SPEECH PERCEPTION OUTCOMES IN KANNADA SPEAKING CHILDREN USING COCHLEAR IMPLANTS

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This Dissertation is submitted as part of fulfilment for the Degree of

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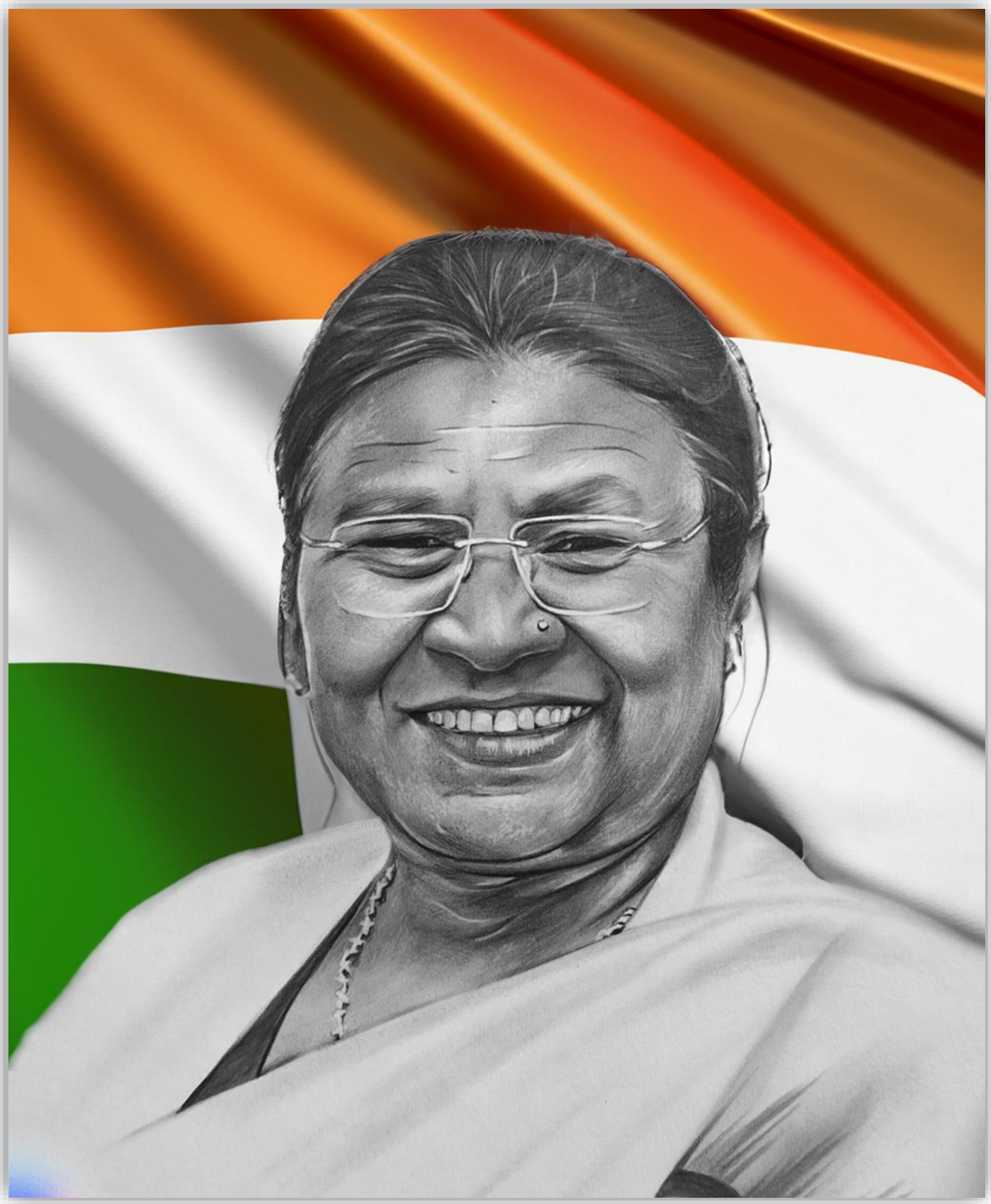

"Strive for excellence, Everything else will follow".

Madam Droupadi Murmu

15th President of India

CERTIFICATE

This is to certify that this dissertation entitled **"Speech Perception Outcomes in Kannada Speaking Children Using Cochlear Implants"** is the bonafide work submitted as part of fulfilment for the Degree of Master of Science in Audiology of the student with Registration No. P01II21S0061. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other Universities for the award of any otherdiploma or degree.

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CERTIFICATE

This is to certify that this dissertation entitled **"Speech Perception Outcomes in Kannada Speaking Children Using Cochlear Implants"** has been prepared under my supervision and guidance. It is also certified that this has not been submitted earlier to any other Universities for the award of any other diploma or degree.

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DECLARATION

This is to certify that this dissertation entitled **“Speech Perception Outcomes in Kannada Speaking Children Using Cochlear Implants”** is the result of my own study under the guidance of Dr. Prawin Kumar, Associate Professor, Department of Audiology, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier to any other Universities for the award of any other diploma or Degree.

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"It ain't about how hard you hit. It's about how hard you can get hit and keep moving forward. How much you can take and keep moving forward. That's how winning is done".

- Rocky Balboa

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ABSTRACT

The present study aimed to assess early speech perception test and rating scales in children with cochlear implants (CI) and compare the performance with typically developing children (TDC). There were 20 Kannada speaking children (10 CI & 10 TDC), in the age range of 4 to 7 years. All the CI children received funds under central government scheme for the implants and other costs involved in it. The modified early speech perception test in Kannada includes syllabic categorization (bi-syllabic, tri-syllabic & poly-syllabic words), word identification (WI) and vowel identification (VI) presented in audio (A) and audio-visual (AV) mode. In addition, CAP and MAIS rating scale were also performed. The results showed overall mean score of CI children having poorer performance in comparison to typically developing children for syllabic categorization, word identification and vowel identification in both auditory and audio-visual mode. Further, ANOVA showed significant difference between groups for syllabic categorization, word identification and vowel identification in auditory and audio-visual mode. In addition, the statistical differences were also observed between two groups for Ling's six sound identification test, CAP and MAIS scores. Paired 't' test showed no significant differences between audio and audio-visual mode for syllable categorization and word identification. The above differences in performance noticed among CI children could be due to late implantation, minimal use of critical period, and low socioeconomic status. It is also observed that CI children performance were alike in audio and audio-visual mode. This probably indicates minimal dependence of the CI children on visual cues. Overall performance of CI children was poorer in comparison to typically developing children.

Key words: Cochlear implants, Speech Perception, Word identification, CAP, MAIS

Chapter 1

INTRODUCTION

A cochlear implant (CI) is an electronic device that is surgically implanted to help individuals with severe-to-profound hearing loss caused by damage to the inner ear. It works by directly stimulating the auditory nerve, bypassing any damaged or injured sensory receptors in the inner ear, known as hair cells. It is an electronic device that has been demonstrated to be particularly beneficial in those with severe-to-profound sensorineural hearing loss (SNHL). So far, about 600,000 individuals have had cochlear implants fitted globally (Sahai, Ghosh & Anjankar, 2022; Jank, Haas, Riss & Baumgartner, 2021). Individuals with severe-to-profound SNHL relied on speech reading, sign language, or amplification equipment for communication prior to the introduction of cochlear implants, which were unable to make speech sounds intelligible for them (Cosetti et al., 2016). Most cochlear implant recipients can now identify speech sounds much below normal hearing thresholds (Vermeire, Brokx, Heyning, Cochet & Carpentier, 2003). The use of an electrical signal to restore the function of a damaged cochlea has been shown to provide audibility and improved speech interpretation in both quiet and noisy environments, as demonstrated by more than 35 years of cochlear implant experience (Roland, Gantz, Waltzman, & Parkinson, 2018).

A cochlear implant can significantly improve the ability to comprehend speech (Bazon et al., 2016). In adults and children with hearing impairment, it enhances verbal intelligibility, linguistic abilities, and sound perception (Raine et al., 2016). Auditory perception refers to the ability of the brain to receive and interpret auditory stimuli, which involves recognizing, interpreting, and being aware of sounds (Ciscare et al., 2017). As opposed to this, speech intelligibility was defined by Jalil-Abkenar et al. in 2013 as the amount of precision and intelligibility of the language used by the speaker as it relates to the listener's capacity to grasp the message or content. In comparison to a hearing aid, a cochlear implant improves reading, language, speech output, and auditory perception in children using cochlear implants (Van De Velde et al., 2019).

The improvement in auditory perception, auditory function and speech comprehension are the three main outcomes for children who utilize cochlear implants. Cochlear implanted children have been subjects for prior research that used rating scales to examine the growth of speech understanding and auditory perception (Ashori, 2020). Research has also shown that longitudinal speech comprehension abilities improve after cochlear implantation in children (Phillips et al., 2009).

Despite advances in cochlear implant technology, a variety of factors, including implantation age, GJB2- gene related deafness, inner ear abnormalities, and meningitis, may be associated with gains in speech recognition and auditory competence in these implanted children (Black et al., 2013). Along with these, increased speech perception in cochlear implant recipients is also a result of technological advancements in the device (Krueger et al., 2008). Sequential CI improved perception of speech as well as quality of life for individuals with inter-implant intervals in noisy circumstances, and its performance was connected to consistent hearing aid use in contra-lateral side (Li et al., 2022). When auditory information is limited in children with cochlear implants, speech perception ratings through the audio-visual condition were higher than comprehension through each channel (auditory, visual, & audio-visual alone) (Most et al., 2009).

Since the early 1980s, cochlear implantation has been accepted as a measure for treating children with severe sensorineural hearing impairment (Bouchard et al., 2009). It is widely believed that using this instrument will significantly improve the capacity of young children with hearing impairment to engage in aural-oral communication and develop speech and language skills. In the long-term follow-up, auditory awareness and speech intelligibility for children with eighth nerve aplasia improved, however this development was noticeably sluggish than for children with normal-sized eighth nerves (Chao et al., 2022). With persistent CI use and auditory training, the majority of children with eighth nerve aplasia can also learn to comprehend simple spoken language and common phrases. While the significant enhancement in speech perception skills after implantation has been well documented, little research has been done on the differences between children with cochlear implants and typically developing children. The functioning of cochlear implants is detailed, along with the clinical, social, and cognitive elements that are known to contribute to children's successful implantation. Cochlear implantation may accelerate speech perception to near-normal rates, but initial delays are not entirely reversible (Park et al., 2021). Furthermore, there is significant variation across all performance metrics, and the causes of both successful and unsuccessful results are only partially understood.

Thus, outcome measurement plays a crucial role in any effective rehabilitation programme. The same principles apply when rehabilitating a younger children with a cochlear implant. It is possible to determine if patients benefit from the gadget or treatment method being employed based on the outcome measures. Nearly all training programmes or alternative tools used by individuals with communication difficulties employ these result indicators. A valid and trustworthy outcome measure is required to evaluate children's listening abilities. This is crucial for setting suitable treatment objectives and monitoring children's post-cochlear implant listening progress. These evaluation techniques should be used to evaluate performances in real-world contexts rather than merely in clinical or laboratory settings. By assuring the validity and reliability of such outcome measures, we also enhance professionals' capacity to create a suitable intervention programme by realistically assessing the listening skills of their clients. There are currently several tools accessible to measure the outcome. These include the Speech Intelligibility Rating scale (SIR; Cox & McDaniel, 1989), the Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS; Zimmerman-Phillips, 1997), the Meaningful Auditory Integration Scale (MAIS; Robbins et al., 1991), and the Integrated Scales of Development (ISD; Cochlear Ltd, 2010). A few researchers have also argued in favour of less subjective methods (Dowell et al., 2002; Kameswaran et al., 2006; Spiric et al., 2015).

The Government of India also advises applying the rating scales for cochlear implants (CI) for youngsters that were discussed earlier. The specific outcome metrics have been advised to track the development of children utilizing CI devices. Unfortunately, despite the benefits of cochlear implant surgery, India has a lower adoption rate than other nations. Numerous researchers have indicated that the cost of the procedure and the views of the parents towards the procedure are important determinants (Dutt et al., 2002). So as to promote the use of CI among qualified applicants, it is crucial to evaluate the results and explore the full benefits following cochlear implantation utilizing rating scales and speech perception tests. It will also be fascinating to learn if there are any methods for predicting the outcomes of each other. Recognizing the potential benefits of cochlear implantation, the Indian government has taken the initiative to provide subsidized cochlear implants through programmes such as ADIP-CI (scheme of assistance to disabled persons for the purchase/fitting of aids/appliances). The Government of India established this system in year 2014. The project aims to reach out to the economically disadvantaged segments of society who would otherwise be denied restoring hearing impairment due to the excessive expenses of cochlear implantation and hearing aids. The devices were procured by ALIMCO (Artificial Limbs Manufacturing Corporation of India) Kanpur, and the implants were distributed by Ali Yavar Jung National Institute of Speech and Hearing Disabilities (Divyangjan) Mumbai.

Similarly, the Karnataka government launched SAST-RBSK-CI (Rashtriya Bal Swasthya Karyakram conducted by Suvarna Arogya Suraksha Trust). This effort aims to improve early detection and intervention for children from birth to 18 years. It encompasses a wide range of illnesses, including hearing loss. The District Early Intervention Centre (DEIC) oversees children aged zero to six years. The SAST executes a Shravanadosha Mukta Karnataka initiative. Children are tested in anganwadis and government or government-aided schools before being referred to the tertiary care regional hospital for further evaluation.

There is a lack of agreement among researchers, despite the fact that current literature has found a wide range of variables and factors that affect cochlear implantation performance (Geers et al., 2007). Speech comprehension and auditory perception are two factors that affect performance in this situation. Age of onset, age of cochlear implantation, pre-implant hearing aid usage history, communication approach, speech processor type, child's mental abilities, duration and aetiology of hearing impairment, period of cochlear implant use, parental education, home training, family support, socioeconomic status, and additional disabilities are a few of the factors identified with influencing the benefit and performance post-cochlear implantation (Nikolopoulos et al., 2008). Thus, the key purpose of this study is to identify the gap in speech perception skills between children with normal hearing and children with severe to profound hearing loss who use cochlear implants.

Need for the study

Cochlear implants benefit many youngsters with significant SNHL. Unfortunately, while many CI children demonstrate considerable increases in their capacity to interpret spoken language and recognise speech after cochlear implantation, many patients have poor results (Pisoni, Kronenberger, Harris & Moberly, 2017). Despite its critical clinical importance, defining and explaining the reasons of poor post-implantation results is a difficult undertaking that has received little attention (Pisoni et al., 2017).

Torkildsen and colleagues found that even with minimal auditory experience, numerous youngsters wearing the device achieved speech perception ratings of 90% or higher in quiet. The above data support the idea that the cochlear implant effectively transfers the speech signal (Torkildsen, Von, Hitchins, Myhrum & Wie, 2019). The ability of only a few children to perform well with limited auditory exposure could be related to the fact that these children were trained using the auditory-verbal method and had usable hearing prior to implantation. The available research, while limited, supports the value of early auditory experience and intensive aural (re)habilitation in children with implants (Kishon-Rabin et al., 2016). The current study intends to investigate whether such an improvement occurs in children with hearing impairment who use cochlear implants in an Indian setting.

Aim of the study

The present study is aimed to investigate the speech perception outcomes in Kannada speaking children with cochlear implants in comparison to typically developing children.

Objectives of the study

1. To estimate the speech perception in Kannada speaking children with cochlear implants in comparison to typically developing children using
    a. Modified Early Speech Perception Test in Kannada (MESP-K)
    b. Identification of Ling's six sound test (/a/, /i/, /u/, /m/, /s/, &/sh/)
2. To estimate the perceptual abilities in children with cochlear implants in comparison to typically developing children using
    a. Revised Categorical Auditory Performance Scale (R-CAPs)
    b. Meaningful Auditory Integration Scale (MAIS)/Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS)

Chapter 2

REVIEW OF LITERATURE

A cochlear implant (CI) is an electronic device that helps individuals with severe-to-profound hearing impairment to hear better by making sounds audible. It has a significant impact on the individual's ability to perceive speech (Bazon et al., 2016). It enhances auditory perception, language abilities, and verbal intelligibility in children and adults with hearing impairment (Raine et al., 2016). Auditory perception is described by Ciscare and colleagues as the awareness, recognition, and interpretation of auditory stimuli in the brain (Ciscare et al., 2017). Whereas on the other hand, speech intelligibility is defined as the degree to which a listener can grasp the message or content based on the precision and intelligibility of the language used by the speaker (Jalil-Abkenar et al., 2013). Cochlear implants have transformed the quality of life of those individuals having severe-to-profound hearing impairment either pre-lingual or post-lingual. Children using cochlear implants are outperforming hearing aid users in terms of speech perception (Jalil-Abkenar et al., 2013), language, speech production and reading (Van De Velde et al., 2019). Understanding the differences in speech perception abilities among children with hearing impairment before acquisition of language compared to typically developing children is critical for appropriate optimization of interventions (Rinaldi et al., 2013).

Speech perception abilities in children can be assessed using a combination of subjective and objective tests. Subjective tests involve the child's active participation and self-reporting, while objective tests measure physiological or electrophysiological responses without the child's active involvement. Objective assessment can include electrophysiological measures, whereas some of the behavioural measures include speech perception tests such as speech-in-noise tests, temporal processing tests and binaural processing tests. In addition, subjective assessments can also include questionnaires or interviews, feedback and self-reports, listening diaries and self-assessment scales.

2.1. Behavioral measures (Speech Perception test) in Cochlear Implantees

Speech perception test is one of the most often used subjective measure and considered as basic assessment yet very useful tool while examining the individuals speech understanding. There are different speech stimuli used in speech perception tests such as monosyllabic words, bisyllabic words, phrases, and sentences in children using amplification devices. The major factor affecting speech perception test results are poor spectral and temporal resolution among children with hearing impairment. Ling's six sound test is another subjective measure used most often to determine sound identification level across frequencies (Ling, 1978). The various factors which can affect the performance in these tests could be degree of hearing impairment, mapping variables in cochlear implant users, auditory rehabilitation and training, communication mode, advances in device technology, listening age, consistency of device use, listening environment etc.

Language acquisition and development in individuals with normal hearing rely heavily on speech perception abilities. Children detect and process numerous acoustic cues contained in speech, such as phonemes, prosody, and intonation, via the auditory system. This technique enables children to distinguish between various sounds, recognize words, and comprehend spoken language (Bailey & Snowling, 2002). Infants as early as a few months old have been demonstrated in studies to be able to discern speech sounds. Environmental factors like exposure to linguistic input and social interactions influence the development of speech perception abilities. Understanding these abilities helps to detect hearing issues earlier and enables efficient interventions for optimum language development (Gervain & Werker, 2013).

Hearing impairment has a substantial impact on children's speech and language acquisition. Children with hearing impairment put great effort to perceive and distinguish between different speech sounds, which can cause delays in speech production and articulation. They may also have difficulty in comprehending and processing complicated sentence patterns and terminology. This might lead to a limited vocabulary, poor grammar skills, and communication issues. Several studies reported the link between hearing loss and speech-language difficulties (Moeller, 2000; Yoshinaga-Itano, 2003; Bailey & Snowling, 2002). To minimize these problems and promote optimum language development in children with hearing impairment, early intervention with appropriate amplification and speech therapy is critical.

Furthermore, studies reported to assess the impact due to hearing loss on speech perception using speech perception metrics (Fryauf-Bertschy et al., 1997; Dowell et al., 2002). Fryauf-Bertschy and colleagues investigated the effects of cochlear implants on speech perception in 34 children who had three or more years of cochlear implant experience. After three years of cochlear implant use, children implanted before the age of 5 years performed considerably better in open-set speech perception tests than children implanted after the age of 5 years. However, there was no statistically significant difference in closed-set performance between groups. This supports the notion that longer duration of hearing impairment might result in less functional benefit and more difficulty in adjusting with the devices in pre-lingual children with hearing impairment (Fryauf-Bertschy et al., 1997).

Dowell and colleague investigated speech perception measures in 102 children (with mean age of 5.9 ± 4.4 years), six months after receiving a cochlear implant. They discovered that the duration of hearing loss, aural rehabilitation, and use of cochlear implants, all had a substantial impact on speech perception outcomes. They also mentioned that pre-implant residual hearing, psychophysical parameters such as number of electrodes used and electrical dynamic ranges, and psychosocial issues that might influence outcomes for some of the implanted children. The authors concluded that speech perception measures are clinically valuable instruments that accurately predict outcomes following cochlear implantation (Dowell et al., 2002). In a similar line, study done by Svirsky and colleagues reported that the recipient of cochlear implantees who discriminates sounds better may respond to instruction and develop the necessary abilities for speech perception. Those who were unable to distinguish the sounds may require individualized auditory training to improve their speech perception abilities (Svirsky et al., 2001).

In another study done by Feng and colleagues evaluated neuro-morphological variations between children with cochlear implants and age-matched children with normal hearing to determine how neural reorganization following cochlear implant affects postsurgical language results. There were 37 children with bilateral sensorineural hearing loss who received cochlear implantation and 40 children with normal hearing participated in the study. The assessment includes T1-weighted neuro-anatomical MRI, IT-MAIS, Early speech perception, and the Multisyllabic lexical neighbourhood test. The study implies that neural preservation helps cochlear implant recipients to improve their speech by preserving higher-level auditory and cognitive regions that are not affected due to hearing loss. These unaffected regions, such as the dorsal auditory network, are involved in speech perception and are linked to differences in auditory performance. According to the findings of the study, these regions provided the best accuracy, specificity, and sensitivity in patient classification as well as the best prediction of outcomes. As a result, the study emphasizes the significance of neural preservation in enhancing speech outcomes in young children with hearing deprivation who underwent cochlear implants surgery (Feng et al., 2018).

Geers et al. (2007) assessed whether clinical practice, implant technology, or a rehabilitative method provided the most accurate estimates of expected post-implant results. The study comprised 126 children (67 boys & 59 girls) aged 5 to 6 years old during the time of testing and had received a cochlear implant between the ages of 11 and 59 months. The Peabody Picture Vocabulary Test Standard Score was used to assess receptive vocabulary. Cochlear implants were used for a period ranging from 1 year to 5 years and 10 months, with an average of 3 years and 4 months. The study found that individuals with specific intrinsic characteristics (congenital or premature onset hearing loss, average cognitive functioning, and strong family involvement) can be predicted to attain age-appropriate expressive receptive language levels through early childhood (4 to 6 years of age) if a cochlear implant is fitted between 1 to 2 years of age. Individuals with better aided residual hearing before implant and greater nonverbal intellect (IQ = 107 or above) might be anticipated to attain age-appropriate scores at smaller test ages or at a somewhat older age at stimulation.

Isaiah and colleagues studied clinical outcomes following cochlear implantation in children with inner ear anomalies. They examined the demographic, clinical, surgical, and speech perception results of 497 patients evaluated at children's medical center's paediatric cochlear implant programme between January 1, 1986, and December 31, 2014. This study also shows that speech perception scores after cochlear implantation in children with inner ear defects are lower than in children with normal anatomy. Despite this, the benefit of sound awareness and open set speech recognition with cochlear implantation in children with inner ear malformation (IEM) may support the use of a CI in these individuals. Prior to surgery, families should be counselled on realistic expectations for the development of speech perception in the setting of IEMs other than an expanded vestibular aqueduct (Isaiah et al., 2017).

Tolan and colleagues conducted a study in year 2017 that examined delays in awareness of sound and repetition in toddlers undergoing implantation through public insurance versus private insurance policies. The study included 123 children aging from 1 to 12 years (mean age 5 years 4 months) with cochlear implants. They reported that publicly insured patients (late implantees) had Ling-6 proficiency 6.0 months (95% CI, 5.5-6.5 months) later than privately insured recipients (11.0 vs 5.0 months). Despite having comparable speech detection scores, publicly insured cochlear implant recipients experienced a considerable major delay in achieving competency in an essential criterion for sound recognition and identification for which the reasons could be limited device use or number of therapy sessions received (Tolan et al., 2017).

2.2 Questionnaire based measures in Cochlear Implantees

The Revised Categories of Auditory Performance (R-CAP) developed by (Archbold et al., 1995) and Meaningful auditory integration scale (MAIS) given by (Zimmerman & Philips, 1997) are used to assess the auditory skills and speech perception abilities of individuals, especially children, who use cochlear implants. The R-CAP scale categorizes performance into different levels based on the individual's ability to perceive and understand speech sounds. The MAIS is used to evaluate meaningful use of sound in everyday situations by children using cochlear implants. Several studies reported outcome measures based on R-CAP, MAIS and speech intelligibility rating (SIR) scales (Bakhshaee et al., 2007; Gupta, 2012; Ashori, 2013; Jalil-Abkenar et al., 2013; Hota, 2019).

Bakhshaee et al (2007) studied CAP and SIR to assess auditory performance in cochlear implanted children. Children's performance was evaluated up to 5 years after cochlear implantation. At 6 months, the mean CAP in children with hearing impairment was 3.25, 5.34 after one year, and 6.01 three years following cochlear implantation. After six months, 91% of youngsters could recognize speech sounds. By one year after cochlear implantation, 96% of patients could distinguish speech sounds. By the end of three years after cochlear implantation, 84% of youngsters could identify common sentences without speech reading. The authors find that children's auditory skills continue to improve five years after cochlear implantation.

Gupta (2012) studied the outcomes of cochlear implant users by considering pre-operative parameters such as CAP, SIR, and MAIS. The study comprised 30 children who were implanted in a tertiary referral centre. Postoperatively, the individuals were followed up on at 3 months, 6 months, and 12 months following implantation for a maximum of 1 year. Using the previous score system, many determinants affecting the outcome were examined, and a prediction algorithm was built in the framework of the Indian subcontinent. Their model revealed that factors such as implantation age, length of auditory deprivation, and preserved hearing influenced the outcomes of children who received cochlear implants.

Jalil-Abkenar et al. in 2013 investigated verbal intelligibility and auditory perception in children with cochlear implants, hearing aids, and normal hearing. The study included 60 youngsters in the age range of 5 to 7 years. The participants were further divided into three groups of 20 children each. A convenient sampling strategy was used to include children in the first two groups. Children in groups one and two were fitted with cochlear implants and hearing aids, respectively. CAP and SIR were administered to all the participants. They concluded that the mean CAP and SIR scores of children with normal hearing were considerably higher (better) than the mean scores of children in other two groups (hearing aids & CI users). Furthermore, children with cochlear implants performed much better on CAP tests than children with hearing aids. The mean scores of SIR in children with cochlear implants did not differ from those of children with hearing aids. Thus, using the previously mentioned rating scales, these authors concluded that verbal intelligibility and aural perception are complicated and multifaceted phenomena. Furthermore, improving speech abilities requires a one-of-a-kind rehabilitation programme.

Hota (2019) calculated speech intelligibility and auditory performance in 40 children who had bilateral severe to profound sensorineural hearing impairment since birth. The age of the children at cochlear implantation ranged from 19 months to 109 months, with an average of 50.23 months, a standard deviation of 17.74 months, and a median of 48 months. These children were fitted with cochlear implants. The SIR was used to assess speech intelligibility, while the revised CAP score was used to assess auditory performance. SIR and revised CAP were evaluated preoperatively and three, six, and one year after cochlear implantation. The total time of auditory deprivation, duration of hearing aid use before the cochlear implantation, total duration of auditory verbal therapy prior to cochlear implantation, and age at which cochlear implantation was performed were all statistically analysed. Study reported that lesser duration of auditory deprivation and the younger age of cochlear implantation showed better speech intelligibility and audiological performance following cochlear implantation.

Ashori in 2020 compared speech perception in children who had hearing aids and cochlear implants to children who did not have cochlear implants or hearing aids. There were 75 male kindergarten students from 4 to 6 years of age who participated in the study. These children were separated into three groups of 25 in each group. The SIR and CAP were administered to all participants. The findings indicated that children with normal hearing had considerably higher (better) average scores for auditory perception and speech intelligibility than the other two groups (hearing aids & CI users). Mean auditory perception ratings in the cochlear implant group were considerably higher (better) compared to hearing aid users. At the same time, children in the cochlear implant and hearing aid groups showed no significant differences in speech intelligibility. To summarize, the rating scales were utilized in this study to emphasize the value of cochlear implantation at a younger age and how it dramatically changes the auditory experience of children with hearing loss.

Liu and Gao (2019) grouped 98 children with cochlear implants into three age groups. Group A consisted of children aged 3 years, Group B included children aged 4 to 7 years, and Group C of children aged 8 to 16 years. Following surgery, these children were monitored for one year to assess their speech and hearing abilities. Before CI and after 3, 6, and 12 months after cochlear implantation, various assessment methods and rating scales such as the complete Auditory Perception Assessment, MAIS, CAP, and SIR were done. In each age group, the MAIS score recorded after the implant activation was markedly higher (better) than that before the surgery, indicating the improvement of the speech intelligibility. The differences among groups were not statistically significant before the surgery or at 3 months or 6 months after the device activation. But, 12 months after activation, the CAP scores showed significant differences across different age groups. The authors successfully assessed speech perception skills using various assessment instruments and rating systems.

The scores on all scales after cochlear implantation improved gradually as the recovery period increased.

Studies have also focused on analysing the outcomes using both rating scales and speech perception measurements. Kameswaran et al (2006) investigated CAP, SIR, and speech perception assessments in 100 cochlear implant recipients ranging in age from 1 year to more than 30 years. After comparison of results between early implantees and late implantees, they found that for the equal hearing age of both the groups, early implantees scored better than late implantees in both CAP and MAIS. The study emphasized that early implantation promotes appropriate auditory, speech, and language development processes. However, there was no comparison of rating scales with speech perception tests.

Similarly, Hwang et al., (2016) investigated the causes, hearing, and speech performance of Mandarin-speaking users before and after cochlear implant re-implantation. Among 589 children who had cochlear implantation, 18 individuals underwent re-implantation on whom the authors effectively used Categorical Auditory Performance and the Speech Intelligibility Rating. These scores were much higher after re-implantation than before the procedure.

Govaerts et al., (2002) compared the CAP scores of children with cochlear implants to children with normal hearing. The age range was 1-6 years for longitudinal group and 9 months to 6 years for cross-sectional group. The authors created normative data using data from 84 normal-hearing children aged 12, 18, 24 and 30 months. A mean CAP score of 2 was obtained at the age of 12 months, while CAP scores of 5, 6, and 7, respectively, were obtained at the ages of 18, 24, and 30 months.

A second version of the CAP (CAP-II) was employed in a series of research that examined auditory ability solely using CAP (Colletti et al., 2012). They compared four age groups of children: 2 to 6 months (12 children), 7 to 12 months (9 children), 13 to 18 months (11 children), and 9 to 24 months (13 children). These children received cochlear implants and were observed for four years. They discovered that youngsters implanted between the ages of 2 to 6 months outperformed their contemporaries inserted later. Children under the age of 6 months outperformed all other implanted groups. The rating scale was effectively employed by the authors to demonstrate substantial differences between children implanted before the age of two. There was also no significant difference between the youngest CI group and their normal hearing peers. As a result, the age of implantation was an important factor in outcome measurements.

Similarly, Schauwers et al., (2004) used the CAP score to compare children at the one-year follow-up. The study included 10 children aged 6 to 18 months. They discovered that 80% of children implanted between the ages of 6 and 18 months had CAP scores between 5 and 6. Though not statistically significant, a trend was seen in which children implanted at roughly 18 months of age typically lag behind their normal hearing peers. Children implanted before the age of 1 year, on the other hand, followed a typical curve. Overall, children who were implanted before the age of 12 months demonstrated normal progress on CAP as early as three months after cochlear implantation. Children implanted in their second year of life required at least 12 months to get age-appropriate CAP scores.

Suh et al., (2009) included in their study 86 children with substantial hearing loss who were implanted before the age of six years and had been observed for more than three years. They concluded that four children implanted between the ages of 0 and 24 months improve faster on the CAP scale than their older CI peers. As a result, CAP is a widely used rating system with children who have cochlear implants. There are, however, different ranking scales. In a multi-objective study, Fortunato-Tavares et al. (2012) employed MAIS as one of the questionnaires to assess and analyse hearing skills on 10 children aged 4 to 8 years with cochlear implants. The authors employed MAIS to successfully correlate auditory skills and quality of life in these children. The authors discovered no link between the development of auditory skills as measured by MAIS and the children's quality of life. This revealed that there was no direct relationship between the skills included in this questionnaire and better quality of life. This was mostly from the standpoint of the parents. According to these researchers, a probable explanation is that certain clinical measures are not observed directly by non-experts, such as parents.

In a prospective research of 50 children utilizing CI, Gaurav et al (2020) employed MAIS and CAP measures to investigate the impact of CI age on auditory outcomes. Only 15 of them (30%) underwent CI when they were "more than 5 years" old, whereas 35 kids (70%) did it when they were "5 years or less" old. They concluded that knowing the age of implantation can help predict auditory perception outcome and provide optimal counselling to CI candidates' families.

Li et al., (2022) did a study to look at the link between preserved hearing and developing auditory speech ability in Mandarin-speaking toddlers who were fitted with implant devices. The study comprised 24 prelingually deaf children with ages ranging from 12 to 67 months, with a mean age at implantation of 37.21+/-19.93 months. Infant-toddler meaningful auditory integration scale/meaningful auditory integration scale, speech intelligibility rating, and meaningful use of speech scale categories were used to assess auditory performance and speech intelligibility longitudinally. Children were classified as having "better" or "worse" residual hearing based on their postoperative pure tone average threshold. They reported that those children with better residual hearing performed better in early auditory and verbal outcomes.

The above review of literature reflects studies reported outcome measures in terms of speech perception among cochlear implantees, in different conditions and comparison with typically developing children. Further, there are several factors such as age of implantation, device used, duration of rehabilitation, socioeconomic status, auditory deprivation etc. which could influence these outcomes are discussed. At the end, early identification and intervention is the key for the success of cochlear implantation as discussed. Therefore, cochlear implant team needs to emphasize on the early identification and intervention for the age appropriate speech and language development using cochlear implants.

Chapter 3

METHOD

A comparative research design was adopted. To achieve the above aim and objective of the study, the below mentioned method was used.

Participants

There was a total of 20 participants, out of which 10 children with cochlear implants (Clinical group) and 10 typically developing children (Control group) in the age range of 4-7 years (mean age 5.9 years) were considered for the study. All the participants were native speakers of the Kannada language. The inclusion and exclusion criteria for each group were as mentioned below:

Control group (Typically developing children): This group was considered as a reference group because it consisted of children with normal hearing and age-appropriate speech and language. Their pure tone thresholds were within 15 dB HL in the frequencies between 250 Hz to 8000 Hz. The functioning of the middle ear system was confirmed with the presence of A/As-type tympanograms with acoustic reflexes present at 90 dB HL in both ears for at least 500 Hz, and 1000 Hz. Also, their speech identification scores in quiet were between 80-100% at 40 dB SL (ref: PTA) in both ears. Based on structured case history, it was ensured that they had no history of hearing loss and no otologic or neurologic problems. On the day of testing, they had no illness.

Clinical group (Children using cochlear implants): Participants in this group were using cochlear implants at least in one ear. Only one company's implant users were preferred to restrict the device related variability if any. All the participants in this group should have had a stable map after switch-on to the cochlear implants. All the participants' implant age was between 6 to 18 months. The aided responses with device were well within the speech spectrum. They had attended regular listening training between 6 to 18 months. There were no participants who had any history of cochlear anomalies, and co-morbid conditions (autism, mental retardation, cognitive deficit etc) in this study.

Test Environment

All the audiological testing was carried out in an acoustically and electrically shielded room where the levels were within the permissible limits (ANSI S3.1; 1991).

Instrumentation

- Calibrated dual channel GSI – Audiostar Pro diagnostic audiometer was used for sound field audiometry, MESP-K test, and Ling Six sound identification test.
- Calibrated GSI –Tympstar (Version 2.0) middle ear analyser was used for tympanometry and Acoustic reflexes.
- Calibrated Biologic Navigator Pro Evoked potential (version 7.2.0) system was used to carry out click evoked ABR.
- ILO (Version 6) was used for measuring TEOAEs.
- Personal computer (HP Pavilion PC) was used for the presentation of auditory stimuli.

Ethical clearance

An informed written consent was taken from the parents/caregivers of each client before participation in the study.

Procedure

Detailed structured case history was taken from all the participants to get information about their medical history, nature and duration of hearing loss and to rule out any middle ear pathologies. The modified Hughson and Westlake approach (Carhart & Jerger, 1959) was used to determine pure tone threshold at octave frequencies ranging from 250 Hz to 8000 Hz for air conduction threshold and 250 Hz to 4000 Hz for bone conduction threshold.

The individuals were advised not to swallow or move their head in any other way throughout the immittance evaluation. Tympanometry was performed with a 226 Hz probe tone at 85 dBSPL. Using a pump speed of 50 daPa/s, a tympanogram was produced by varying the pressure inside the ear canal from +200 to -400 daPa. Using a 226 Hz probe tone, the ipsilateral and contralateral acoustic reflex thresholds for 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz were measured.

The reproducibility of transient evoked otoacoustic emissions was documented utilizing click stimuli and signal-to-noise ratio (SNR). For TEOAEs, +3 dB SNR at two consecutive frequencies was employed as the cut off threshold, with more than 80% reproducibility.

Auditory brainstem response recording was done using Biologic Navigator Pro Evoked (version 7.2.0) system. Electrodes were placed at Fz, M1 and Fpz position. Electrode impedance should be less than 5 kΩ. To present the stimulus, ER-3A insert earphone was used. The details about the click evoked ABR protocol were mentioned below in table 3.1.

Table 3.1

Click evoked ABR stimulus and acquisition protocol

Click evoked-ABR (Threshold estimation)			
STIMULIUS PARAMETERS		ACQUISITION PARAMETERS	
Type of stimuli	Click (100ms)	Analysis Time	12ms
Intensity	Between 90dBnHL to 30dBnHL	Filter Setting	High pass: 100 Hz, Low pass: 3000 Hz
Repetition rate	30.1/sec	Amplification	100000
Polarity	Rarefaction	Number of channels	2
Stimuli	1500	Number of recordings	2
		Transducer	Insert earphone (ER-3A) Insert earphone (ER-3A)
		Electrode Montage	-Noninverting electrode (+): Upper forehead (Fz) or Vertex (Cz) -Inverting electrode (-): Both ear mastoids. -Ground electrode: Lower forehead (Fpz)

For the clinical group, Mapping levels (for cochlear implantees) were kept at recent and best program for speech sound accessibility prior to the speech perception test. Sound field audiometry was done for octave frequencies starting from 250 Hz to 8000 Hz using calibrated double channel Inventis piano coupled to RadioEar SP105 speakers. Using modified Hughson and Westlake (Carhart & Jerger, 1959) procedure, aided threshold was estimated.

Test material

The Speech perception test was done using the Modified Early Speech Perception Test in Kannada (MESP-K) (Priya, 2017). The standard version of MESP-Kannada was administered where three modalities of auditory perception i.e. Syllable categorization (Bisyllabic, Trisyllabic, & Polysyllabic), Bisyllabic word identification and Vowel identification were assessed. The recorded speech identification test material was presented through a personal computer and the output was routed through a calibrated audiometer. Stimulus was presented in a sound-field condition at 40 dB SL (ref PTA).

Instruction

Participants were instructed to respond through picture identification mode. Before testing, the child was made familiar with the tokens used in the MESP-K to understand the procedure. To ensure that the child knew the words, first the testing had to be done through an audio-visual mode. If the child was able to identify all the words through the audio-visual mode, then the actual testing through auditory modality could be carried out.

Scoring

All the stimuli were presented twice in the auditory modality. For the syllable categorization subtest, a score of ‘1’ was awarded for each correctly identified word within the syllable category. For the word identification subtest, a score of ‘1’ was awarded for each correct identification of word and ‘0’ for each incorrect word identification.

Identification of Ling's six sound test (Ling, 1978) (/a/, /i/, /u/, /m/, /s/ & /sh/) was done for both children with cochlear implants and typically developing children. A repetition task was done to estimate the speech identification scores in Kannada speaking children with cochlear implants and typically developing children. All the available stimulus in this test were converted into recorded audio samples. The recorded material was presented through a computer, the output of which was routed through an audiometer. Stimulus was presented in a sound-field condition at 40 dB SL (ref PTA) and participants were instructed to repeat the sounds heard.

For the perceptual measures, each group was assessed with:

1. Revised Categories of Auditory Performance (R-CAP) (Archbold et al., 1995), a scale for evaluating the outcomes of paediatric cochlear implantation in daily life. It distinguished itself from more technical approaches by being simply administered and comprehended by non-specialist professionals and parents. The R-CAP consisted essentially of a nonlinear, hierarchical scale on which children's developing auditory abilities were rated in 12 categories of increasing difficulty from no awareness of environmental sounds (category 0) to telephone use with an unfamiliar speaker (category 12). It was the only auditory perception scale that was applicable to children irrespective of age and was particularly suitable for use in younger children. This scale was administered in an interview format, where questions were asked in ascending order from 0 to 12 to parent/caregiver of the children and category was determined according to auditory performance.
2. The Infant-Toddler Meaningful Auditory Integration Scale (IT-MAIS) developed by (Zimmerman-Phillips, 1997) /Meaningful Auditory Integration Scale (MAIS) developed by (Robbins et al., 1991), both were used concomitantly, depending on the participant's

age. It was a structured interview schedule designed to assess the child's spontaneous responses to sound in his/her everyday environment. The assessment was based upon information provided by the child's parent(s) in response to 10 probes. These 10 probes assessed three main areas: 1) vocalization behaviour; 2) alerting to sounds; and 3) deriving meaning from sound. Specific scoring criteria had been developed for each of the 10 probes. This parent-report scale was administered in an interview format. Performance was scored in terms of the total number of points accrued out of 40 possible points. Each question had a potential of 0 (lowest) to 4 (highest) points. Scoring was based on the percentage of time that a child demonstrated specific auditory abilities.

Statistical Analyses

The statistical analyses included descriptive statistics (mean & standard deviation) of MESP-K test, Ling six sound identification test, R-CAP and MAIS/IT-MAS scores for both control and clinical group. Further, normality test was done using Shapiro-Wilk test. Since the normality test showed normal distribution of the data, parametric test was done. One-way analysis of variance (ANOVA) was done to compare each parameter between the groups (control & clinical). Paired 't' test was done to compare between audio and audio-visual mode for each group.

Chapter 4

RESULTS

The collected data were tabulated and analyzed using Statistical Package for the Social Sciences (SPSS) version 21.0. One-way ANOVA test was used to compare the performance between cochlear implanted and typically developing children on various outcome measures. The outcome measures included were modified early speech perception test in Kannada (with syllabic categorization, bisyllabic word identification & vowel identification), revised categories of auditory performance, meaningful auditory integration scale and Ling's sound identification test. The descriptive statistics includes mean and standard deviation (SD) for MESP-K test (in both audio and audio-visual condition), Ling's sound identification test, CAP and IT-MAIS among both cochlear implanted and typically developing children.

4.1 Modified early speech perception test (MESP-K)

The MESP-K test include syllabic categorization, word identification, vowel identification in audio- and audio-visual mode which were measured among cochlear implant users and compared with TDC with normal hearing. The findings of these outcome measures are mentioned under below headings:

4.1.1 *Syllabic categorization- Bisyllabic Words*

The mean scores of the bisyllabic words showed lower (poorer) scores for children using cochlear implants compared to TDC in each mode i.e. audio- and audio-visual mode (Table 1). Further, standard deviation (SD) was reported to be higher (more variability) in CI user compared to TDC in both audio and audio-visual mode. Between two modes of the presentation among CI users, the mean scores of the audio-visual mode was higher (better) compared to audio mode alone. Whereas, among typically developing children, there were equal mean scores obtained for audio and audio-visual mode. Figure 1 showed the mean and 95% confidence interval of bisyllabic words among CI users and TDC in both audio and audio-visual mode.

Table 4.1

The mean and standard deviation (SD) of the audio and audio-visual performance for bisyllabic words

Population		**Audio-visual mode**		**Audio mode**	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	100.00	0.00	100.00	8.43
CI	10	87.50	24.29	76.25	19.04

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear Implanted children

One-way ANOVA was done to compare between cochlear implanted children and typically developing children performance in audio as well as in audio-visual modality for syllabic categorization using bisyllabic words. The results revealed statistically significant differences between groups in audio mode [$F(1,19)=9.21$; $p=0.007$] whereas there were no statistically significant difference between two groups noticed in audio-visual mode [$F(1,19)=2.64$; $p=0.121$]. Further, to compare between audio and audio-visual mode in each group, Paired ‘t’ test was done which showed no significant differences between two modes of presentation among children using cochlear implants [$t(9)= -1.06$; $p=0.317$] as well as TDC [t(9)= -1.40; p=0.193] for syllable categorization of bisyllabic words.

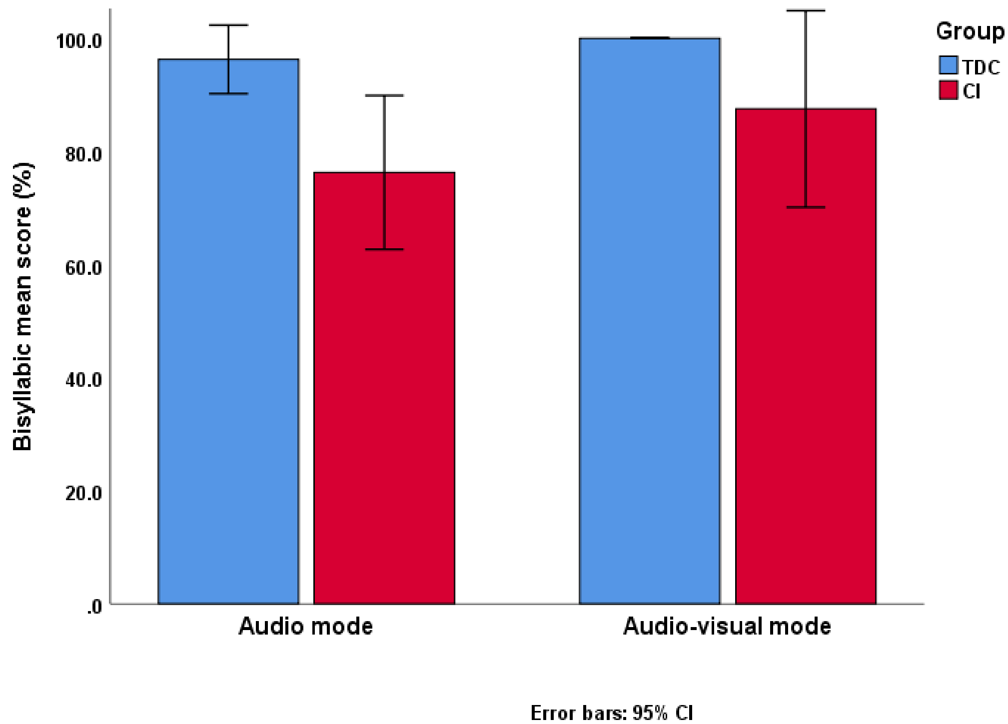

Figure 4.1

Mean and 95% confidence interval (CI) in audio and audio-visual modality for bisyllabic words

4.1.2 *Syllabic categorization- Trisyllabic Words*

The mean scores for trisyllabic words were lower (poorer) for children with cochlear implants than for typically developing children in both audio and audio-visual modes, as shown in Table 2. Further, standard deviation was found to be higher (more variability) for children using cochlear implants compared to typically developing children in both audio and audio-visual modes. Among children using cochlear implants, the mean scores for the audio-visual mode were higher (better) than for the audio mode alone. For typically developing children, the mean scores for the audio and audio-visual modes were the same. Figure 2 shows the mean scores and 95% confidence intervals for trisyllabic words among children with cochlear implants and typically developing children in both audio and audio-visual modes.

Table 4.2

The mean and standard deviation of the audio and audio-visual performance for trisyllabic words

Population	**Audio-visual mode**			**Audio mode**	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	95.00	10.54	95.00	6.45
CI	10	92.50	12.07	67.50	19.72

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear implanted children

One-way ANOVA was done to compare between cochlear implanted children and typically developing children performance in audio as well as in audio-visual modality for syllabic categorization using trisyllabic words. The results revealed statistically significant differences between groups in audio mode [$F(1,19)=17.56$; $p=0.001$] whereas there were no statistically significant difference between two groups noticed in audio-visual mode [$F(1,19)=0.24$; $p=0.628$]. Further, to compare between audio and audio-visual mode in each group, Paired 't' test was done which showed significant differences between two modes of presentation among children using cochlear implants [$t(9) = -6.00$; $p=0.00$], but not for TDC [$t(9)= 0.00$; $p= 1.00$] for syllable categorization of trisyllabic words.

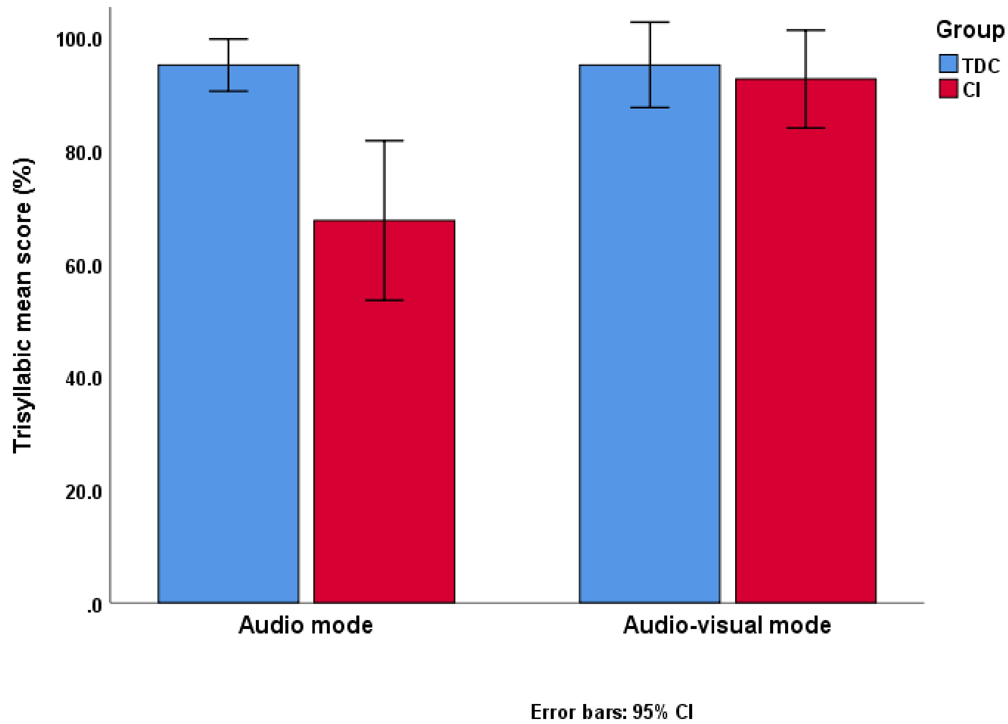

Figure 4.2

Mean and 95% confidence interval (CI) in audio and audio-visual modality for trisyllabic words

4.1.3 *Syllabic categorization- Polysyllabic Words*

In each modality, audio- and audio-visual, the mean scores of polysyllabic words were lower (poorer) for children having cochlear implants compared to TDC (Table 4). Furthermore, the standard deviation in both audio and audio-visual mode was reported to be larger (more variable) in CI users compared to TDC. When comparing two modalities of presentation among CI users and normally developing youngsters, the audio-visual mode had higher (better) mean scores than the auditory mode alone. Figure 3 depicted the mean and 95% confidence interval of polysyllabic words among CI users and TDC in both audio and audio-visual mode.

Table 4.3

The mean and standard deviation of the audio and audio-visual performance for polysyllabic words

Population	**Audio-visual mode**			**Audio mode**	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	100.00	0.00	90.00	9.86
CI	10	65.00	29.34	55.00	22.20

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear implanted children

One-way ANOVA was done to compare between cochlear implanted children and typically developing children performance in audio as well as in audio-visual modality for syllabic categorization using polysyllabic words. The results revealed statistically significant differences between groups in audio mode [F(1,19)= 20.75; p=0.00] as well as in audio-visual mode [F(1,19)= 14.22; p=0.00]. Further, to compare between audio and audio-visual mode in each group, Paired 't' test was done which showed significant differences between two modes of presentation among TDC [t(9)= -3.20; p= 0.01], but not for children using cochlear implants [t(9)= -0.83; p=0.42] for syllable categorization of trisyllabic words.

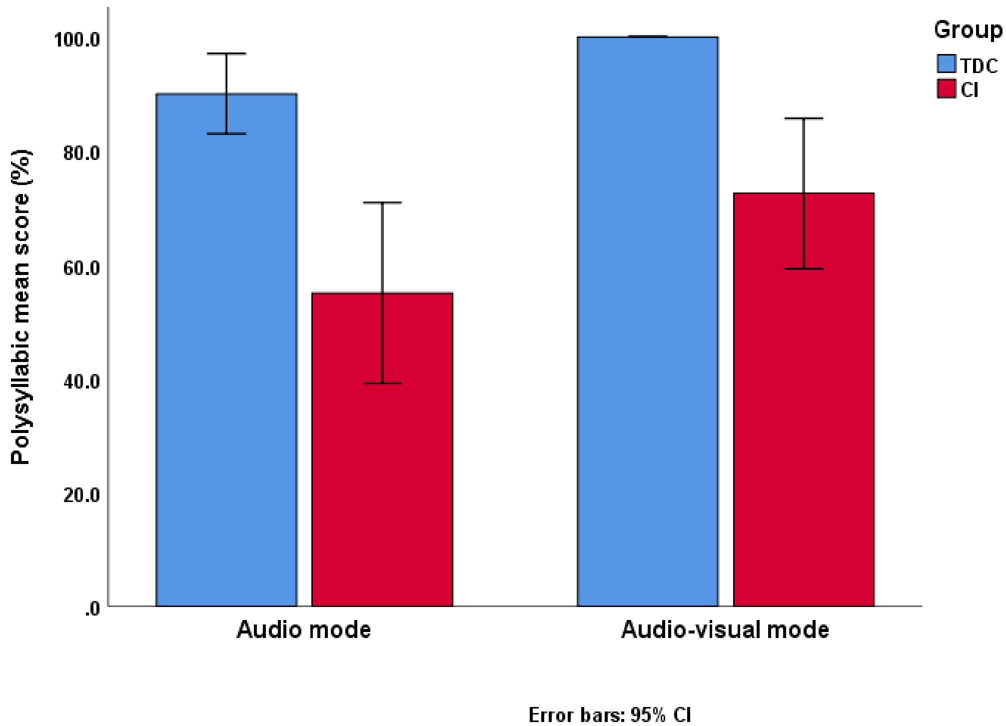

Figure 4.3

Mean and 95% confidence interval (CI) in audio and audio-visual modality for polysyllabic words

4.1.4 *Word identification*

According to Table 5, children with cochlear implants had lower (poorer) word recognition scores than typically developing children in both audio and audio-visual modes. The standard deviation was found to be higher (more variability) for children using cochlear implants (CI) compared to typically developing children in both audio and audio-visual modes. The mean scores for the audio-visual mode were higher (better) than the audio mode alone for both children using cochlear implants and typically developing children. Figure 4 displays the mean word identification scores and their 95% confidence intervals for both children using cochlear implants and typically developing children in both audio and audio-visual modes.

Table 4.4

The mean and standard deviation of the audio and audio-visual performance for word identification

Population	**Audio-visual mode**			**Audio mode**	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	100.00	0.00	98.32	2.93
CI	10	79.98	22.29	75.80	13.15

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear implanted children

One-way ANOVA was done to compare between cochlear implanted children and typically developing children performance in audio as well as in audio-visual modality for word identification score. The results revealed statistically significant differences between groups in audio mode [$F(1,19)= 27.91$; $p=0.00$] as well as in audio-visual mode [$F(1,19)= 8.06$; $p=0.01$]. Further, to compare between audio and audio-visual mode in each group, Paired 't' test showed no significant differences between two modes of presentation among TDC [$t(9)= -1.80$; $p= 0.10$] and for children using cochlear implants [$t(9)= -0.53$; $p=0.60$] for word identification score.

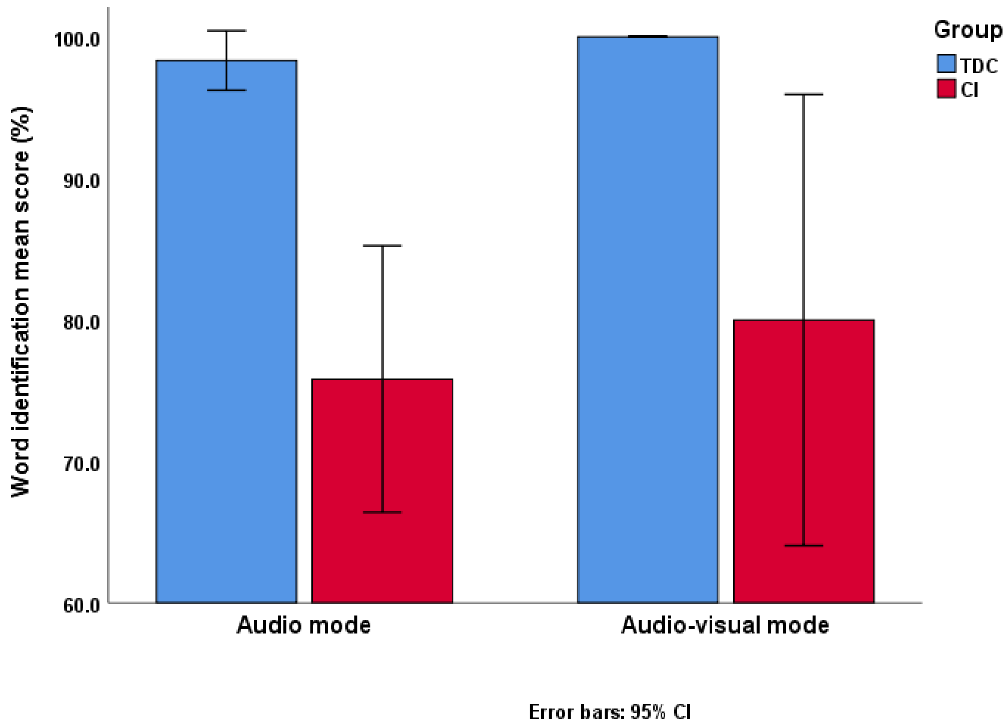

Figure 4.4

Mean and 95% confidence interval (CI) in audio and audio-visual modality for word identification scores

4.1.5 *Vowel identification*

In each mode, audio- and audio-visual, the mean scores of the vowel identification score were lower (poorer) for children with cochlear implants compared to TDC (Table 6). Furthermore, the CI user's standard deviation was reported to be larger (more variable) than the TDC in both audio and audio-visual mode. When comparing two modalities of presentation among CI users and normally developing children, the audio-visual mode had higher (better) mean scores than the auditory mode alone. Figure 5 depicted the mean and 95% CI of vowel identification scores among CI users and TDC in both audio and audio-visual mode.

Table 4.5

The mean and standard deviation of the audio and audio-visual performance for vowel identification

Population	Audio-visual mode			Audio mode	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	100.00	0.00	100.00	0.00
CI	10	91.00	9.94	74.00	9.06

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear implanted children

One-way ANOVA was done to compare between cochlear implanted children and typically developing children performance in audio as well as in audio-visual modality for vowel identification score. The results revealed statistically significant differences between groups in audio mode [$F(1,19)= 82.21$; $p=0.00$] as well as in audio-visual mode [$F(1,19)= 8.19$; $p=0.01$]. Further, to compare between audio and audio-visual mode in each group, Paired 't' test was done which showed significant difference between two modes of presentation among children using cochlear implants [$t(9)= -4.29$; $p=0.02$] but not for TDC [$t(9)= -1.80$; $p= 0.10$] for word identification score.

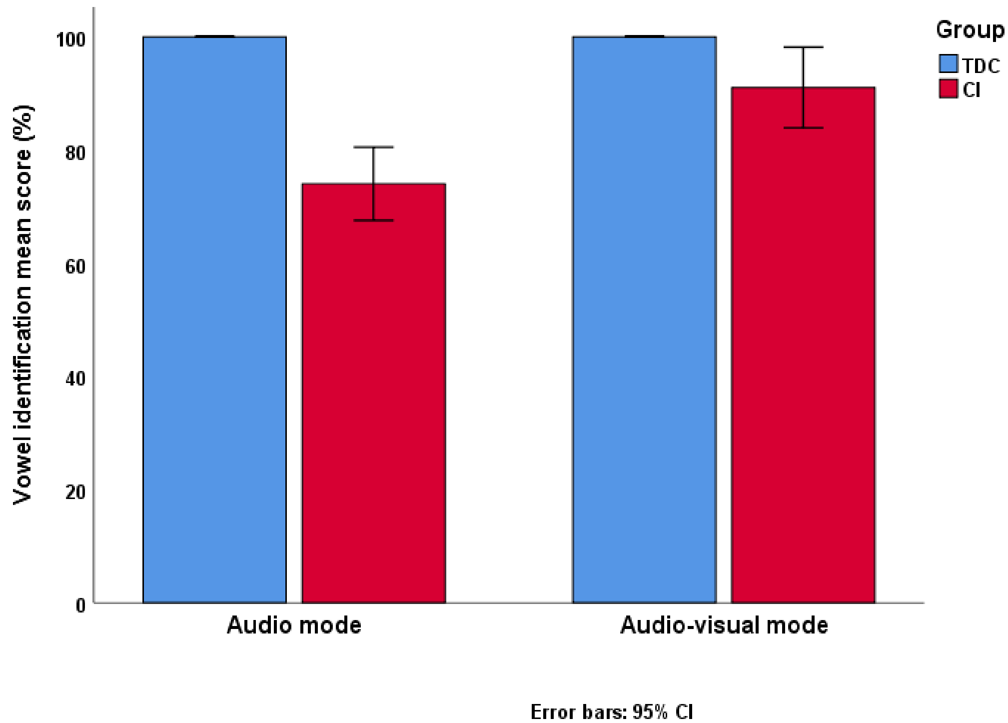

Figure 4.5

Mean and 95% confidence interval (CI) in audio and audio-visual modality for vowel identification

4.2 Ling's Sound Identification Test

In comparison to TDC, children with cochlear implants had poorer thresholds on the Ling's sound recognition test (Table 7). Additionally, it was noted that CI users' standard deviations were larger (more variable) than TDC. In both audio and audio-visual modes,

Figure 6 displayed the mean and 95% confidence interval of the vowel identification score among CI users and TDC.

Table 4.6

The mean and standard deviation of Ling's Six sound test

Stimulus		**Typically developing children**		**Cochlear Implanted children**	
	N	Mean (Response in dB)	SD	Mean (Response in dB)	SD
/a/	10	12.00	2.58	34.50	7.97
/i/	10	13.00	2.58	38.50	7.09
/u/	10	12.50	3.53	27.00	12.06
/m/	10	13.50	2.41	35.00	11.30
/s/	10	14.50	2.83	25.50	7.97
/sh/	10	13.50	2.41	24.50	8.31

N: Number of participants; SD: Standard deviation

One-way ANOVA test was done to compare between typically developing children and cochlear implanted children performance for Ling's sound identification test. The results revealed statistically significant differences between groups for /a/ [F(1,19) = 72.036; p=0.000], /i/ [F(1,19) = 114.190; p=0.000], /u/ [F(1,19) = 13.302; p=0.002], /m/ [F(1,19) = 34.597; p=0.000], /s/ [F(1,19) = 605.000;p=0.001], and /sh/ [F(1,19) = 16.133; p=0.001] speech sounds.

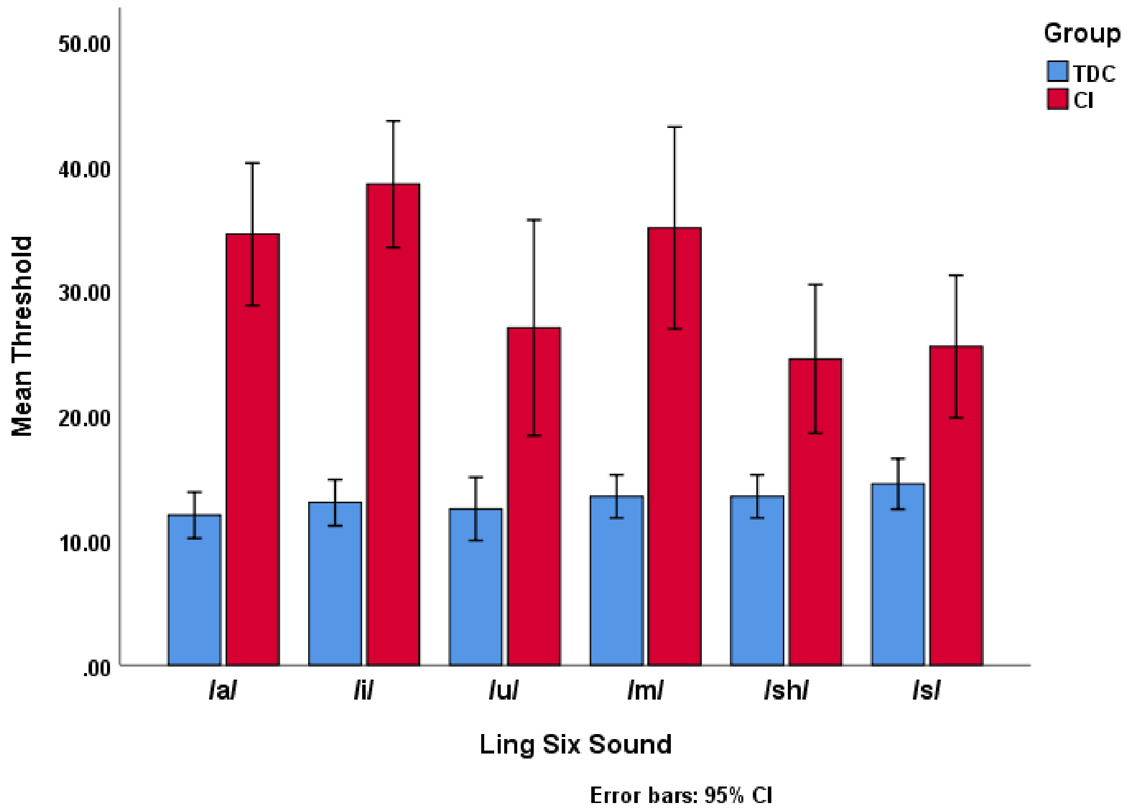

Figure 4.6

Mean and 95% confidence interval (CI) in Ling's sound identification test

4.3 Perceptual measures

There are two perceptual measures which include R-CAP and MAIS used for assessing performance among CI users and typically developing children. In comparison to children who use cochlear implants, TDC's thresholds were better according to the R-CAP and MAIS mean scores (Table 8). Additionally, it was noted that CI users' standard deviations were larger (more variable) than TDC users. Figure 7 and 8 shows the mean and 95% confidence interval of the R-CAP and MAIS scores respectively in both groups.

Table 4.7

The mean and standard deviation of revised categories of auditory performance and Meaningful auditory integration scale

Population		**R-CAP**		MAIS	
	N	Mean (%)	SD	Mean (%)	SD
TDC	10	100.00	0.00	100.00	0.00
CI	10	84.96	12.30	84.75	12.04

N: Number of participants; SD: Standard deviation; TDC: Typically developing children; CI: Cochlear implanted children; R-CAP: categories of auditory performance; MAIS: Meaningful auditory integration scale

One-way ANOVA test was done to compare between typically developing children and cochlear implanted children for revised categories of auditory performance and meaningful auditory integration scale ratings. The results revealed statistically significant differences between groups for R-CAP [F(1,19) = 14.93; p=0.001] as well as for MAIS [F(1,19) = 16.03; p=0.001] rating scale.

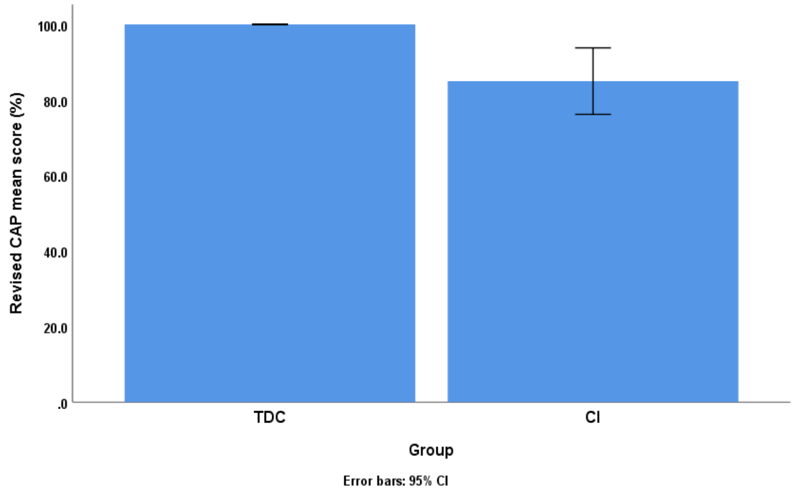

Figure 4.7

Mean and 95% confidence interval in R-CAP scale

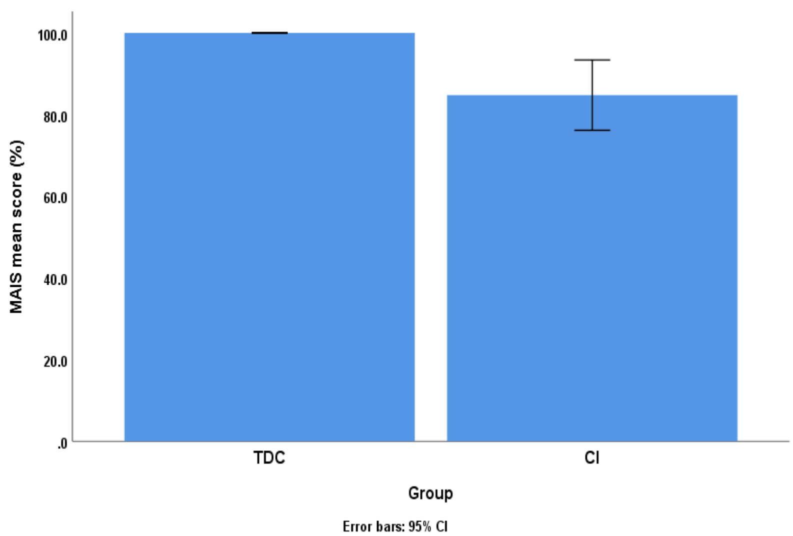

Figure 4.8

Mean and 95% confidence interval in MAIS scale

Chapter 5

DISCUSSION

The purpose of the present study was to investigate the speech perception outcomes in Kannada speaking children with cochlear implants in comparison to typically developing children using behavioural measures and rating scales. For this purpose, Modified early speech perception test in Kannada (MESP-K), Ling's sound identification test, revised categories of Auditory Performance (R-CAP), Meaningful Auditory Integration Scale (MAIS) were administered at minimum five months of post-cochlear implantation in children using cochlear implants.

5.1 Modified early speech perception test in Kannada (MESP-K) in cochlear implant users

Syllabic categorization was estimated in typically developing children and cochlear implant users in both audio and audio-visual conditions. The mean syllabic (bisyllabic, trisyllabic and polysyllabic words) categorization scores were lower (poorer) in children with cochlear implants in both audio and audio-visual conditions compared to typically developing children. Furthermore, the mean scores in audio mode were poorer compared to audio-visual mode in CI users. The present study findings are in consonance with other studies (Eisenberg et al., 2001; Most, Rothem & Luntz, 2009;) which reported better performance in audio-visual condition compared to only auditory mode in cochlear implantees. Most et al (2009) studied auditory, visual and audio-visual speech perception among late cochlear implantees and reported poorer performance in auditory alone compared to audio-visual and they should be exposed to both modality for better audio-visual integration among cochlear implantees. Similarly, study done by Eisenberg and colleagues reported poorer performance of cochlear implantees in auditory alone mode compared to audio-visual mode. In addition, they reported more discrepancy between audio-visual and audio mode compared to hearing aid users and typically developing children. They also reported better perception of vowel contrast compared to consonant contrast among cochlear implantees as well as typically developing children.

Word identification scores for children with cochlear implants were found to be poorer in both audio and audio-visual conditions when compared to typically developing children. Furthermore, mean scores were better in audio-visual mode compared to audio modality alone for children with cochlear implants. Present study's finding is in agreement with other studies (Vermeulen et al., 2007;Wauters et al., 2008).They reported that better reading comprehension (word identification in audio-visual mode) in children with CI compared to audio mode alone.

Children implanted later performed better on the audio-visual task of speech comprehension measures, whereas children implanted earlier performed better on the auditory only mode of the speech comprehension measures. Moreover, Schorr and colleaguesfound similar effects of age at implantation in a replication of the McGurk audio-visual speech perception test (McGurk & Mac-Donald, 1976; Schorr et al., 2005).They suggested differences could be due to the limited use of the sensitive period i.e. stimulation within 2.5 years. Children with cochlear implants are reported to be influenced more by the visual input rather than the auditory input alone once they are receiving stimulation after the sensitive period.

Vowel identification scores for children with cochlear implants were found to be poorer in both conditions (audio & audio-visual) when compared to typically developing children. Children with cochlear implants performed better when tested using both audio and visual cues, as opposed to when tested using only audio mode. Present study finding is in similar line as reported in literature (Hack & Erber, 1982;Lachs et al., 2001). They reported that children who derived more gain from combined sensory inputs (audio-visual mode) were better performers compared to auditory-alone measures. However, children with hearing impairment probably found the vowel subtest more difficult, as the words differed in only one or two phonemes than that required for the children to perceive subtle spectral variations. These findings are in consonance with study done by Priya (2017).

Ling's sound identification task was administered to both typically developing children and cochlear implanted children. The results showed that the mean score for children with cochlear implants across all sounds was significantly higher (poorer) than that of typically developing children. The above finding indicates that the thresholds of correct identification of sounds are much higher (better) in cochlear implantees than typically developing children. Tolan and colleaguereported that late implantees had Ling-six sounds proficiency later than early implantees (Tolan et al., 2017).

5.2. Perceptual measures (R-CAP & MAIS) in children with cochlear implants

There are two perceptual measures which include R-CAP and MAIS used for assessing performance among CI users and typically developing children. In comparison to children who use cochlear implants, TDC's scores were higher (better) for R-CAP and MAIS scores. Present study’s finding is in agreement with other studies (Colletti et al., 2005;Govaerts et al., 2002; Jalil-Abkenar et al., 2013) where authors established that children using cochlear implants had far lower (poorer) R-CAP scores compared to typically developing children. Baser and colleagues reported factors like age at implantation, use of hearing aid prior to surgery and cochlear morphology have direct impact on the outcomes of cochlear implant (Baser et al., 2020). In a study done by Shakrawal et al (2022), it was revealed that the R-CAP scores in older implantees were not significant after 3- and 6-months post-implantation, but became significant after 12 months of cochlear implantation. In another study done by Karandikar and Valame (2020) reported that late implanted participants did not reach normal or near normal auditory performance based on CAP scores but they did show some promise with implantation provided they had earlier exposure of hearing aids and parent support along with compliance to therapy.

Children using cochlear implants had far lower (poorer) MAIS scores compared to typically developing children reported in other studies (Lu & Qin, 2018, Robbins et al., 2004). In one of the studies done by Lala and colleague reported significant improvement in speech perception skills in everyday situations after cochlear implantation which continued to improve over time. Further, they also reported better results in those children implanted at younger age (Lala et al., 2015). According to Yu-fen and colleague study, age of the patient had shown positive correlation with the MAIS score along with pre-operative language intervention and its beneficial effect. They reported that the cochlear implantation significantly improves language development of children with cochlear implants with better rehabilitation (Yu-fen et al., 2016).

Overall, present study observed poorer performance among cochlear implantees post-implantation for early speech perception tests (syllabic categorization, word identification, and vowel identification) and Ling six sound identification task in comparison to typically developing children with normal hearing. Further, they are also having poorer performance for auditory performance and auditory integration skills in CI children compared to TDC. However, cochlear implantees performance are expected to improve further and might be comparable with typically developing children if they regularly attending the listening training, good home training and received optimum speech and language stimulation. Therefore, early identification and intervention is the key to achieve the alike performance between cochlear implantees and typically developing children.

Chapter 6

SUMMARY AND CONCLUSION

The present study aimed to measure speech perception abilities in Kannada speaking children using cochlear implants in comparison to typically developing children. MESP-K and Ling sound identification test were used as speech perception measures along with R-CAP and MAIS, as questionnaire based subjective measures to compare between two groups. Also, the dependence of CI children on visual cues were assessed in MESP-K test with two modes of presentation i.e., audio and audio-visual.

There was a total of 20 participants, out of which 10 children with cochlear implants (Clinical group) and 10 typically developing children (Control group) in the age range of 4-7 years (mean age 5.9 years) were considered for the study. All the participants were native speakers of the Kannada language. The control group was considered as a reference group because it consisted of children with normal hearing and age-appropriate speech and language. The clinical group consisted of children using cochlear implant on one side and attending regular listening training at least for 5 months. All the participants in this group had a stable map and the aided responses with device were well within the speech spectrum.

The data had a normal distribution and hence a parametric test was carried out. Overall, cochlear implant users performed poorer than typically developing children for syllabic categorization, word identification, and vowel identification in both auditory and audio-visual mode. Further, one-way ANOVA revealed significant differences between groups for bi-syllabic, tri-syllabic, poly-syllabic, word identification and vowel identification in auditory mode. Only poly-syllabic, word identification and vowel identification exhibited a significant difference between groups in the audio-visual mode.

Additionally, the R-CAP and MAIS scores showed statistically significant differences between the two groups. When comparing the audio and audio-visual modes for syllable categorization and word identification, a paired 't' test revealed no significant differences in each group.

The typically developing children scored near perfect on all three subtests (syllable categorization, word identification, and vowel identification) on the standard version of the test. In Ling sound identification test, CI children had higher (poorer) thresholds in comparison to the typically developing children. Auditory skills and speech perception abilities were compared using R-CAP & MAIS which showed better performance in TDC compared to CI children.

Implications of the Study

- The present study outcome will help clinician to understand speech perception abilities of the children using cochlear implants.
- The present study outcome will be helpful in monitoring the progress post-implantation of the child using cochlear implants.
- Add information to the literature.

REFERENCES

Archbold, S., Lutman, M. E., & Marshall, D. H. (1995). Categories of Auditory Performance. *The Annals of Otology, Rhinology & Laryngology. Supplement*, *166*(9 II SUPPL.), 312–314. https://europepmc.org/article/med/7668685

Ashori, M. (2020). Speech intelligibility and auditory perception of pre-school children with Hearing Aid, cochlear implant and Typical Hearing. *Journal of Otology*, *15*(2), 62–66. https://doi.org/10.1016/j.joto.2019.11.001

Bailey, P. J., & Snowling, M. J. (2002). Auditory processing and the development of language and literacy. *British Medical Bulletin, 63(1)*, 135-146. https://academic.oup.com/bmb/article/63/1/135/377474

Bakhshaee, M., R Sharifian, S. M., Ghasemi, M. M., Naimi, M., & Moghiman, T. (2007). Speech development and auditory performance in children after cochlear implantation. *Medical Journal of the Islamic Republic of Iran*, *20*(4), 184–191.

Baser, B., Patidar, M., & Surana, P. (2020). A Study to Determine Various Factors Influencing Auditory Outcomes in Paediatric Cochlear Implantation. *Indian Journal of Otolaryngology and Head and Neck Surgery*, *72*(4), 453–456. https://doi.org/10.1007/s12070-020-01900-2

Bazon, A. C., Mantello, E. B., Gonçales, A. S., Isaac, M. D. L., Hyppolito, M. A., & Reis, A. C. M. B. (2016). Auditory Speech Perception Tests in Relation to the Coding Strategy in Cochlear Implant. *International Archives of Otorhinolaryngology*, *20*(3), 254–260. https://doi.org/10.1055/s-0035-1559595

Black, J., Hickson, L., Black, B., & Perry, C. (2011). Prognostic indicators in paediatric cochlear implant surgery: a systematic literature review. *Cochlear implants international*, *12(2)*, 67-93. Http://Dx.Doi.Org/10.1179/146701010X486417

Bouchard, M.-E., Ouellet, C., & Cohen, H. (2009). Speech Development in Prelingually Deaf Children with Cochlear Implants. *Language and Linguistics Compass*, *3*(1), 1–18. https://doi.org/10.1111/j.1749-818X.2008.00079.x

Carhart, R., & Jerger, J. F. (1959). Preferred Method For Clinical Determination Of Pure-Tone Thresholds. *Journal of Speech and Hearing Disorders*, *24*(4), 330–345. https://doi.org/10.1044/JSHD.2404.330

Chao, X., Luo, J., Wang, R., Hu, F., Wang, H., Fan, Z., & Xu, L. (2022). Long-Term Auditory and Speech Outcomes of Cochlear Implantation in Children with Cochlear Nerve Aplasia. *Ear & Hearing*, *44(3), 558*. https://doi.org/10.1097/AUD.0000000000001299

Ciscare, G. K. S., Mantello, E. B., Fortunato-Queiroz, C. A. U., Hyppolito, M. A., & Dos Reis, A. C. M. B. (2017). Auditory speech perception development in relation to patient's age with cochlear implant. *International Archives of Otorhinolaryngology*, *21*(3), 206–212. https://doi.org/10.1055/s-0036-1584296

Colletti, L., Mandalà, M., & Colletti, V. (2012). Cochlear implants in children younger than 6 months. *Otolaryngology - Head and Neck Surgery (United States)*, *147*(1), 139–146. https://doi.org/10.1177/0194599812441572

Colletti, V., Carner, M., Miorelli, V., Guida, M., Colletti, L., & Fiorino, F. G. (2005). Cochlear implantation at under 12 months: Report on 10 patients. *Laryngoscope*, *115*(3), 445–449. https://doi.org/10.1097/01.mlg.0000157838.61497.e7

Cosetti, M. K., Pinkston, J. B., Flores, J. M., Friedmann, D. R., Jones, C. B., Roland Jr, J. T., & Waltzman, S. B. (2016). Neurocognitive testing and cochlear implantation: insights into performance in older adults. *Clinical interventions in aging,* 603-613. https://doi.org/10.2147/CIA.S100255

Cox, R. M., & McDaniel, D. M. (1989). Development of the Speech Intelligibility Rating (SIR) Test for hearing aid comparisons. *Journal of Speech and Hearing Research*, *32*(2), 347–352. https://doi.org/10.1044/jshr.3202.347

Dowell, R. C., Dettman, S. J., Blamey, P. J., Barker, E. J., & Clark, G. M. (2002). Speech perception in children using cochlear implants: prediction of long-term outcomes. *Cochlear Implants International*, *3*(1), 1–18.

Dutt, S. N., McDermott, A.-L., Jelbert, A., Reid, A. P., & Proops, D. W. (2002). The Glasgow beneet inventory in the evaluation of patient satisfaction with the bone-anchored hearing aid: quality of life issues. *The Journal of Laryngology & Otology*, *116*(28), 7–14.

Eisenberg, L. S., Martinez, A. S., & Boothroyd, A. (2003). Auditory-visual and auditory-only perception of phonetic contrasts in children. *Volta Rev, 103,* 327-346. https://www.researchgate.net/publication/289689969

Feng, G., Ingvalson, E. M., Grieco-Calub, T. M., Roberts, M. Y., Ryan, M. E., Birmingham, P., Burrowes, D., Young, N. M., & Wong, P. C. M. (2018). Neural preservation underlies speech improvement from auditory deprivation in young cochlear implant recipients. *Proceedings of the National Academy of Sciences of the United States of America*, *115*(5), E1022–E1031. https://doi.org/10.1073/pnas.1717603115

Fortunato-Tavares, T., Befi-Lopes, D., Ferreira Bento, R., & Furquim De Andrade, C. R. (2012). Children with cochlear implants: communication skills and quality of Life Abstract. In *Publishing Management System-Brazilian Journal of Otorhinolaryngology) on February* (Vol. 78, Issue 1, 15-25). http://www.bjorl.org/http://www.bjorl.org/

Fryauf-Bertschy, H., Tyler, R. S., Kelsay, D. M. R., Gantz, B. J., & Woodworth, G. G. (1997). Cochlear implant use by prelingually deafened children: The influences of age at implant and length of device use. *Journal of Speech, Language, and Hearing Research*, *40*(1), 183–199. https://doi.org/10.1044/jslhr.4001.183

Gaurav, V., Sharma, S., & Singh, S. (2020). Effects of Age at Cochlear Implantation on Auditory Outcomes in Cochlear Implant Recipient Children. *Indian Journal of Otolaryngology and Head and Neck Surgery*, *72*(1), 79–85. https://doi.org/10.1007/s12070-019-01753-4

Geers, A. E., Nicholas, J. G., & Moog, J. S. (2007a). Estimating the influence of cochlear implantation on language development in children. In *Audiological Medicine* (Vol. 5, Issue 4, pp. 262–273). https://doi.org/10.1080/16513860701659404

Geers, A. E., Nicholas, J. G., & Moog, J. S. (2007b). Estimating the influence of cochlear implantation on language development in children. In *Audiological Medicine* (Vol. 5, Issue 4, pp. 262–273). https://doi.org/10.1080/16513860701659404

Gervain, J., & Werker, J. F. (2013). Prosody cues word order in 7-month-old bilingual infants. *Nature Communications*, *4(1)*, 1490. https://doi.org/10.1038/ncomms2430

Govaerts, P. J., De Beukelaer, C., Daemers, K., De Ceulaer, G., Yperman, M., Somers, T., ... & Offeciers, F. E. (2002). Outcome of cochlear implantation at different ages from 0 to 6 years. *Otology & neurotology*, 23(6), 885-890. http://journals.lww.com/otology-neurotology

Gupta, D. (2012). A predictive model for outcome of cochlear implantation in children below the age of 5 years: A multivariate analysis in Indian scenario. *Indian Journal of Otology*, *18*(3), 129–135. https://doi.org/10.4103/0971-7749.103439

Hack, Z. C., & Erber, N. P. (1982). Auditory, visual, and auditory-visual perception of vowels by hearing-impaired children. *Journal of Speech and Hearing Research*, *25*(1), 100–107. https://doi.org/10.1044/jshr.2501.100

Hota, A. (2019). Factors affecting audiological performance and speech intelligibility in prelingually deaf children after cochlear implantation: a study. *International Journal of Otorhinolaryngology and Head and Neck Surgery*, *5*(4), 1035. https://doi.org/10.18203/issn.2454-5929.ijohns20192726

Hwang, C. F., Ko, H. C., Tsou, Y. T., Chan, K. C., Fang, H. Y., & Wu, C. M. (2016). Comparisons of auditory performance and speech intelligibility after cochlear implant reimplantation in Mandarin-speaking users. *BioMed Research International*, *2016*. https://doi.org/10.1155/2016/8962180

Isaiah, A., Lee, D., Lenes-Voit, F., Sweeney, M., Kutz, W., Isaacson, B., Roland, P., & Lee, K. H. (2017). Clinical outcomes following cochlear implantation in children with inner ear anomalies. *International Journal of Pediatric Otorhinolaryngology*, *93*, 1–6. https://doi.org/10.1016/j.ijporl.2016.12.001

Jank, B. J., Haas, M., Riss, D., & Baumgartner, W. (2021). Acceptance of patients towards task-autonomous robotic cochlear implantation: An exploratory study. *The International Journal* *of Medical Robotics and Computer Assisted Surgery*, *17*(1), 1–6. https://doi.org/10.1002/rcs.2172

Kameswaran, M., Raghunandhan, S., Natarajan, K., & Basheeth, N. (2006). Clinical audit of outcomes in cochlear implantation an Indian experience. *Indian Journal of Otolaryngology and Head and Neck Surgery*, *58*(1), 69–73. https://doi.org/10.1007/BF02907745

Karandikar, P., & Valame, D. A. (2020). Auditory Performance in Late Implanted Congenitally Hearing Impaired Children: A Reality Check. *Indian Journal of Otolaryngology and Head and Neck Surgery*, *72*(3), 313–319. https://doi.org/10.1007/s12070-020-01808-x

Kishon-Rabin, L. I. A. T., Gehtler, I., Taitelbaum, R., Kronenberg, J., Muchnik, C., & Hildesheimer, M. I. N. K. A. (2002). Development of speech perception and production in children with cochlear implants. *Annals of Otology, Rhinology & Laryngology, 111(5_suppl)*, 85-90. https://doi.org/10.1177/00034894021110S518

Krueger, B., Joseph, G., Rost, U., Strauß-Schier, A., Lenarz, T., & Buechner, A. (2008). Performance groups in adult cochlear implant users: Speech perception results from 1984 until today. *Otology and Neurotology*, *29*(4), 509–512. https://doi.org/10.1097/MAO.0B013E318171972F

Lachs, L., Pisoni, D. B., & Kirk, K. I. (2001). Use of Audiovisual Information in Speech Perception by Prelingually Deaf Children with Cochlear Implants: A First Report. *Ear and Hearing*, *22*(3), 236–251.

Lala, N., Vishwakarma, R., Vishwakarma, C., & Kumar, P. (2015). Study of MAIS (Meaningful Auditory Integration Scale) Score in post-Cochlear Implantation in Pre-lingual Deaf Patients. *Online Journal of Otolaryngology, Volume 5 Issue 3 2015*, *5*(3) 48.

Ling, D. (1978). Speech development in hearing-impaired children. *Journal of Communication Disorders*, *11*(2–3), 119–124. https://doi.org/10.1016/0021-9924(78)90004-7

Liu, J., & Gao, B. (2019). Assessment of outcomes of hearing and speech rehabilitation in children with cochlear implantation. In *Journal of Otology* (Vol. 14, Issue 2, pp. 57–62). Taylor and Francis Ltd. https://doi.org/10.1080/26395932.2019.1560699

Li, Y.-L., Chen, C.-S., Yang, H.-M., Chen, H.-C., & Wu, J.-L. (2022). Performance of Sequentially Bilateral Cochlear Implanted Children Who Speak Mandarin. *Audiology and Neurotology*, 28(2), 106-115. https://doi.org/10.1159/000526695

Li, Y., Zhou, X., Jin, X., Zheng, J., Zhang, J., & Liu, H. (2022). Residual Hearing Improves Early Auditory Perception and Speech Intelligibility in Mandarin-Speaking Children with Cochlear Implants. *Journal of International Advanced Otology*, *18*(4), 291–296. https://doi.org/10.5152/iao.2022.21442

Lu, X., & Qin, Z. (2018). Auditory and language development in Mandarin-speaking children after cochlear implantation. *International Journal of Pediatric Otorhinolaryngology*, *107*, 183–189. https://doi.org/10.1016/j.ijporl.2018.02.006

McGurk and Mac-Donald. (1976). Hearing Lips and Seeing Voices. *Nature*, *264*, 746–748.

Moeller, M. P. (2000). Early intervention and language development in children who are deaf and hard of hearing. *Pediatrics,* 106(3), e43-e43. www.pediatrics.org/cgi/content/full/106/3/e43

Nikolopoulos, T. P., Archbold, S. M., Wever, C. C., & Lloyd, H. (2008). Speech production in deaf implanted children with additional disabilities and comparison with age-equivalent implanted children without such disorders. *International Journal of Pediatric Otorhinolaryngology*, *72*(12), 1823–1828. https://doi.org/10.1016/j.ijporl.2008.09.003

Park, L. R., Perkins, E. L., Woodard, J. S., & Brown, K. D. (2021). Delaying Cochlear Implantation Impacts Postoperative Speech Perception of Nontraditional Pediatric Candidates. *Audiology & Neuro-Otology*, *26*(3), 182–187. https://doi.org/10.1159/000510693

Phillips, L., Hassanzadeh, S., Kosaner, J., Martin, J., Deibl, M., & Anderson, I. (2009). Comparing auditory perception and speech production outcomes: Non-language specific assessment of auditory perception and speech production in children with cochlear implants. *Cochlear Implants International*, *10*(2), 92–102. https://doi.org/10.1002/cii.396

Pisoni, D. B., Kronenberger, W. G., Harris, M. S., & Moberly, A. C. (2017). Three challenges for future research on cochlear implants. *World Journal of Otorhinolaryngology - Head and Neck Surgery*, *3*(4), 240. https://doi.org/10.1016/J.WJORL.2017.12.010

Priya, K. (2017). *Modified early speech perception test in Kannada (MESP-K)[dissertation]. Unpublished Dissertation submitted at University of Mysore, Mysore.*

Raine, C., Atkinson, H., Strachan, D. R., & Martin, J. M. (2016). Access to cochlear implants: Time to reflect. *Cochlear Implants International*, *17*, 42–46. https://doi.org/10.1080/14670100.2016.1155808

Rinaldi, P., Baruffaldi, F., Burdo, S., & Caselli, M. C. (2013). Linguistic and pragmatic skills in toddlers with cochlear implant. *International Journal of Language and Communication Disorders*, *48*(6), 715–725. https://doi.org/10.1111/1460-6984.12046

Robbins, A. M., Koch, D. B., Osberger, M. J., Zimmerman-Phillips, S., & Kishon-Rabin, L. (2004). Effect of age at cochlear implantation on auditory skill development in infants and toddlers. *Archives of Otolaryngology–Head & Neck Surgery*, 130(5), 570-574.

Robbins, A. M., Renshaw, J. J., & Berry, S. W. (1991). Evaluating meaningful auditory integration in profoundly hearing-impaired children. *The American Journal of Otology*, *12 Suppl*, 144–150.

Roland, J. T., Gantz, B. J., Waltzman, S. B., & Parkinson, A. J. (2018). Long-Term Outcomes of Cochlear Implantation in Patients With High-Frequency Hearing Loss. *The Laryngoscope*, 1939–1945. https://doi.org/10.1002/lary.27073

Sahai, I., Ghosh, B., & Anjankar, A. (2022). A Spectrum of Intraoperative and Postoperative Complications of Cochlear Implants: A Critical Review. *Cureus*, *14*(8). https://doi.org/10.7759/CUREUS.28151

Schauwers, K., Gillis, S., Daemers, K., De Beukelaer, C., & Govaerts, P. J. (2004). Cochlear Implantation Between 5 and 20 Months of Age: The Onset of Babbling and the Audiologic Outcome. *Otology & Neurotology*, *25*, 263–273.

Schorr, E. A., Fox, N. A., van Wassenhove, V., & Knudsen, E. I. (2005). Auditory-visual fusion in speech perception in children with cochlear implants. *Proceedings of the National Academy of Sciences, 102(51),* 18748-18750. www.pnas.orgcgidoi10.1073pnas.0508862102

Shakrawal, N., Sonkhya, N., Agarwal, S., & Grover, M. (2022). The Effect of Age at Cochlear Implantation on Speech and Auditory Performances in Prelingually Deaf Children. *Indian*

Journal of Otolaryngology and Head and Neck Surgery, *74*, 52–61. https://doi.org/10.1007/s12070-020-01821-0

Somaye Jalil-Abkenar, S., Ashori, M., Pourmohammadreza-Tajrishi, M., & Hasanzadeh, S. (2013). Auditory Perception and Verbal Intelligibility in Children with Cochlear Implant, Hearing Aids and Normal Hearing A B S T R A C T. *Practice in Clinical Psychology*, *1*(3), 141–147.

Suh, M. W., Cho, E. K., Kim, B. J., Chang, S. O., Kim, C. S., & Oh, S. H. (2009). Long term outcomes of early cochlear implantation in Korea. *Clinical and Experimental Otorhinolaryngology*, *2*(3), 120–125. https://doi.org/10.3342/ceo.2009.2.3.120

Svirsky, M. A., Silveira, A., Suarez, H., Neuburger, H., Lai, T. T., & Simmons, P. M. (2001). Auditory Learning and Adaptation after Cochlear Implantation: A Preliminary Study of Discrimination and Labeling of Vowel Sounds by Cochlear Implant Users. *Acta Otolaryngologica*, *121*, 262–265.

Tolan, M., Serpas, A., McElroy, K., Craun, P., Williams, C., Reilly, B. K., & Preciado, D. (2017). Delays in sound recognition and imitation in underinsured children receiving cochlear implantation. *JAMA Otolaryngology - Head and Neck Surgery*, *143*(1), 60–64. https://doi.org/10.1001/jamaoto.2016.2730

Torkildsen, J. von K., Hitchins, A., Myhrum, M., & Wie, O. B. (2019). Speech-in-Noise Perception in Children With Cochlear Implants, Hearing Aids, Developmental Language Disorder and Typical Development: The Effects of Linguistic and Cognitive Abilities. *Frontiers in Psychology*, *10*, 2530. https://doi.org/10.3389/fpsyg.2019.02530

Van De Velde, D. J., Schiller, N. O., Levelt, C. C., Van Heuven, V. J., Beers, M., Briaire, J. J., & Frijns, J. H. M. (2019). Prosody perception and production by children with cochlear implants. *Journal of Child Language*, *46*(1), 111–141. https://doi.org/10.1017/S0305000918000387

Vermeire, K., Brokx, J. P. L., Van De Heyning, P. H., Cochet, E., & Carpentier, H. (2003). Bilateral cochlear implantation in children. *International Journal of Pediatric Otorhinolaryngology*, *67*(1), 67–70. https://doi.org/10.1016/S0165-5876(02)00286-0

Vermeulen, A. M., van Bon, W., Schreuder, R., Knoors, H., & Snik, A. (2007). Reading comprehension of deaf children with cochlear implants. *Journal of Deaf Studies and Deaf Education*, *12*(3), 283–302. https://doi.org/10.1093/deafed/enm017

Wauters, L. N., Tellings, A. E. J. M., van Bon, W. H. J., & Mak, W. M. (2008). Mode of acquisition as a factor in deaf children's reading comprehension. *Journal of Deaf Studies and Deaf Education*, *13*(2), 175–192. https://doi.org/10.1093/deafed/enm050

Yoshinaga-Itano, C. (2003). From Screening to Early Identification and Intervention: Discovering Predictors to Successful Outcomes for Children with Significant Hearing Loss. *Journal of deaf studies and deaf education, 8(1), 11-30.* https://academic.oup.com/jdsde/article/8/1/11/333253

Yu-fen, G., physician, C., supervisor, D., Guo-dong, M., Bai-cheng, X., Xiao-wen, L., Xiao-long, Y., Yu-hong, P., & Xing-jian, C. (2016). Effect of cochlear implantation in speech rehabilitation of children with severe sensorineural deafness: changes in the scores of Meaningful Auditory Integration Scale. *Chinese Journal of Tissue Engineering Research*, *20*(46), 6397–6942. www.CRTER.org

Zimmerman-Phillips, S. (1997). IT-MAIS: Infant-Toddler meaningful auditory integration scale. In *International Cochlear Conference*, *New York*, 1997.