental noise.

Despite the importance of assessing speech across the intensity range, cochlear implant programming procedures have conventionally prioritised conversational-level listening conditions. Cochlear implant mapping typically focuses on optimising speech perception at conversational speech levels, which might compromise audibility at both low and high intensities (Elsayed, 2022). Therefore, children showed adequate speech perception during clinical assessment conducted at conversational levels, while still experiencing listening difficulties in everyday communication (Walker et al., 2019).

Conventional audiological assessments conducted in clinical settings may underestimate the listening challenges experienced by children with cochlear implants. Thus, these speech perception tests conducted in quiet settings may not accurately reflect the real-world communication situations encountered by children during daily activities (Walker et al., 2019). Although children who use cochlear implants may demonstrate good speech perception during clinical evaluations, their performance may decrease significantly in more complex listening environments (Walker et al., 2019).

Because of these limitations, researchers have emphasised the need to evaluate not only speech perception at a conventional level but also at high and low levels of assessment, and to assess subjective functional listening abilities in children with hearing loss (Davis et al., 2022). Functional listening is the ability to use listening information effectively in everyday communication, such as following commands, responding to conversational talk, and engaging in social communication. Unlike traditional speech perception questionnaires, which assess listening recognition alone under controlled conditions, functional listening measures provide information on

Furthermore, speech perception abilities across different intensity levels may influence these functional listening outcomes. Children who can perceive speech signals at low intensities may benefit from increased opportunities for incidental learning. In contrast, those who demonstrate improved perception at higher intensities may perform better in noisy environments such as classrooms or playgrounds. Investigating the relationship between speech perception scores across different presentation levels and functional listening outcomes may therefore provide valuable insight into the real-world auditory performance of children using cochlear implants.

Justification for the study

Speech perception testing is routinely done in an audiological setup. It will be used for assessment and to measure the outcome of rehabilitation in a conventional way. Conventional audiological speech perception assessments conducted at 45 dB HL in clinical settings may underestimate the listening challenges experienced by children with cochlear implants, and outcomes are often assessed only in terms of speech perception at conversational levels, rather than in real listening situations and are limited by not assessing functional listening skills. Most audiological tests focus on assessing at a normal conversational level, but children still have difficulty in real-world settings outside quiet test rooms (Elsayed, 2022). Even if a child performs well on audiological tests that use normal conversational levels, it doesn't mean they'll be able to hear well in the real world. Similarly, one needs to hear well in noisy places like classrooms and playgrounds, as well as in soft-spoken environments.

Exposure to speech sounds across multiple intensity levels is vital for listening, learning, and language development (Wolfe et al., 2015). Soft speech signals, such as whispered speech or distant conversational speech, offer opportunities for incidental learning in natural communication environments. Children acquire vocabulary and language through passive exposure to surrounding communication rather than through direct instruction in a controlled setup (Tyler et al., 2000). The importance of assessing loud speech in children exposed to loud sounds cannot be overstated, as it can cause problems such as speech distortion or discomfort when hearing. This can make it harder to understand what's being said and may make a child less likely to participate in important school and social environments (Meijer et al., 2025; Svirsky & Meyer, 1999).

Further, loud sounds can cause problems, such as distorting or discomforting speech, making it harder to understand what's being said, and potentially leading a child to avoid important play and social environments (Meijer et al., 2025). Despite the increasing use of cochlear implants in paediatric populations, relatively little research has examined the relationship between level-dependent speech-perception performance and its association with functional listening outcomes. Most clinical assessments continue to focus primarily on speech perception performance measured at conversational intensity levels (Elsayed, 2022). The relationship between speech perception across intensity levels and functional listening remains insufficiently explored.

Aim of the study

The present study aimed to evaluate speech perception across various presentation levels in children using cochlear implants and to compare it with the FLI-P.

Objectives

1. To compare speech perception performance across three different input intensity levels in children using cochlear implants
2. To compare speech perception scores of these three intensity levels with the FLI-P

Hypotheses of the Study

The null hypotheses for the objectives are given below:

Objective 1(H_0): There is no significant difference between the speech perception performance across three different input intensity levels**.**

Objective 2(H_0): There is no significant correlation between speech perception scores of these three intensity levels with the FLI-P**.**

REVIEW OF LITERATURE

2.1 Auditory Development and Speech Perception in Children

Hearing through the auditory mode plays an essential role in the acquisition of speech, language, and communication abilities during the early years of childhood. In typically developing children, auditory development occurs progressively through continuous exposure to auditory stimuli, facilitating the maturation of auditory neural pathways and supporting the perception of speech signals (Boothroyd, 1997). The developing auditory system tunes to extract relevant acoustic cues such as frequency, intensity, and temporal patterns from speech signals, enabling children to detect, discriminate, and identify spoken language. Continuous acoustic exposure during early childhood, therefore, supports the development of phonological awareness and linguistic competence, which are essential for communication and educational development (Moeller et al., 2007).

The maturation of auditory sensory pathways is strongly influenced by early childhood sensory experience. Neurophysiological investigations have shown that auditory deprivation during early childhood can alter cortical organisation and, in turn, reduce the efficiency of neural processing of speech signals (Cardon et al., 2012). Children with hearing impairment often receive reduced auditory input, which disrupts the normal maturation of the auditory cortex and negatively affects speech perception. However, early intervention and access to amplified or electrically stimulated sound via a cochlear implant can promote neural plasticity and facilitate the reorganisation of the auditory cortical neural network responsible for speech processing and perception (Cardon et al., 2012).

Speech perception involves the ability to analyse complex acoustic signals and to extract meaningful linguistic information from the auditory input. This process requires access to speech signals across a broad range of sound frequencies, intensities and different acoustic environments. In everyday communication, speech may vary in intensity, from soft, whispered speech to louder speech in noisy situations (Smiljanic & Gilbert, 2017). Exposure to this dynamic range of acoustic information allows children to develop robust auditory processing skills and adapt to different listening environmental conditions. Consequently, the broad richness of auditory information across multiple intensity levels, as well as the broad range of the speech spectrum, is considered essential for supporting normal speech perception development in children (Peng et al., 2008).

Children with hearing impairment very often experience limitations in accessing these acoustic differences across frequencies and different auditory input levels, particularly when speech signal audibility is reduced. Reduced access to speech signals can significantly affect the development of phonological representations in the auditory cortex, vocabulary acquisition, and syntactic understanding (Tomblin et al., 2015). Literature report emphasised that adequate audibility across speech frequencies and intensity levels is critical for supporting language development in children with hearing loss and limited access to speech information may therefore delay speech perception development and communication abilities (Stelmachowicz et al., 2004).

2.2 Impact of Hearing Loss on Speech and Language Development

Speech and language development in children is closely linked to the quality and quantity of auditory information received during early infancy and childhood. Children with hearing impairment due to sensory and neural deprivation have difficulty accessing speech signals, which delays both receptive and expressive language development (Moeller et al., 2007). These delays occur because auditory information serves as the primary source of linguistic input required for the acquisition of phonological structure and vocabulary development (Nittrouer & Burton, 2005).

Incidental learning of young children is a key mechanism through which children acquire speech and language. Basically, children's vocabulary development occurs through passive exposure to environmental speech and conversations rather than through direct instruction, and access to low-level or distant speech signals therefore plays an important role in the acquisition of natural speech and language (Moeller et al., 2007). When children are unable to perceive soft speech signals, they may miss important linguistic cues necessary for vocabulary development and conversational understanding, which is more important for speech and language acquisition (Moeller et al., 2007).

Studies done by McCreery et al in 2012 has shown that children with hearing loss often require higher signal-to-noise ratios to perceive speech accurately than children with normal hearing (McCreery et al., 2012). And same study reported that children with hearing impairment require greater auditory effort to recognise speech sounds, particularly in noisy environments. Thus, these limitations can affect listening performance in classroom settings, where speech signals are often masked by environmental noise and reverberation (McCreery et al., 2012).

Additionally, the perception of speech signals at different intensity levels is essential for overall effective communication. These soft speech signals allow children to access incidental learning opportunities. In contrast, conversational speech levels support everyday communication for better receptive and expressive language skills, and louder speech signals that occur in noisy environments where children must distinguish speech from competing sounds. Access to speech across these varying intensity levels plays an important role in supporting language acquisition and communication development in children with hearing impairment (Peng et al., 2008).

2.3 Cochlear Implants and Auditory Rehabilitation in Children

Cochlear implants have become one of the most effective rehabilitation options for children with severe to profound sensorineural hearing loss who receive limited benefit from conventional amplification devices. A cochlear implant bypasses damaged hair cells in the cochlea. It directly stimulates the auditory nerve with electrical signals, enabling individuals with profound hearing loss to perceive sounds required for speech and environmental sound perception (Sharma et al., 2020). The introduction of cochlear implants has significantly improved auditory outcomes for children with severe hearing impairment by providing access to speech signals that would otherwise remain inaudible (Sharma et al., 2020).

Paediatric cochlear implant recipients often show substantial improvement in speech perception, language development, and communication abilities after implantation. Research examining speech perception, language development, and speech production found that children who received cochlear implants showed greater improvement in speech recognition and production than those using hearing aids alone (Waltzman & Shapiro, 1999). Similarly, Svirsky and Meyer (1999) reported that cochlear implant users showed better speech perception outcomes than hearing aid users with similar degrees of hearing loss.

Prospective studies done by Tyler et al in 2000 indicate that speech perception abilities in children with cochlear implants continue to improve with increasing years of auditory experience and rehabilitation. A longitudinal examination of speech perception outcomes in prelingually deaf children using cochlear implants for years reported progressive improvements in speech recognition scores. Thus, these improvements are attributed to neural plasticity and the gradual development of auditory processing abilities over time following electrical stimulation of the auditory nerve via cochlear implants (Tyler et al., 2000).

Moreover, speech perception outcomes among cochlear implant users vary depending on various factors. Several factors also influence auditory performance, including age at implantation, duration of deafness, rehabilitation services, and consistency of device use (Davidson et al., 2011). Children who received cochlear implants earlier in life often show better speech-perception outcomes because early auditory stimulation supports neural development during critical periods of auditory maturation (Tyler et al., 2000).

Consistent use of a cochlear implant device also plays a vital role in speech perception outcomes. This was studied by Easwar et al. (2018), who investigated daily cochlear implant device usage patterns among paediatric cochlear implant recipients and reported that children who used their devices consistently demonstrated significant improvement in speech perception performance compared to children with irregular device use. These findings show the importance of continuous auditory stimulation using a cochlear implant in supporting the development of speech recognition abilities in children (Easwar et al., 2018).

2.4 Development of Speech Perception in Paediatric Cochlear Implant Users

Speech perception development in children with cochlear implants differs from that of normally hearing children because the auditory signals delivered by cochlear implants are electrically encoded rather than acoustically transmitted through normal cochlear mechanisms (Sharma et al., 2020). Children must therefore learn to convert these electrical stimulation patterns into linguistic meaning.

Young and Kirk (2002) reported that paediatric cochlear implant users gradually develop the phonetic representations of speech through auditory exposure with the implant. Over time, children learn to analyse the spectral and temporal cues provided by electrical stimulation and to use them to recognise speech sounds. Thus, this learning process requires consistent auditory exposure and support for rehabilitation (Young & Kirk, 2002).

Speech perception abilities in cochlear implant users typically improve over time with increased auditory exposure. Longitudinal studies have shown that paediatric cochlear implant users demonstrate progressive improvements in speech recognition performance over several years of implant use (Tyler et al., 2000). These improvements reflect the auditory system's adaptive plasticity and the role of auditory rehabilitation in improving speech processing abilities in a child using a cochlear implant.

Various factors also influence speech perception outcomes. Lexical knowledge, for example, plays an important role in spoken word recognition among paediatric cochlear implant users. Studies related to that demonstrated that children with larger vocabularies are better able to use contextual cues to identify spoken words, thereby improving speech recognition accuracy (Young & Kirk, 2002).

Peng et al. (2008) examined the perception and production of speech intonation among paediatric cochlear implant users. They reported that although children with cochlear implants can perceive some prosodic cues, their performance is often lower than that of normal-hearing children. These limitations may affect their ability to interpret the emotional and pragmatic aspects of speech communication (Peng et al., 2008).

2.5 Assessment of Speech Perception and Functional Listening in Children with Cochlear Implants

Clinically, cochlear implant outcomes are traditionally evaluated using speech perception tests, administered in a controlled acoustic environment within an audiometric setup. These tests typically involve word recognition or sentence identification tasks at conversational levels of intensity, enabling clinicians to assess a child's ability to recognise speech signals under controlled conditions (Elsayed, 2022). Although these traditional assessment procedures provide valuable information about speech recognition alone, they may not fully reflect the real-world listening challenges faced by children using cochlear implants (Walker et al., 2019).

In day-to-day communication environments, children encounter speech signals that vary in intensity and are influenced by background noise. Classrooms, playgrounds, and social gatherings often contain competing speech signals, which make speech perception even more difficult in the auditory modality, especially with cochlear implants (Walker et al., 2019). Studies that have been evaluated have shown that children with cochlear implants frequently demonstrate good speech perception in quiet controlled environments. However, children experience significant difficulty understanding speech in real-world communication situations (Walker et al., 2019). This discrepancy highlights the limitations of relying solely on clinical speech-perception tests to evaluate auditory performance.

Because of current limitations in speech perception testing, studies have emphasised the importance of evaluating the child with a cochlear implant at different intensities, which reflects the child’s ability to use auditory information effectively in everyday environments. Functional listening assessments also provide insight into how well a child can access and interpret speech signals during natural communication situations, rather than only in controlled testing conditions in clinics.

The Functional Listening Index – Paediatric (FLI-P) was developed as an ordered clinical material to assess the development of listening skills in a child with hearing loss in everyday communication situations (Davis et al., 2022). The FLI-P assess a range of listening behaviours that show the child's ability to detect, discriminate, and understand speech in a real-world complex environment. Unlike conventional subjective speech perception questionnaires, the FLI-P assesses the functional use of listening information in natural communication environments, yielding reliable, functional scores that quantify overall speech perception, making it a valuable tool for subjective assessment of overall benefit in real-life situations (Davis et al., 2022).

Davis et al. (2022) demonstrated the feasibility of the FLI-P, which provides clinically meaningful information on listening development in young children with hearing impairment. Various studies have reported that the FLI-P can be more effective for monitoring functional listening progress in children with hearing loss who use hearing aids or cochlear implants. The measurement of the FLI-P allows clinicians to document and report changes in listening behaviour over the course of rehabilitation and to identify areas in which the child is lacking and thus requires further therapy (Davis et al., 2022).

Speech perception ability and functional listening performance are interrelated, as accurate perception of speech signals provides the base for effective communication in daily life, which is important for the overall quality of life (Geers, 2003). Children who show good speech perception performance are generally better able to use auditory-relevant information to participate in everyday conversations, follow classroom instructions, and interact socially with peers. On the other hand, children who have difficulty perceiving speech signals may exhibit reduced functional listening skills in everyday communication situations (Fitzpatrick et al., 2015).

Additionally, the ability to perceive speech across different intensity levels may affect functional listening outcomes. Soft-level speech is often heard in distant daily conversations or quiet classroom interactions with friends; on the other hand, the louder speech signals are more common in noisy listening environments. If children are unable to perceive speech effectively across this range of intensities, their ability to engage in everyday communication may be compromised, leading to overall poor performance. Consequently, evaluating speech perception at multiple presentation levels may provide valuable insight into the relationship between auditory perception abilities and functional listening development, enabling us to develop a new assessment protocol giving an advantage (Davidson et al., 2010).

Associating speech perception measurements with functional listening assessments thus provides a more comprehensive and valuable evaluation of auditory outcomes in children with cochlear implants. By assessing both controlled speech perception performance and real-world listening behaviour, clinicians can better understand how children utilise auditory information during everyday communication activities (Davidson et al., 2010).

The reviewed literature showed that listening performance is influenced by several factors stated above, and is highly influenced by input intensity, and that functional outcomes provide an enormous amount of information regarding real-life listening performance. The integration of speech perception measures with functional outcome measures is very limited. This large gap in the literature highlights the need for further studies to fill this gap, and thereby the rationale for the present study.

CHAPTER III

METHOD

3.1 Research Design

The present study aimed to assess level-dependent speech identification performance in paediatric cochlear implant recipients using a cross-sectional within-subject research design to evaluate its relationship with functional outcome measures.

3.2 Participants

A total of 22 children with unilateral cochlear implants participated in the present study. Participants were recruited through purposive sampling based on inclusion and exclusion criteria. Ethical approval was obtained from the Institutional Review Board. Informed written and oral consent was obtained from one of the children's guardians. The sample included an equal number of males and females aged between 5 to 8 years (11 males and 11 females). The demographic details are presented in Table 1. All participants were native Kannada speakers from Kannada-speaking families and had undergone auditory-verbal rehabilitation in Kannada following cochlear implantation. All participants used a unilateral cochlear implant system manufactured by Cochlear Limited, comprising the CI 422 implant and the Nucleus 7 (CP1002) speech processor. To ensure adequate language proficiency, children were required to achieve receptive and expressive language abilities to a minimum developmental age of 36 months, as evaluated using the Assessment Checklist for Speech and Language Skills (ACSLS) (Swapna et al., 2006). In addition, all participants had achieved and maintained a minimum closed-set speech perception score of 80% for at least 1 year following implantation and had used their cochlear implant consistently for at least 1 year prior to participation. All children had also attended regular auditory-verbal rehabilitation sessions for at least 12 months following implantation. Participants were excluded if they had any associated neurological, cognitive, developmental, or additional sensory impairments. Children who had cochlear implant electrode abnormalities, including open or short circuits, or electrodes deactivated due to non-auditory sensations, were also excluded. Furthermore, children with inconsistent cochlear implant use, irregular attendance at rehabilitation programmes, inadequate post-implantation auditory rehabilitation, or device-related complications were not included in the study.

Table 1

Participant Demographic Characteristics: Means and Standard Deviations (N = 22)

Characteristic	M	SD
Participant age (years)	6.28	0.65
Age at cochlear implantation (years)	4.45	0.61
Duration of cochlear implant use and rehabilitation therapy (years)	1.83	0.43
Aided PTA average (500Hz, 1kHz, 2 kHz, 4 kHz) in dBHL (with loudspeaker at 1m distance).	20.5	2.75

Note. M = mean; SD = standard deviation; PTA = Pure Tone Average.

3.3 Instrumentation

A calibrated two-channel diagnostic audiometer (Inventis Piano) and sound-field speakers were used to estimate speech identification performance. A HP computer running Windows 11 and a 64-bit operating system, sound card featuring an integrated Realtek® High-Definition Audio codec, and a 3.5 mm stereo AUX cable was used to present the stimuli for the speech perception tests. Along with this, a smartphone was used to record the participants' responses, which was kept close to them.

3.4 Test Environment

Testing was conducted in a sound-treated room with noise levels within the permitted limits per ANSI/ASA S3.1-1999 (R2018). The temperature and lighting of the test room were adequate and comfortable enough for the subject. Participants were seated comfortably at 1 meter from the loudspeaker, which was positioned at 45° azimuth, and the loudspeaker side of the implant was switched on accordingly.

3.5 Test Materials

Speech perception performance was assessed using a recorded version of open-set speech identification material for children (Sarnash et al., 2015). To compare it with functional outcomes, functional listening abilities were assessed using the Functional Listening Index – Paediatric (FLI-P), which evaluates real-world auditory behaviour across everyday listening contexts (Davis et al., 2022).

3.6 Procedure

The children were made to sit alone and comfortably in the sound-treated audiometric test room. If the child was uncomfortable, the child's parents were made to sit next to the child and instructed not to help the child during the test. The hearing aid in the contralateral ear was switched off if used. Then, an open-set speech perception test was conducted by presenting preloaded audio stimuli from the computer, which was routed to the audiometer and delivered to the loudspeaker. The loudspeaker was placed at 45° azimuth and 1 meter away from the child. Before presenting the stimuli, the 1 kHz calibration tone was used to adjust the audiometer output. The stimuli were presented in a sound field condition at three different intensity levels (60 dBHL, 45 dBHL, and 30 dBHL) in a randomised order, and the three sets of stimuli were also randomised across these levels to reduce order effects. Presentation levels above 60 dB HL were not included because excessively high-intensity users due to the limited electrical dynamic range of cochlear implant processing systems in Cochlear Nucleus implants (Wolfe et al., 2015). Children were instructed to repeat the words they heard. To ensure they understood the instructions, they would first be made to listen to orally presented practice items that were not part of the test items. The test consisted of 25 words in each presentation level and was presented one after the other. The response was video recorded and transcribed in the International Phonetic Alphabet (IPA).

To minimise the influence of articulation-related distortions on speech perception scoring, speech production abilities were evaluated using the Kannada Diagnostic Photo Articulation Test (KDPAT) (Deepa & Savithri, 2010). Speech samples obtained during testing were transcribed using the IPA, and articulation errors identified through KDPAT were analysed according to substitution, omission, distortion, and addition (SODA) patterns. Responses were scored after accounting for speech-production errors to ensure that incorrect articulatory output was not misinterpreted as reduced speech-perception ability. Then, responses were analysed at each intensity level, and each correctly identified word was assigned a score of 1, whereas incorrect responses received a score of 0. The maximum obtainable score for each intensity level was 25.

After testing was completed, Functional listening ability was assessed using the Functional Listening Index–Paediatric (FLI-P) developed by Davis et al. (2022). The FLI-P is a structured clinical tool designed to evaluate listening development and auditory-functional performance across everyday communication environments in children with hearing impairment. The FLI-P consists of six hierarchical listening phases representing progressive auditory functional development. Phase 1 assess sound awareness (7 items), Phase 2 assess associating sound with meaning (11 items), Phase 3 assess comprehending Simple Spoken Language (12 items), phase assess comprehending language in different listening conditions (11 items), Phase 5 assess listening through discourse and narrative (14 items) and phase 6 assess advanced open-Set Listening (9 items). Each item is a binary choice, and the parents must respond to it based on the child's performance. The total FLI-P score represented the child's overall functional auditory performance across naturalistic communication contexts (Davis et al., 2022).

The clinician did the assessment through a structured parent interview with one of the child's parents who uses a cochlear implant. Each item of the FLI-P was verbally presented to the parent, and responses were obtained based on the child's listening behaviour in everyday communication situations. For each item, the parent's response was categorised as either 'mostly' or 'rarely' depending on the frequency with which the child demonstrated the specified listening behaviour. Responses categorised as 'mostly' were assigned a score of 1, whereas responses categorised as 'rarely' were assigned a score of 0. Responses were documented on the FLI-P response sheet. After that, scores for each individual phase of the FLI-P were calculated. The overall total score was obtained by adding the individual phase scores and used for further statistical analysis.

3.7 Statistical Analysis

In line with the objectives of the study, data from each participant were tabulated and analysed using the Statistical Package for the Social Sciences (SPSS for Windows, Version 31). Initially, all variables were subjected to descriptive and inferential statistical analysis, including computation of the mean and standard deviation.

The Shapiro-Wilk test was done to see the normality of the data distribution. The results included that the data were nearly normally distributed, and the values are given in Table 2.

Table 2

Shapiro–Wilk Tests of Normality for All Study Variables (N = 22)

Variable	*W*	df	*p*	Skewness	Kurtosis	Decision
Speech Identification Score (30 dB HL)	.945	22	.247	−0.44	−0.58	Normal
Speech Identification Score (45 dB HL)	.910	22	.047	−0.61	−0.10	Near-normal
Speech Identification Score (60 dB HL)	.899	22	.029	−0.10	−0.26	Near-normal
FLI-P Score	.951	22	.125	−0.35	−0.16	Normal

Note. W = Shapiro–Wilk statistic. Skewness and kurtosis values are based on z-scores from descriptive statistics. FLI-P = Functional Listening Index – Paediatric. A near-normal distribution; given the sample size (N = 22) and minimal skew, parametric analyses were considered appropriate (Field, 2018).

To examine differences in speech perception scores across presentation levels, a one-way repeated-measures analysis of variance was conducted. Post-hoc pairwise comparisons were evaluated using the Bonferroni test, with Bonferroni adjustment of significance levels. The relationship between speech perception scores and functional listening outcomes (FLI-P scores) was analysed using the Pearson correlation test.

CHAPTER IV

RESULTS

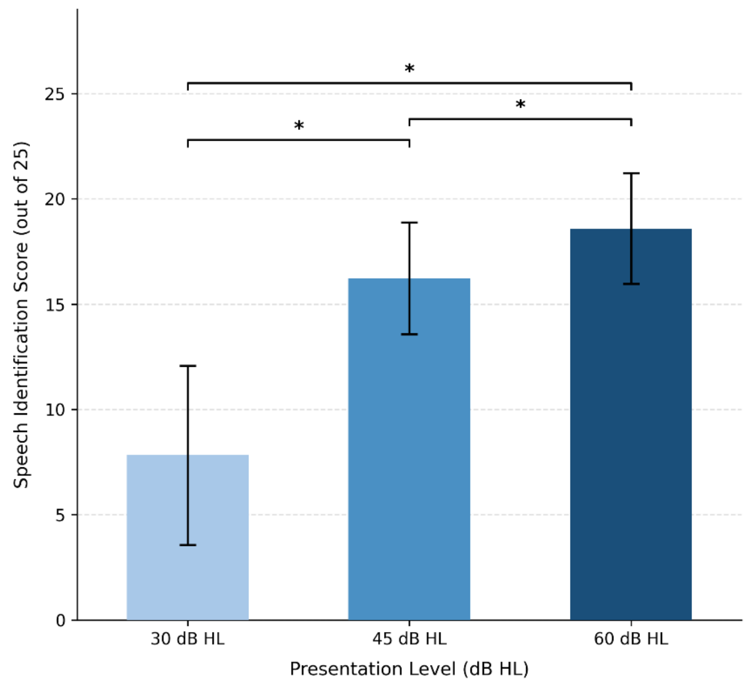
The aim of the study was to compare speech-perception performance across different input intensities in children with cochlear implants and to compare it with functional outcome measures. The responses of 22 children with cochlear implants were analysed using appropriate statistical methods, and the test results are presented below.

4.2 Descriptive Statistics

Descriptive data analysis indicated that speech identification scores increased with increasing presentation level. The raw mean speech perception score was lowest at 30 dB HL. At 45 dB HL, the mean score increased, indicating improved performance. The highest mean score was at 60 dB HL, which indicates maximum performance at moderately high intensity levels. Variability was highest at the lowest intensity level, with participants showing inconsistent, poor responses during low-intensity listening. The FLI-P had a total mean score of 48.50 with a SD of 4.39. Both descriptive statistics for speech identification scores across three input intensities and for FLI-P are presented in pictorial form. Figure 1 depicts the mean speech identification scores across input intensity, along with the standard deviation, and Figure 2 depicts the mean FLIP, along with its standard deviation.

Figure 1

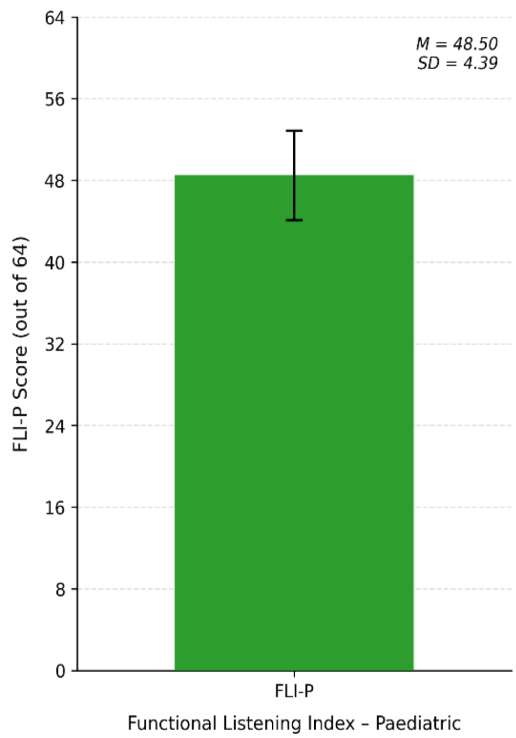
Mean speech identification scores (out of 25) with Standard Deviation error bars across three presentation levels for children with cochlear implants (N = 22).



Note. Error bars represent ±1 standard deviation. Significance brackets indicate Bonferroni-corrected pairwise differences between all presentation levels (*p < .001).

Figure 2

Mean FLI-P Score in Paediatric Cochlear Implant Users (N = 22) with standard deviation error bars across three presentation levels for children with cochlear implants (N = 22)



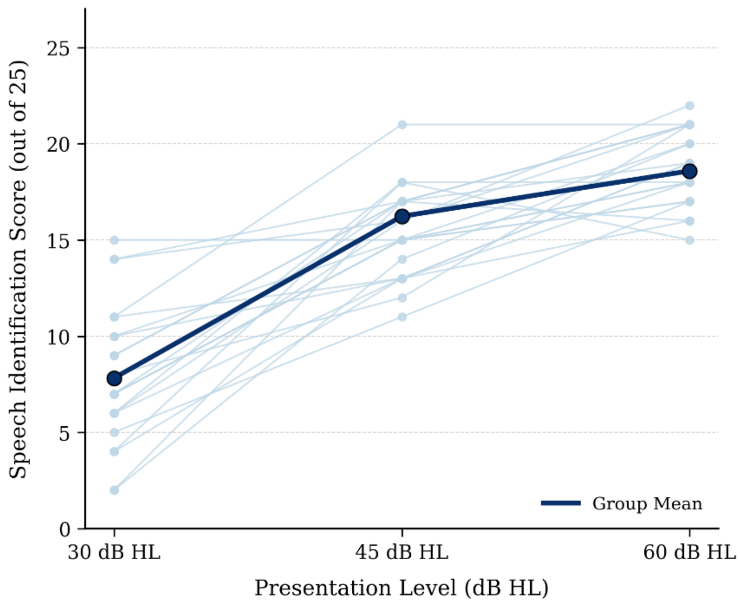
Note. FLI-P; Total score range = 0–64. Error bars represent standard deviation, N = 22. Mean = 48.50 (75.78% of maximum), SD = 4.39.

4.3 Psychometric Function of Speech Perception

Data showed a sigmoidal pattern of performance, with lower speech identification scores at lower intensities and a near plateau at moderately high intensities. This pattern shows that performance is input-intensity-dependent, improving with increasing stimulus intensity until reaching a ceiling at higher intensities. The psychometric function curve is depicted in Figure 3.

Figure 3

Psychometric Function of Speech Identification Scores as a Function of Presentation Level for Children with Cochlear Implants (N = 22)



Each line = one participant (N = 22). Bold line = group mean. Scores out of 25.

Note. Psychometric function depicting the relationship between presentation level (dB HL) and mean speech identification score (out of 25) for children with cochlear implants (N = 22).

4.4 Effect of Presentation Level on Speech Identification

As the data were near normally distributed, a one-way repeated-measures analysis of variance was conducted to assess the effect of presentation level (30, 45, and 60 dB HL) on speech identification performance. The analysis showed a statistically significant effect of presentation level [$F(2, 58) = 12.46$, $p < .001$, partial $\eta^2 = .30$, $p < .001$], indicating that speech identification scores varied across intensity levels. Analysis of descriptive statistics indicated a progressive increase in mean from 30 dB HL to 60 dB HL, indicating improved speech recognition scores with increasing intensity levels.

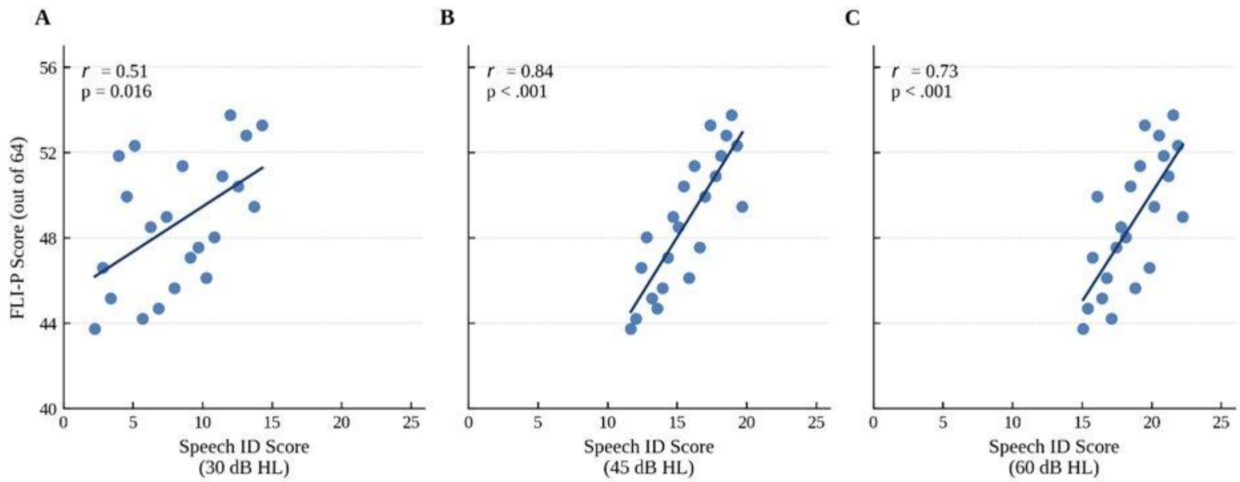
Bonferroni post hoc pairwise comparisons indicated significant differences across all presentation levels after adjusted Bonferroni correction. Speech identification scores increased significantly from 30 to 45 dBHL (mean difference = -8.41, $p<.001$), from 30 to 60 dBHL (mean difference = −10.77, $p < .001$), and from 45 to 60 dBHL (mean difference = −2.36, $p < .001$), indicating a systematic improvement in performance with increasing intensity.

4.5 Relationship Between Speech Perception Scores and FLI-P

The relationship between speech perception performance at different presentation levels and functional listening ability was examined by using Pearson's product–moment correlation. A statistically significant positive correlation was observed between FLI-P scores and speech identification scores at 30 dB HL ($r = 0.501$, $p < .001$), indicating that individuals with higher functional listening skills performed better under a lower intensity level. Similarly, significant positive correlations were found at 45 dB HL ($r = 0.84$, $p < .001$) and 60 dB HL ($r = 0.735$, $p < .001$). Based on Cohen's (1988) criteria, the obtained Pearson's correlation coefficient (r) represented a strong relationship between the study variables, reflecting a consistent association between speech perception and real-world listening outcome measures. Although all intensity levels showed significant strong positive correlations, the highest correlation coefficient was observed at 45 dB HL, followed by 60 dB HL and 30 dB HL. The correlation analysis is represented in the scatter plots of speech identification scores at each presentation level against FLI-P scores, with regression lines, as presented in Figure 4.

Figure 4

Scatter Plots of Speech Identification Scores at Each Presentation Level Against FLI-P Scores, with Regression Lines



Note. Each panel depicts speech identification scores (out of 25; x-axis) plotted against FLI-P total scores (out of 64; y-axis) at 30 dB HL (Panel A), 45 dB HL (Panel B), and 60 dB HL (Panel C). Solid lines represent ordinary least squares regression lines. Pearson's coefficient (r) and two-tailed exact p-values are presented within each panel. (N = 22).

4.7 Summary of Findings

The results demonstrated that:

- Speech perception performance improved significantly with increasing presentation level.
- Low-intensity speech perception showed greater variability and reduced performance
- Functional listening abilities were strongly associated with speech perception performance at all three intensity levels.

- Speech perception at a 45 dB HL level had the strongest association among the three intensity levels with the amount of real-world listening performance.

CHAPTER V

DISCUSSION

The present study investigated the relationship between speech perception performance across different presentation intensity levels and functional listening outcomes in paediatric cochlear implant (CI) users. The findings showed that speech perception performance improved systematically with increasing presentation intensity. Speech perception scores obtained at 30 dB HL and 60 dB HL also showed significant associations with functional listening skills. Though these relationships were strong, the strongest association was observed at conversational intensity levels. These findings provide important evidence regarding the relevance of speech perception assessment in representing real-world communication outcomes in paediatric CI users.

The present findings showed a clear intensity-dependent improvement in speech perception performance. Participants had the lowest performance at 30 dB HL, improved performance at 45 dB HL, and the highest speech perception scores at 60 dB HL. The ANOVA analysis and pairwise comparisons confirmed that these differences were statistically significant with a larger effect size. *Since, there was a significant difference in the observed mean speech perception performance across three input intensity levels, the null hypothesis ($1H_0$) was rejected.*

This pattern is consistent with previous studies showing that increased presentation intensity improves audibility and enhances speech cues necessary for accurate speech recognition (Shannon et al., 1995). At lower intensity levels, reduced audibility may limit access to low-intensity consonantal and spectral cues, particularly high-frequency speech components critical for accurate speech discrimination and linguistic processing (Stelmachowicz et al., 2004).

Consequently, children may experience greater perceptual ambiguity and variability in speech recognition under soft listening conditions.

The high variability observed at 30 dB HL further highlight the challenges of soft-level speech perception in children with hearing loss. Soft speech perception is important because children can acquire language incidentally through overheard conversations and ambient auditory exposure during everyday communication, which are present at low levels (Shneidman & Goldin-Meadow, 2012). Reduced access to low-intensity speech may therefore restrict opportunities for vocabulary acquisition, grammatical learning, and auditory-linguistic development. Similar findings have been reported by Walker et al. (2015) and Tomblin et al. (2015), who observed that limited access to audible speech cues was associated with poorer spoken language outcomes in children with hearing loss. Although speech perception at 30 dB HL showed a significant relationship with functional listening outcomes in the present study, the comparatively weaker correlation co-efficient suggests that low-level audibility alone may not fully represent broader real-world communicative functioning.

Speech perception scores significantly improved at 45 dB HL, corresponding to conversational-level speech. Importantly, this level showed the strongest association with functional listening outcomes across all analyses. These findings showed that speech perception measured at conversational intensity levels may better reflect day-to-day listening functioning than performance obtained under low or high listening conditions. Several authors, such as Nittrouer and Chapman (2009) and Ching et al. (2018), have reported the importance of assessing natural communication environments when examining functional language and communication outcomes in children with hearing impairment. The clinical relevance of conversational-level speech perception is particularly relevant because conversational speech represents the listening condition most frequently encountered in homes and social environments (McCreery et al., 2012; Walker et al., 2019). However, a few previous studies have also suggested that conventional speech perception measures may not adequately capture real-world communicative participation and everyday listening performance in paediatric cochlear implant users (Archbold et al., 2000; Spitzer et al., 2023). Thus, it is necessary to evaluate which phase of the FLI-P best associate with conversational speech perception scores to understand outcomes in a real-life environment.

There was a strong, significant correlation between speech perception scores across these three intensity levels and FLI-P. Thus, the null hypothesis (2H_0) was rejected. Although the highest raw speech perception scores were observed at 60 dB HL, the relationship between moderately high intensity speech perception and FLI-P was comparatively weaker than that observed at 45 dB HL. Improved performance at 60 dB HL likely reflects enhanced audibility and greater accessibility of speech cues under highly favourable listening conditions. Increased presentation intensity enhances the audibility of acoustic speech cues, thereby reducing perceptual ambiguity and facilitating more accurate speech detection and recognition (Meyer et al., 2013). Consequently, many participants showed near-ceiling performance at this intensity level. However, despite these improved speech perception scores, moderately high intensity performance may have slightly lower validity because everyday communication does not often occur continuously under highly amplified listening conditions. Rather, children must process speech across dynamically varying acoustic environments in which conversational-level listening predominates (McCreery et al., 2012; Walker et al., 2019). The comparatively weaker association between speech perception at 60 dB HL and functional listening outcomes may also reflect reduced variability in speech perception scores at moderately high intensities. When speech perception performance approaches ceiling levels, the speech perception measure may become less sensitive in differentiating children with varying levels of functional communication ability. Consequently, children with substantially different real-world listening competence may demonstrate similar high speech perception scores under favourable listening conditions. This reduction in score dispersion may weaken the predictive value of moderately high intensity speech-perception testing for functional auditory outcomes. Similar concerns regarding the limited validity of clinical speech perception measures in representing real-world communication and functional listening abilities have been highlighted in previous paediatric cochlear implant research (Archbold et al., 2000; Iglehart, 2016; Spitzer et al., 2023).

From a clinical perspective, the findings strongly support prioritising conversational-level speech perception assessment during paediatric cochlear implant evaluation when the objective is to estimate functional auditory benefit in everyday communication settings. Although assessment across multiple intensity levels remains valuable for identifying specific listening difficulties related to soft-level audibility or performance under highly amplified conditions, conversational-level testing appears to provide the most representative estimate of practical communication ability.

CHAPTER VI

SUMMARY AND CONCLUSION

Cochlear implant recipients are assessed only for speech perception at conversational levels, rather than in real listening situations. Most audiological tests focus on assessing at a normal conversational level, but children still have difficulty in real-world settings outside quiet test rooms (Elsayed, 2022). Assessment of both soft and higher-intensity speech is equally important. Perception of low-level speech is critical for understanding whispered speech, soft speech from distant speakers, and incidental speech in quiet environments, all of which are important for language learning in early childhood (Peng et al., 2008). It's important that children can hear loud sounds so they can deal with noisy places like classrooms and playgrounds. But loud sounds can cause problems too, like making speech sound distorted or uncomfortable. This can make it harder to understand what's being said and may make a child less likely to participate in important school and social environments (Meijer et al., 2025; Svirsky & Meyer, 1999). However, there was a major clinical gap that needed to be filled by confirming the necessity of intensity-specific assessment protocols that are more comprehensive and go beyond only conversational-level testing, and the current study was necessary to investigate in a systematic way the speech perception changes that are aided in different intensities, such as low, conversational, and moderately high intensities, in children with cochlear implants. There is a need to understand how corelate the scores correlate across different intensity levels associated with the functional listening abilities of the child in a real-life context.

The present study investigated level-dependent speech identification performance scores and their relationship with functional listening skills in paediatric cochlear implant users. A cross-sectional within-subject design was used. Twenty-two unilateral paediatric cochlear implant users aged between 5-8 years (M=6.28, SD=0.65) participated in the study. Open-set Kannada bi-syllabic word identification testing was carried out in a sound-field at 30 dB HL, 45 dB HL, and 60 dB HL presentation levels. Functional listening ability was assessed using the FLI-P. The findings showed a clear, systematic effect of presentation level on speech perception performance, with significantly lower scores at 30 dB HL, improved performance at 45 dB HL, and high scores at 60 dB HL. This shows that access to speech information in children with cochlear implants is highly influenced by signal intensity, consistent with earlier findings that audibility plays a central role in speech recognition (Stelmachowicz et al., 2004; Recker & Edwards, 2013).

The variability observed at low intensity levels may reflect reduced and inconsistent access to soft speech cues. Previous research has reported that children with hearing loss have difficulty perceiving low-level speech due to limited access to high-frequency acoustic information (Stelmachowicz et al., 2004). Speech perception at conversational-intensity levels showed a marked improvement, with subjects demonstrating significantly higher scores at 45 dB HL. This finding supports the view that cochlear implants are better optimised for conversational-level input, leading to improved speech recognition under these conditions (Elsayed, 2022). Further study found that improvement in speech perception was observed at 60 dB HL, where participants achieved the highest scores. Increased signal level intensity enhances audibility and reduces acoustic masking, thereby facilitating speech recognition (Recker & Edwards, 2013).

The relationship between speech perception and functional listening ability was another objective of the study, FLI-P. FLI-P showed a statistically significant, strongest positive correlation with the speech identification score at 45 dB HL, followed by 60 dB HL and 30 dB HL, and the highest correlation was observed at 45 dB HL among all the presented intensities, suggesting that

FLI-P and 45 dB HL assessment can provide better information. Previous research has reported similar findings, linking speech perception ability to broader communication outcomes, including language development and academic performance (Geers, 2006; Tyler et al., 2000).

To conclude, the present study's findings showed that speech perception in children with cochlear implants is influenced by presentation level. Functional listening ability is closely linked with speech perception at conversational levels, highlighting the importance of assessing auditory performance at conversational levels.

Implications of the Study

- Speech perception in children using cochlear implants was influenced by intensity levels.
- Better performance was seen at 45 dB HL, associated with better functional listening in daily life.
- Conversational-level testing would be ideal to relate to the real-world functional listening ability.

Limitations of the Study

The study was limited by the cross-sectional design and the small sample size. Longitudinal examination of speech perception and real-world functional communication outcomes may provide a better understanding of the observed findings. In addition, the current study assesses only open-set speech perception performance. Measures such as speech perception in noise and the Lexical Neighbourhood Test could offer better insights into functional listening abilities in everyday communication. Thus, further research employing diverse speech materials and other research designs is essential to strengthen and extend the interpretation of the present results.

Future Directions of the Study

- Future studies should include a larger sample to improve the reliability and generalizability of the findings.
- Research can focus on speech perception in realistic listening conditions, especially in the presence of background noise. This may provide a better understanding of everyday listening challenges.
- Future studies may examine the relationship between speech perception and other areas such as language development, academic performance, and social communication.
- Longitudinal research can help understand how speech perception and functional listening improve over time with continued cochlear implant use and rehabilitation.

References

Archbold, S., Nikolopoulos, T. P., Tait, M., O'Donoghue, G. M., Lutman, M. E., & Gregory, S. (2000). Approach to communication, speech perception and intelligibility after paediatric cochlear implantation. *British Journal of Audiology*, *34*(4), 257–264. https://doi.org/10.3109/03005364000000013

Archbold, S., Sach, T., O'Neill, C., Lutman, M., & Gregory, S. (2008). Outcomes from cochlear implantation for child and family: Parental perspectives. *Deafness & Education International*, *10*(3), 120–142. https://doi.org/10.1002/dei.242

Blamey, P. J., Sarant, J. Z., Paatsch, L. E., Barry, J. G., Bow, C. P., Wales, R. J., Wright, M., Psarros, C., Rattigan, K., & Tooher, R. (2001). Relationships among speech perception, production, language, hearing loss, and age in children with impaired hearing. *Journal of Speech, Language, and Hearing Research*, *44*(2), 264–285. https://doi.org/10.1044/1092-4388(2001/022)

Boothroyd, A. (1997). Auditory development of the hearing child. *Scandinavian Audiology Supplementum*, *46*, 9–16.

Ching, T. Y. C., Dillon, H., Button, L., Seeto, M., Van Buynder, P., Marnane, V., Cupples, L., Leigh, G., Martin, L., Whitfield, J., Gunnourie, M., & Flynn, C. (2017). Age at intervention for permanent hearing loss and 5-year language outcomes. *Pediatrics*, *140*(3), Article e20164274. https://doi.org/10.1542/peds.2016-4274

Davidson, L. S., Geers, A. E., Blamey, P. J., Tobey, E. A., & Brenner, C. A. (2011). Factors contributing to speech perception scores in long-term pediatric cochlear implant users. *Ear and Hearing*, *32*(2), 19S–26S. https://doi.org/10.1097/AUD.0b013e3181fa41e4

Easwar, V., Sanfilippo, J., Papsin, B., & Gordon, K. (2018). Impact of daily device use consistency on speech perception in children with cochlear implants: Datalogging evidence. *Journal of the American Academy of Audiology*, *29*(9), 835–846. https://doi.org/10.3766/jaaa.17051

Elsayed, S. M. A. (2022). Assessment of speech-perception abilities in children with cochlear implants. *Iranian Journal of Otorhinolaryngology*, *34*(3), 155–161. https://doi.org/10.22038/IJORL.2022.60164.3070

Geers, A. E. (2004). Speech, language, and reading skills after early cochlear implantation. *Archives of Otolaryngology–Head & Neck Surgery*, *130*(5), 634–638. https://doi.org/10.1001/archotol.130.5.634

Iglehart, F. (2016). Speech perception in classroom acoustics by children with cochlear implants and with typical hearing. *American Journal of Audiology*, *25*(2), 100–109. https://doi.org/10.1044/2015_AJA-15-0041

King, S. B. (2010). *Texas architects' knowledge and attitude regarding an ANSI standard for classroom acoustics* [Doctoral dissertation, University of Northern Colorado]. ProQuest Dissertations and Theses Global.

Kronenberger, W. G., Colson, B. G., Henning, S. C., & Pisoni, D. B. (2014). Executive functioning and speech-language skills following long-term use of cochlear implants. *Journal of Deaf Studies and Deaf Education*, *19*(4), 456–470. https://doi.org/10.1093/deafed/enu011

Madell, J., & Hewitt, J. (2022). The Ling-Madell-Hewitt (LMH) test battery. *Volta Voices*, *29*(1), 20–23.

Mamun, N., Khorram, S., & Hansen, J. H. L. (2019). Convolutional neural network-based speech enhancement for cochlear implant recipients. In *Proceedings of Interspeech 2019* (pp.

4265–4269). International Speech Communication Association. https://doi.org/10.21437/Interspeech.2019-1850

McCreery, R. W., Venediktov, R. A., Coleman, J. J., & Leech, H. M. (2012). An evidence-based systematic review of frequency lowering in hearing aids for school-age children with hearing loss. *American Journal of Audiology*, *21*(2), 313–328. https://doi.org/10.1044/1059-0889(2012/12-0015)

Meijer, A., Benard, M. R., Woonink, A., Başkent, D., & Dirks, E. (2025). The auditory environment in early intervention groups for young children with hearing loss: Signal-to-noise ratio, background noise, and reverberation. *Ear and Hearing*, *46*(3), 827–837. https://doi.org/10.1097/AUD.0000000000001627

Meyer, J., Dentel, L., & Meunier, F. (2014). Correction: Speech recognition in natural background noise. *PLOS ONE*, *9*(1), Article e85043. https://doi.org/10.1371/annotation/012d9419-8135-40ab-8c81-ce46e8e708d0

Meyer, T. A., Svirsky, M. A., Kirk, K. I., & Miyamoto, R. T. (2013). Improvements in speech perception with increased presentation level in children with cochlear implants. *Ear and Hearing*, *34*(4), 426–432. https://doi.org/10.1097/AUD.0b013e31827bc3ae

Moeller, M. P., Tomblin, J. B., Yoshinaga-Itano, C., Connor, C. M., & Jerger, S. (2007). Current state of knowledge: Language and literacy of children with hearing impairment. *Ear and Hearing*, *28*(6), 740–753. https://doi.org/10.1097/AUD.0b013e318157f07f

Niparko, J. K., Tobey, E. A., Thal, D. J., Eisenberg, L. S., Wang, N.-Y., Quittner, A. L., & Fink, N. E. (2010). Spoken language development in children following cochlear implantation. *JAMA*, *303*(15), 1498–1506. https://doi.org/10.1001/jama.2010.451

Nittrouer, S., & Chapman, C. (2009). The effects of bilateral electric and bimodal electric–acoustic stimulation on language development. *Trends in Amplification*, *13*(3), 190–205. https://doi.org/10.1177/1084713809349744

Nittrouer, S., Caldwell-Tarr, A., Sansom, E., Twersky, J., & Lowenstein, J. H. (2014). Nonword repetition in children with cochlear implants: A potential clinical marker of language processing ability. *Otolaryngology–Head and Neck Surgery*, *151*(4), 602–609. https://doi.org/10.1177/0194599814542716

Peng, S.-C., Tomblin, J. B., & Turner, C. W. (2008). Production and perception of speech intonation in pediatric cochlear implant recipients and individuals with normal hearing. *Ear and Hearing*, *29*(2), 206–220. https://doi.org/10.1097/AUD.0b013e3181645399

Pichora-Fuller, M. K., Kramer, S. E., Eckert, M. A., Edwards, B., Hornsby, B. W. Y., Humes, L. E., Lemke, U., Lunner, T., Matthen, M., Mackersie, C. L., Naylor, G., Phillips, N. A., Richter, M., Rudner, M., Sommers, M. S., Tremblay, K. L., & Wingfield, A. (2016). Hearing impairment and cognitive energy: The framework for understanding effortful listening (FUEL). *Ear and Hearing*, *37*(Suppl. 1), 5S–27S. https://doi.org/10.1097/AUD.0000000000000312

Pisoni, D. B., Conway, C. M., Kronenberger, W. G., Henning, S. C., & Anaya, E. M. (2011). Executive function, cognitive control, and sequence learning in deaf children with cochlear implants. In M. Marschark & P. E. Spencer (Eds.), *The Oxford handbook of deaf studies, language, and education* (Vol. 1, 2nd ed., pp. 439–457). Oxford University Press.

Poluboina, V., Pulikala, A., & Muthu, A. N. P. (2023). An improved noise reduction technique for enhancing the intelligibility of sinewave vocoded speech: Implications in cochlear implants. *IEEE Access*, *11*, 787–796. https://doi.org/10.1109/ACCESS.2022.3232549

Ramkumar, V., Joshi, D. B., Prabhakar, A., Hall, J. W., & Vaidyanath, R. (2025). Development and beta validation of an mHealth-based hearing screener (SRESHT) for young children in resource-limited countries: Pilot validation study. *JMIR Formative Research*, *9*, Article e53460. https://doi.org/10.2196/53460

Sarant, J. Z., Harris, D. C., Bennet, L. A., & Bant, S. (2014). Bilateral versus unilateral cochlear implants in children: A study of spoken language outcomes. *Ear and Hearing*, *35*(4), 396–409. https://doi.org/10.1097/AUD.0000000000000010

Shafiro, V., Luzum, N., Moberly, A. C., & Harris, M. S. (2022). Perception of environmental sounds in cochlear implant users: A systematic review. *Frontiers in Neuroscience*, *15*, Article 788899. https://doi.org/10.3389/fnins.2021.788899

Shneidman, L. A., & Goldin-Meadow, S. (2012). Language input and acquisition in a Mayan village: How important is directed speech? *Developmental Science*, *15*(5), 659–673. https://doi.org/10.1111/j.1467-7687.2012.01168.x

Smiljanic, R., & Gilbert, R. C. (2017). Intelligibility of noise-adapted and clear speech in child, young adult, and older adult talkers. *Journal of Speech, Language, and Hearing Research*, *60*(11), 3069–3080. https://doi.org/10.1044/2017_JSLHR-S-16-0165

Spitzer, E. R., Landsberger, D. M., Lichtl, A. J., & Waltzman, S. B. (2024). Ceiling effects for speech perception tests in pediatric cochlear implant users. *Cochlear Implants International*, *25*(1), 1–9. https://doi.org/10.1080/14670100.2023.2244859

Stelmachowicz, P. G., Pittman, A. L., Hoover, B. M., Lewis, D. E., & Moeller, M. P. (2004). The importance of high-frequency audibility in the speech and language development of children with hearing loss. *Archives of Otolaryngology–Head & Neck Surgery*, *130*(5), 556–562. https://doi.org/10.1001/archotol.130.5.556

Svirsky, M. A., & Meyer, T. A. (1999). Comparison of speech perception in pediatric Clarion cochlear implant and hearing aid users. *Annals of Otology, Rhinology & Laryngology Supplement*, *177*, 104–109.

Swapna, N., Jayaram, M., Prema, K. S., & Geetha, Y. V. (2006). *Assessment checklist for speech and language skills*. All India Institute of Speech and Hearing.

Tomblin, J. B., Oleson, J., Ambrose, S. E., Walker, E., & Moeller, M. P. (2015). The influence of hearing aids on the speech and language development of children with hearing loss. *JAMA Otolaryngology–Head & Neck Surgery*, *141*(9), 810–817. https://doi.org/10.1001/jamaoto.2015.1489

Tyler, R. S., Teagle, H. F. B., Kelsay, D. M. R., Gantz, B. J., Woodworth, G. G., & Parkinson, A. J. (2000). Speech perception by prelingually deaf children after six years of cochlear implant use: Effects of age at implantation. *Annals of Otology, Rhinology & Laryngology Supplement*, *185*, 85–87.

Walker, E. A., Holte, L., McCreery, R. W., Spratford, M., Page, T., & Moeller, M. P. (2015). The influence of hearing aid use on outcomes of children with mild hearing loss. *Journal of Speech, Language, and Hearing Research*, *58*(5), 1611–1625. https://doi.org/10.1044/2015_JSLHR-H-14-0201

Walker, E. A., Sapp, C., Oleson, J. J., & McCreery, R. W. (2019). Longitudinal speech recognition in noise in children: Effects of hearing status and vocabulary. *Frontiers in Psychology*, *10*, Article 2421. https://doi.org/10.3389/fpsyg.2019.02421