ARTICULATION ABILITIES OF CHILDREN WITH HEARING IMPAIRMENT USING HEARING AIDS AND COCHLEAR IMPLANT: A COMPARISON IN TELUGU

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CERTIFICATE

This is to certify that this dissertation entitled **"Articulation abilities of children with hearing impairment using hearing aids and cochlear implant: A comparison in telugu"** is a Bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration number 20SLP019. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for award of any other Diploma or Degree.

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DECLARATION

This is to certify that this dissertation entitled " **Articulation abilities of children with hearing impairment using hearing aids and Cochlear implant: A Comparison in Telugu**" is the result of my own study under the guidance of Dr. N. Sreedevi, Professor of Speech Sciences & Head, Department of Prevention of Communication Disorders, All India Institute of Speech and Hearing, Mysuru and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

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ABSTRACT

Background: The most damaging effect of hearing loss reflects on the speech and language development of children with hearing impairment. The technological advancements in recent years have paved the way for improved amplification devices for these children to develop age-adequate language skills. However, good articulatory skills still elude them. Hence understanding their articulatory performances and differences in the articulatory production of children using CI and HA is paramount for both SLPs and Audiologists for effective rehabilitation.

Aim: The aim of the study is to examine and compare the articulation abilities of Telugu-speaking children using Digital hearing aids or are fitted with Cochlear implants with age and gender matched typically developing children.

Methods: A total of 15 Telugu-speaking children aged 4 to 6 years were recruited for the study. Participants were divided into three groups (Group-1) consisting of 5 children using digital Hearing Aids had a minimum hearing age of 2 years, (Group-2) consisting of 5 children using Cochlear implants fitted with multichannel cochlear implants and had an implant age of a minimum of 2 years Group-3 consisting 5 of age-matched typically developing children. For all the groups of participants, revised norms of the Test of

Articulation and Discrimination in Telugu-(Padmaja,1988), by Usha and Sreedevi (2010) were administered. The recorded speech sample compared the consonant productions to target productions, error categories were identified at the segmental level based on SODA and PMV analysis. Frequent phonological processes exhibited by all participants were documented. Appropriate Statistical analysis for the results obtained was carried out using SPSS software.

Results: Statistical comparisons for vowels, diphthongs, and consonants classified based on place of articulation were made using the nonparametric Kruskal Wallis test across the HA, CI, and TDC groups. No significant difference was obtained for vowels and diphthongs across the three groups. However, few apparent vowels errors were seen in CI and HA groups. Considering consonant articulation, participants in the CI group performed better than the HA group, and both groups had prominent substitution errors There was a statistically significant difference for the consonants across the three groups. In the HA group, for the consonants, the most to least accurately produced consonants are as follows, bilabial>labiodental>dentals>palatal>velar>alveolar>clusters. For the CI group, the most to least accurately produced consonants are as follows, bilabials>dentals>alveolar>labiodentals>velars>palatals>clusters. Production of consonants was better in CI participants.

Statistical comparison for the SODA errors revealed a statistical difference across the three groups. From the qualitative and statistical analysis of the SODA, errors reveal that substitution errors were more prevalent among the SODA errors for HA and CI (HA>CI). However, the omission errors were prevalent in the HA group

only. And distortion errors were more prevalent in HA, followed by CI, and minimal errors were observed in TDC (HA>CI>TDC). From PMV analysis, it was observed that in HA and CI groups place errors were more, followed by voicing and manner errors (Place>voicing>manner). A comparison of phonological processes analysis across the three groups reveals that partial and total cluster reduction, rhotacism, and deaspiration are commonly observed in both HA and CI groups. Initial consonant deletion and stopping were present only in the HA group. Deaffrication was observed only in the CI group. And in TDC, partial cluster reduction which was the only articulatory error in them was occasionally seen.

Conclusion: The present study indicated similarities and differences in the articulatory errors produced by children using digital HA and CI in Telugu. The study represents the detailed information on the phonemes that are most frequently produced correctly and erroneously. This would assist SLPs in developing effective articulation training intervention strategies to promote speech intelligibility in children who use HA and CI.

Keywords: articulatory errors in Hearing aid users, articulatory errors in CI users. SODA errors. PMV analysis.

Chapter 1

INTRODUCTION

Language is unique to the homo-sapiens and is one of the primary tools used throughout the course of human evolution and development with which we comprehend, express, and store knowledge. Humans prefer speech as an essential and primary mode to communicate through language can be expressed through other modalities e.g., Written language. To achieve this oral language development humans, rely on their sensory system, fundamentally on Hearing. The importance of hearing in communication development has been proved by various studies throughout history in the field of communication sciences. The importance of Hearing in speech and language development, communication, literacy, and learning cannot be emphasized further.

Early identification and intervention of hearing loss can lessen the impact on a child's development. Most estimates suggest that 1 to 3 per 1,000 children are born with a hearing loss, based on screening and/or medical records (Centres for Disease Control and Prevention [CDC], 2009, National Institute on Deafness and Other Communication Disorders [NIDCD], 2010. According to WHO data from 2018, the prevalence of hearing impairment (HI) in India is around 6.3 percent (63 million people suffering from significant auditory loss). 7.6% of Indians suffer from adult-onset deafness, while 2% of the population suffer from childhood-onset deafness. Hearing impairment was the second most common cause of disability and the top source of sensory deficit, according to the 58th round of the National Sample Survey (NSS) (2002), which looked at disability in the

Indian population. Hearing loss was responsible for 9% of all disabilities in urban areas and 10% in rural ones.

The primary goal of intervention for children with congenital hearing loss is to acquire intelligible speech. The interaction of several processes such as articulation, phonation, and resonation is posited as the source of intelligible speech. The acquisition of intelligible speech is challenging for children with congenital hearing loss or pre-lingual deafness.

The consonant inventories of children with hearing impairment are restricted when compared to children with normal hearing. Many studies have shown that speech sounds with more visible articulatory gestures (such as labiodentals) are simpler for hearing impaired speakers to produce because of the enhanced visual input offered, as opposed to sounds like alveolars, which are more hidden in the mouth Monsen et al., 1983. A study by Banik (2003), reported that children with Hearing impairment took longer to develop all categories of stop sounds, developing /ma/, /ba/, and /pa/ at the ages of 5-6, 6-7, and 7-8 years, respectively and there was also a delay or deviation in consonant cluster acquisition, as well as a failure to distinguish between voiced and voiceless consonants.

The auditory cortex can be irreversibly altered if there is no sound input during the first few years of life—the plasticity of the developing auditory system peaks at birth and declines with age. Several studies support the existence of a critical phase for brain development that is critical for the formation of spoken language. Recent advances in amplification devices such as digital hearing aids and cochlear implants have made it possible for children with congenital hearing loss to achieve intelligible speech compared to the earlier analog hearing aid users.

Tomblin, et al (2014) studied 108 children with various types of hearing loss (sensorineural, conductive, and mixed) and showed that early provision of Hearing Aids to children with mild to severe Hearing loss is likely to result in better speech and language development, particularly when the child receives good audibility from Hearing Aids and has had a longer opportunity to wear the Hearing Aids.

A cochlear implant (CI) is a relatively new hearing device for severe to profound hearing impairment. According to ASHA cochlear implant is the primary option for treating Severe to profound Hearing Loss since mid-1980s. With the recent advances that are happening in the field of implantable devices, the perception and development of oral language for children with congenital severe to profound hearing loss is now a reality. A review of the literature revealed that using Cochlear implants improves the speech production of prelingually hearing-impaired children. Early implantation may bring several significant benefits in oral communication, one of which is the capacity to speak clearly. This could have significant social and intellectual implications, allowing children to communicate more effectively in the hearing environment in which they live. An examination of development curves and rates of growth over time found that, in addition to the benefits of prolonged use at any given age, there is a value for earlier implantation.

Joy and Sreedevi (2019) studied vowel production in Malayalam Speaking Paediatric Cochlear Implant Users in comparison to typically developing children; the mean values of all formant values were slightly greater in children with Cochlear implant, except for F2 /u/ and vowel space area (VSA). Their findings show that early implantation and comprehensive treatment services can help children with cochlear implants improve their speech, as the individuals in the study achieved near-normal articulatory abilities in terms of vowel production.

Joy (2020) conducted a qualitative analysis of all phonemes and locations in a recent study that included Malayalam-speaking youngsters with Cochlear implants. In the SODA analysis, substitution errors were found to be the most common sort of consonant errors. Place errors are more common than manner errors, according to the Place, Manner, and Voicing Analysis (PVM). Based on the place of articulation, bilabials were the most appropriately produced. In terms of manner, glides were the most accurate and approximants including trills were the most difficult. According to voicing feature analysis, de-voicing errors were more common in voiced aspirated phonemes.

Children who had their implants before the age of 2.5 years showed early bursts of growth in consonant production accuracy and vocabulary, as well as significantly better outcomes than their peers who had their implants later. The amount of early burst decreased progressively with increasing age at implantation, and it was not found in children older than 7 years at implantation for consonant production accuracy or children older than 3.5 years at implantation for vocabulary. For speech production and vocabulary, the effect of age at implantation on children's growth curves varies (Connor et al., 2006).

Dawson et al. (1995) compared vocabulary growth rates from a number of studies of children with substantial hearing loss and found that children who had cochlear implants grew their vocabulary quicker than children who received hearing aids.

Baudonck et al. (2009) compared consonant production of children using hearing aids and cochlear implants and reported that with thresholds above 70 dB (range: 72–105 dB), the HA children had significantly more phonetic and phonological errors. According to a study by Tobey et al. (1991), children with cochlear implants imitate consonants, vowels, and diphthongs better than children with hearing aids.

According to Löfkvist et al. (2020), reduced canonical babbling utterances and occurrences of dental/alveolar stops were found in children with Hearing Aids who had a hearing age of 5 months and who used their hearing technology five hours per day. The children with Cochlear implants reached an expected canonical babbling ratio and consonant production similar to age and gender-matched normal children after 8.5 months with full-time daily use of Cochlear implant.

Need for the study

Improving the speech intelligibility of profound hearing - impaired children has become one of the most important goals in rehabilitation, and technological advancements such as cochlear implantation and digital hearing aids can certainly help. An in-depth investigation of the multiple processes of intelligibility, including consonant production, is required to acquire a complete picture of the speech production outcome following implantation and hearing aid use. Only a few investigations comparing the speech characteristics of Cochlear implant children and children using Digital hearing aids (HA) have been reported in the literature.

In a study by Baudonck et al. (2009), distortions, substitutions, and omissions were identified in both the CI and HA groups, with distortions being the most common error type. As a result, contrary to previous research, the findings show that omissions are no longer the most common form of error in the speech of hearing-impaired children who are fitted with modern hearing aids before the age of two. Between HA and CI groups, there were very significant phonetic and phonological differences. The HA children had a larger mean total of consonant errors. They have much more substitutions and omissions. The CI group has a higher number of distortions than the HA group, while the HA group has a higher number of omissions.

The recent technological advancements in the field of hearing aids has given way for the development of sophisticated devices to provide amplification for children with hearing impairment. Due to the transition from analog to digital mode, documentation of articulatory errors are required to account for the speech production outcome of digital Hearing aid usage as the earlier studies were reported based on analog hearing aids. It is also a fact that in developed countries like USA, UK, Australia etc most children with hearing impairment are CI users. However, in a developing country like India, hearing aid users are much prevalent. Because of the technological advancements as mentioned earlier and also due to free Government schemes, digital hearing aids are widely used. Hence there is a need to compare the articulatory proficiency of both CI and HA users.

Many western studies report that CI children demonstrate greater accuracy in their articulatory production. However, a recent study by Joy (2020) on Malayalam speaking CI children revealed that only 60.10% of the consonants are produced correctly in children with 3-4years of CI use and 46% in children with 2-3 years of CI use. Literature reports are abundant on articulatory analysis on children with CI, however very scanty on digital hearing aid users in both western as well as Indian languages.

Hence from literature reports, it is clear that there is a need to compare the articulatory errors across children using digital HA and CI for better understanding of their speech abilities. This will also help SLP's to plan their speech intelligibility training in a more organized and structured way.

Aim of the study

The aim of the study is to examine and compare the articulation abilities of Telugu-speaking children with hearing impairment using Digital hearing aids or are fitted with Cochlear implants and typically developing children.

Objectives of the study

1) To document the articulation errors and frequent phonological processes used by children with hearing impairment using Digital Hearing Aids and compare with age matched TDC
2) To document the articulation errors and frequent phonological processes used by children with hearing impairment using Cochlear implants with age matched TDC

3) To compare the articulation errors and frequent phonological processes used by children with hearing impairment using Digital Hearing aids and Cochlear implants.

Chapter 2

REVIEW OF LITERATURE

The development of spoken language is one of the most spectacular accomplishments of a child and one of the main characteristics of human beings. One of the most devastating causes of normal speech and language development is hearing loss. According to WHO data from 2018, the prevalence of hearing impairment (HI) in India is around 6.3 percent (63 million people suffering from significant auditory loss). 7.6% of Indians suffer from adult-onset deafness, while 2% of the population suffer from childhood-onset deafness. Hearing impairment was the second most common cause of disability and the top source of sensory deficit, according to the 58th round of the National Sample Survey (NSS) (2002), which looked at disability in the Indian population. Hearing loss was responsible for 9% of all disabilities in urban areas and 10% in rural ones. Children with hearing loss fail to develop intelligible speech because of poor articulation skills.

2.1 Articulatory abilities of children with hearing impairment

Severe auditory deprivation has a detrimental effect on children with hearing impairment's speech and language development. Due to the lack of or insubstantial auditory input and the feedback received by the children with hearing impairment, significant consonantal errors are observed in their speech output.

Nasalization of phonemes, voicing problems, and omissions or distortions of phonemes are common production errors in children with severe hearing loss (Hudgins &

Numbers, 1942). Due to the insufficient gain offered by hearing aids and the distortion within the auditory system, people with profound hearing loss and limited access to auditory input are likely to have delayed or disordered speech production, even when using amplification (Geers, Moog, & Schick, 1984; Levitt, McGarr, & Geffner, 1987).

The consonant inventories of children with hearing impairment are restricted compared to children with normal hearing. Many studies have shown that speech sounds with more visible articulatory gestures (such as labiodentals) are more straightforward for hard-of-hearing speakers because of the enhanced visual input offered, as opposed to sounds like alveolars more hidden in the mouth (Monsen et al., 1983). Children with profound hearing loss are more likely than those with less severe hearing loss to make mistakes with affricate and fricative phonemes (Gordon, 1987).

The errors made by children with hearing loss are affected by several variables such as degree of hearing loss, age of onset of the problem, the age at which intervention started, type of amplification device used, and the amount of therapy and intensity of the auditory stimulation. Children with mild to moderate hearing loss produce fewer errors than children with severe to profound hearing loss (Robbins et al., 1991).

An Indian study by Banik. (2003) in Odiya language reported that children with hearing impairment took longer to develop all categories of stop sounds, developing /ma/, /ba/, and /pa/ at the ages of 5-6, 6-7, and 7-8 years, respectively and there was also a delay or deviation in consonant cluster acquisition, as well as a failure to distinguish between voiced and voiceless consonants.

Significant delay in the acquisition and production of consonants in children with different degrees of hearing loss was investigated by Wiggin (2013). In their study, 269 children of age 15 and 84 months were classified further according to the severity of the hearing loss. 68 participants had mild hearing loss, 93 had moderate hearing loss, 40 had severe hearing loss, 20 had profound hearing loss, and 48 had a cochlear implant. The longitudinal study revealed that as the severity of the hearing loss increases, the consonants typically acquired by specific age groups are delayed.

2.2 Effect of hearing loss on language acquisition

Language acquisition in infants progresses through various stages regardless of the cultural and linguistic variabilities. The infant starts with the cooing stage, then progresses to reduplicated babbling stage and variegated babbling stage, where the infant achieves intonation patterns which are primarily essential and serve as building blocks of words. (Oller, 1978, 1980).

A major landmark in pre-lexical development is the onset of babbling, which can be defined as the production of consonant-vowel sequences. The onset of the babbling stage is critical because it represents the point at which infants produce mature phonetic syllables that can function as “the phonetic building blocks of words” (Oller., 1998). Numerous studies have reported that babbling in hearing-impaired children is markedly delayed. It would imply that humans are born with a phonetic inheritance that develops without significant auditory experience if deaf children babble similarly to their hearing counterparts at the same age. On the other hand, if infants who are deaf vocalize differently from infants who are hearing, it would imply that auditory experience plays a significant role in the timely emergence of speech-like sounds.

Oller and Eilers (1988), in their longitudinal study on 21 normally hearing and nine hearing-impaired infants, reported that deaf infants exhibit significant delays in the initiation of canonical babbling despite receiving acoustic amplification and intense stimulation. Why deaf infants are ever able to do canonical babbling is a legitimate question. The most logical explanation at this time seems to be that, despite their hearing impairment, the infants could still perceive speech sounds visual and through their residual (amplified) hearing. The lower amount and quality of their senses in contrast to hearing newborns appears to have impeded their development of babbling but did not completely prevent it.

Reduced canonical babbling utterances and instances of dental/alveolar stops were observed in children with hearing aids who had a hearing age of 5 months and utilized their hearing technology five hours per day, according to Löfkvist et al. (2020). After 8.5 months of daily usage of the Cochlear implant, the children achieved a predicted canonical babbling ratio and consonant production similar to age- and gender-matched normal children.

Prelinguistic phonetic development is impacted by even slight and temporary hearing loss, such as that brought on by otitis media. Compared to children who did not experience ear infections during the first six months of life, newborns with early-onset otitis media exhibited an average three-month delay in the commencement of canonical babbling. According to Slawinski, Williams, and Green (1999). Early-onset infants produced fewer canonical syllables between 6 and 18 months than infants with late-onset otitis media. They generated more marginal syllables with a quasi-resonant nucleus and vowels that are more quasi-resonant. Additionally, early-onset infants were more likely to generate a limited range of vowels than the later-onset group, and they did not exhibit the age-related expansion of the range of second formant frequencies.

2.3 Early identification and management of children with HL

In children with HI, early auditory rehabilitation is essential. The optimal rehabilitation approach to improve biofeedback is to utilize hearing aids or cochlear implants to reduce the length of the auditory deprivation caused by HI. Because conventional digital hearing aids do not provide enough amplification to make sounds audible and aid with speech perception, very few children with severe to profound HI benefit adequately from them. The next right alternative in this situation would be cochlear implantation. The main benefit of a cochlear implant is the direct stimulation of the auditory nerve and the improvement in the restoration of auditory cues for cochlear intensity, timing, and frequency resolution (Gillis, 2017).

In children with profound hearing loss, the loss is at least greater than 90 dB HL (Wong, 2005). However, the dysfunction of the outer hair cells (OHC) does not lead to hearing loss greater than 50 dB HL in low frequencies or 65 dB HL in high frequencies (Moore, 2001). Therefore, for children with profound hearing loss, it is likely that their hearing impairments are not restricted to the dysfunction of the OHC but also involve the inner hair cells (IHC). The IHC is responsible for converting the vibration of the basilar membrane into electrical potentials to the auditory nerves (Moore, 2001). Therefore, when hearing impairment involves the damage of IHC, the amplification of auditory signals alone by hearing aids could lead to limited restoration of audibility, while cochlear implants could achieve the restoration (Martin, & Clark, 2003; Stelmachowicz et al., 2004).

2.4 The critical period for speech and language development

Schauwers et al. (2003). Compared ten typically developing children and ten children with cochlear implants who were implanted before the age of one year and found that all children began babbling after a short interval of 1 to 4 months after activation of the device, with the youngest subjects beginning babbling at a chronologic age comparable to that of normally hearing infants. The results of the various babbling tests were highly associated with the age of implantation: the earlier the implantation, the closer the results resembled those of normally hearing newborns.

Connor et al. (2006) focused on latent-growth curves for 100 children who received their implants between the ages of 1 and 10 years, used oral communication, and used their devices between the ages of 1 and 12 years using hierarchical linear modeling. Children were divided into four groups based on their age during implantation: those between 1 and 2.5 years, 2.6 and 3.5 years, 3.6 and 7 years, and 7.1 to 10 years. Early spurts of increase in vocabulary and consonant production accuracy were seen in children who had implants before 2.5 years. These children also performed much better than their peers, who received their implants later. It was not noted in children older than seven years at implantation for consonant-production accuracy or children older than 3.5 years at implantation for vocabulary. The magnitude of the early burst decreased systematically with increasing age at implantation.

Svirsky et al. (2007) examined the speech intelligibility of 67 pediatric cochlear implant users who are profoundly and congenitally deaf. The children were divided into five subgroups according to their age of implantation and received implants during the first eight years of life. Standard sentences from the children's tape recordings were digitized and played back to listeners with normal hearing who were unfamiliar with the deaf speech. The average number of words correctly identified across all listeners was used to determine speech intelligibility. The study's results indicated that earlier implantation had a positive and significant effect on the speech intelligibility of cochlear implant users.

2.5 Language acquisition after intervention-Hearing aids vs. Cochlear implants

As mentioned earlier, acquisition of babbling is delayed in children with hearing loss compared to typically developing children. Correspondingly the language acquisition in children with hearing impairment was reportedly delayed. Due to awareness about the various conditions that can lead to Hearing loss and various early screening procedures, the vision of early identification and intervention of children with hearing impairment has become a reality.

Technological advancements in the field of acoustics and amplification devices and with the ultimate need to provide adequate amplification for children who are hard of hearing, the invention of sophisticated devices like cochlear implants and digital hearing aids made it a reality for children with hearing impairment to acquire language.

Deviations in the language development of children using hearing aids and cochlear implants were documented by Yoshinaga-Itano et al. (2010) in a longitudinal study. In their study, they included 38 children using hearing aids and 49 children with cochlear implants. Both groups of children had received the same amount of intervention. Children using hearing aids had significantly lower mean scores in the language evaluation than those using cochlear implants.

Boons et al. (2013) examined the language abilities of 70 school-aged children with cochlear implants and children with normal hearing. Around half of the children with cochlear implants attained a language level appropriate for their age. Error analysis revealed problems with morphological and syntactic rules and ineffective storytelling abilities.

2.6 Errors in Place, Manner, and voicing of children with Hearing Impairment

2.6.1 Place of Articulation

Numerous investigations have observed substitution errors involving the same point of articulation. According to the place of articulation, correctly articulated consonants were analyzed by Nober (1967), who rated them in descending order from high to low score bilabials, 59 percent; labiodentals, 48 percent; glottals, 34 percent; linguadentals, 32 percent; lingua-alveolars, 23 percent; lingua palatal, 18 percent; and lingua alveolars, 12 percent. Smith (1975) and Gold (1978) reported on similar patterns of accurate production; however, these researchers discovered back sounds were less error-prone than those made in the center of the mouth. Improved production for more visible phonemes is a common pattern observed across various word and sentence types (Huntington, Harris, & Sholes, 1968; Geffner & Freeman, 1980; Levitt et al., 1976).

Some mid-and later acquired consonants (/l/, /s/, and /z/) are produced centrally and do not offer obvious visual clues. These consonants could take longer to learn than ones with more powerful visual clues (Stoel-Gammon, 1988). Because of the concentration of energy at relatively high frequencies and low-intensity levels, the production of alveolars and palatals (/t, s, z, c,ɟ, θ/) continues to be accompanied by difficulties, such as distortions, substitutes, and omissions (Blamey et al., 2001). Comparable confusions in perception and production of alveolars, palato-alveolar phonemes like /t, s, c, and z/ that share similar acoustic-phonetic properties, were described by Blamey et al. (2001).

This supports the hypothesis made by Warner-Czyz et al. (2010) and Tobey et al. (2007) that phonemes that are less prominent and distinct via the CI signal may be more challenging to discriminate, recognize, and produce appropriately. Unlike bilabials, the articulatory movements for both alveolar and velar sounds are visibly unclear. The fact that the center of the mouth produces more noises than the back is one factor contributing to compromised alveolar production. To appropriately distinguish the sounds with a medial point of articulation, precise positioning of the articulators is required (Lass, 2014).

2.6.2 Manner of articulation

Children who used CI often exhibited the most correct manner of articulation for early developing sounds like stops, nasals, and glides and the least accurate manner of articulation for later emerging sounds like affricates (Ertmer et al., 2012; Warner-Czyz et al., 2010). The labial stop consonants' strong visibility and simple motoric qualities may account for their relatively early development in the speech of TDC and hearing-impaired children (Kent, 1992). Accurate generation of continuant consonants was also demonstrated as a benefit of kinesthetic and tactile cues (Stoel-Gammon, 1988).

Studies on the production of manner features have indicated that fricatives are the least accurately produced, whereas stop consonants are the most accurately produced. Additionally, children with CI frequently replace fricatives with stop consonants (Bouchard & Normand, 2007; Kent, 1992). The sequence of phonemic development indicated that stops come before fricatives, oral sounds come before nasal sounds, and anterior sounds come before posterior sounds (Peng et al., 2004; Tye-Murray et al., 1995). Children who used CI to produce their consonants had the following accuracy levels: stops (52%), fricatives (54 %), nasals (50 %), and liquids (46 %). Frequently produced correctly were bilabial stops, glides, and the fricatives /f/ and /v/. (Smith, 1975). According to Nober (1967), glides were the most frequently and accurately produced sound, followed by stops, nasals, and fricatives. Children using CI tended to substitute a phoneme from the same sound class as the target phoneme when an error was produced, such as obstruents for target obstruents (stops and fricatives) and sonorants for target sonorants (nasals and liquids). According to Dillon et al. (2004), the children also had a tendency to delete target sonorants more frequently than target obstruents.

Rodvik et al. (2019), in a study, revealed that one of the distinguishing characteristics of cochlear implant users is perceptual confusions between identical consonants. In their study comprising 36 children and adults (29 prelingually deaf and seven post lingual deaf), consonant and vowel perception are assessed through open-set repetition of nine monosyllabic consonant-vowel-consonant nonsense words and sixteen bisyllabic vowel-consonant-vowel nonsense words the result revealed that unvoiced consonants were significantly less confusing for participants with CIs than voiced consonants, which was a significant finding. Unvoiced stops were confused with other unvoiced stops but not with voiced stops and voiced stops were confused with both unvoiced stops and other voiced stops.

With a correct score of only 61.1 percent, the lateral /l/ was determined to have the highest percentage of consonant confusions. Consonants with a different way and inverse voicing were the least frequently confused sounds. In addition, there was a devoicing bias for the stops. Another notable conclusion was that there was no discernible difference between pre-and post-lingually deaf CI users' perceptions of speech sound characteristics. This may be due to two main problems: (1) implants do a poor job of conveying the F0 in voiced sounds because most implant models lack temporal information in the electrical signal and the electrode's insertion depth may be too shallow to cover the entire cochlea; (Hamzavi & Arnoldner, 2006; Svirsky et al., 2015; Caldwell et al., 2017) and (2) the VOT makes the unvoiced stops much easier to perceive than the voiced stops because of the aspirated pause between the voiced and unvoiced stops.

In a study by Ambrose et al. (2013) with the objective to (a) compare the speech sound production skills of 2-year-old children with hard of hearing (HH) to children with normal hearing (NH), (b) narrow down the potential risk factors for specific children who are HH, and (c) ascertain whether speech sound production abilities at age 2 were indicative of speech sound production abilities at age 3. Participants were 37 (21 boys, 16 girls) children with NH and 70 (2-year-olds) with bilateral, mild-to-severe HL (HH group) who were age- and SES-matched (NH group). The research indicates that compared to children with NH, children who are HH typically showed delayed but parallel development of consonant production skills. The accuracy of vowel production between groups did not differ. Children with HH tended to produce speech sounds more accurately than those with later HA fittings or poorer pure tone thresholds, especially those who got their HA at six months of age and/or had better pure tone thresholds. For bilabial, alveolar, and velar consonants, accuracy was also assessed according to the point at which the sound is produced. As a result of ceiling effects at this articulation location, bilabial accuracy did not vary by hearing status. Although there were no between-group differences for bilabials, NH children performed better than HH children in producing alveolar and velar consonants. The less extensive visual cues accompanying the latter two places may cause disparities in accuracy between bilabial and alveolar and velar sounds, making the former two places more difficult than visually salient bilabials for children with HH. (Stoel-Gammon, 1988; von Hapsburg & Davis, 2006).

According to Smith (1975), affricates never substituted other consonants but were frequently replaced by one of their portions, typically the plosive part. But according to Mildner and Liker (2008), fricatives were most frequently used in place of affricates. The fricative /s/ was less accurately produced than other fricatives. Todd et al. (2011) discovered that /s/ was produced with 62 percent accuracy and /ʃ/ with 82.5

percent accuracy among four- to nine-year-old CI children. These accuracy rates were reported to be lower than age-matched TDC but similar to TDC, whose ages matched the CI children's period of implant use. The CI children's frequency distribution of /s/ and /ʃ/ revealed significant overlap, indicating less distinction between these two fricatives.

Studies have generally indicated that CI children exhibit delayed consonant acquisition and less separation of fricatives than age-matched TDC children (Liker et al., 2007). It has been widely shown that /f/ for /s/ and /ʃ/ for /s/ can be substituted (Giezen et al., 2010; Todd et al., 2011; Liker et al., 2007; Uchanski & Geers, 2003). According to transcription analyses, children with CIs are typically more precise on-target /ʃ/ than target /s/ (Blamey et al., 2001; Giezen et al., 2010; Hedrick et al., 2011; Reidy et al., 2015; Serry & Blamey 1999). Even two years after implantation, this significant contrast between /s/ and /ʃ/ is produced; however, it is less accurate than TDC (Grandon & Vilain, 2020). This result contrasts with that of Mildner and Liker (2008), who found that alveolars (/s/) and post-alveolars (/ʃ/) were only distinctly produced after 46 months following implantation. One of the most frequently overused phonological patterns in the speech of profoundly deaf children is the palatal fricative, or /ʃ/. They frequently substitute it /f/ or /s/, /c /, and /ɟ/ in addition to using it in its right place (Mildner & Liker, 2003)

Several researchers have discussed theories as to why the production of /s/ is difficult. The auditory qualities of the sounds a child is exposed to directly influence the auditory representation that the child learns (Cristià, 2011). Because of the CI processor's lower spectrum resolution and constrained processing bandwidth, CI users see a wider disparity between a sound's auditory and acoustic characteristics (Reidy et al., 2017).

Energy for fricatives is concentrated at frequencies between 7 and 10 kHz for /s/ and 4 and 6 kHz for /ʃ/. (Jongman et al., 2000; Li, 2012) and for higher frequencies, CIs provide worse frequency resolution. As a result, it's possible that children with CIs produced the sound /s/ at lower frequencies, contributing to error production. The generation of both fricatives and affricates, as well as speech perception, have been observed to improve with increased CI experience significantly. In a 46-month longitudinal study of Croatian speakers with cochlear implants, it was discovered that the affricates /ʧ/ and /ʤ/ were produced more precisely and closely resembled the target articulations, whereas the fricatives /s/ and /ʃ/ started to demonstrate distinction (Mildner & Liker, 2008). This is consistent with earlier research demonstrating considerable advancements up to five years after implantation (Kishon-Rabin et al., 2002).

2.6.3 Voicing Errors

One of the crucial components of consonant production is voicing. Reduced capacity to distinguish between voiced and unvoiced consonants may compromise speech understanding (Kent et al., 1989). The exact coordination of laryngeal and supralaryngeal processes is necessary for vocal control. One of the last qualities in speech acquisition, precision control of voice, is difficult to achieve in terms of motor control (Ingram, 1999; Kent, 1992). Normal voicing contrast acquisition occurs when voiced sounds give space to unvoiced ones (Flege & Eefting, 1986). One of the most typical forms of consonant errors discovered in children using CI was voicing errors (Higgins et al., 2003; Ryalls et al., 2003; Tye-Murray et al., 1995; Tye-Murray et al., 1995).

A cochlear implant would aid in developing distinctive voicing cognates (Aksoy et al., 2017; Blamey et al., 2001; Horga & Liker, 2006; Kishon- Rabin et al., 2002; Serry

& Blamey, 1999; Uchanski & Geers,2003). Children produced more voiced plosives than their unvoiced cognates one year after implantation (Dillon et al., 2004; Tobey et al., 1991). The CI group accurately reproduced the voicing feature, which places voiced consonants higher than unvoiced consonants. Also mentioned is an equal ratio of voiced and unvoiced consonants deleted (Dillon et al., 2004). According to Baudonck et al. (2010), Rødvik et al. (2019), Tye-Murray et al. (2011), and Wieringen & Wouters (1999), there was a devoicing bias for the stops.

2.6.4 Consonant cluster production

The ability to form consonant clusters is one attribute of speech that is clear and understandable. Consonant clusters are groups of two or more consonants that occur within a syllable and are most frequently seen at the beginning or end of words, such as a plant (/pl ae nt/) (for example, start consonant cluster (/pl/) and final consonant cluster (/nt/).

After implantation, all word places (initial, medial, and final) showed improved consonant production accuracy (Dawson et al., 1995). However, medial and final consonants were generated more precisely after the initial consonants (Ertmer et al., 2012). Most research has considered longitudinal comparisons of improvements in initial phoneme production accuracy since final consonants were produced with the lowest degree of accuracy. Children with 15 months of CI experience were observed to produce initial CV syllables with an accuracy of about 43%. (Warner-Czyz et al., 2010). After two years of device use, another research found 60% accuracy (Ertmer & Goffman, 2011). These findings prove the benefits of implantation at a younger age (Connor et al., 2006), and higher articulation test scores are related to implantation at a younger age (Flipsen, 2011)

According to Murphy and Dodd (1995), final consonants are frequently deleted in the speech of hearing-impaired children compared to initial and middle consonants. This may account for the much greater number of final consonant errors. According to studies on auditory perception, initial consonants have considerably more perceptual saliency than final consonants, which may account for their superior production accuracy (Redford & Diehl, 1999). Additionally, he discovered that initial consonants appeared to have a considerably stronger amplitude and acoustic distinctiveness compared to final consonants.

Serry et al. (1999) tracked phonetic inventories of 9 children with significant hearing loss who used the 22-electrode cochlear implant (Cochlear Limited) before and during the first four years of implant use. At the time of the implants, all children were five years old or less. For each child, spontaneous speech samples were taken at regular intervals and evaluated to examine phone acquisition during the post-implant period. Two separate criteria were used to quantify acquisition. The "target" criterion required the child to generate the phone correctly at least 50% of the time in meaningful words, whereas the "targetless" criterion required the infant to spontaneously produce a phonetically recognizable sound. At four years after the implant, 29 phones (66 percent) and 40 out of 44 phones (91 percent) had both met the target criterion for five or more of the children. During the study, 100% of monophthongs, 63% of diphthongs, and 54% of consonants achieved the target criterion. An average phone progressed from the target less to the target criterion in 15 months. Overall, the findings point to tendencies in phone acquisition patterns comparable to those of typically hearing children, notwithstanding the slower acquisition pace.

2.6.5 Indian Studies on Consonant production in CI

Joy (2020) studied the articulatory errors made by all phonemes in all word locations by Malayalam-speaking children with cochlear implants (CI). According to the SODA (substitution, omission, distortion, addition) analysis, substitution errors were the most common type of consonant error. Place, manner, and voicing analysis (PVM) suggested that more often than not, place errors occurred. The bilabials were the most accurately produced sounds, followed in order of accuracy by the retroflex, alveolar, dental, labiodental, palatals, and velars. In terms of articulation, glides were generated with the highest degree of accuracy, followed by approximants, trill/flap, fricative, affricate, stops, laterals, and nasals. Voiced aspirated phonemes had noticeable devoicing mistakes, according to voicing feature analysis. When the word beginning position appears in relation to the position, it stops, and nasals were easily produced, while the word medial position was preferable for fricatives, affricates, and approximants.

2.7 Articulatory characteristics of children using hearing aids

Wiggin et al. (2013) investigated the development of consonants in children with hearing impairment using hearing aids and cochlear implants. This study examined 269 hearing-impaired children between the ages of 15 and 84 months for consonant development in spoken language. To examine phoneme development across age levels and degrees of hearing loss, speech samples from 885 distinct test sessions of 25-minute parent-child interactions were studied. This study provides the ages at which 50% and 80% of children produced each English language consonant. For the mild group, 68 children provided 232 samples. At least 50% of the children were producing stops, glides, and two of the three nasal consonants by 15 months, and 80% were doing so by 27 months or earlier. By the time they were five years old, 50% of the children could produce every phoneme but /Ʒ/. Only /tʃ,dƷ,h,ʃ, Ʒ/were not produced by 80% of the children by the age of six. For the moderate group, 93 children provided 306 samples. At 27 months old, 80 % or more of the children could make every stop phoneme except for /g/, all glides, and /n/, /m/, and /h/. 80 percent of the children had expanded their consonant repertoire by the time they were 48 months old by adding the sounds /g/,/s/,/l/, and /r/. Only /tʃ/,/dƷ/,/ʃ/,/Ʒ/ were not formed by 80% of the children by the age of 7 years.

For the severe group, 40 children provided 109 samples. By the age of five, 50% of the children could produce all phonemes except for /ð/,/dƷ/,/Ʒ/. There were still 12 consonants at 48 months of age that were not produced by 80% of the children. At seven years of age, only /n/, /ʧ/, /ʤ/, and/v/ were not yet produced by 80% of the children. For the cochlear implant category, 48 children provided 201 samples. The chronological age of the participant, not the individual's age post-implantation, was used to analyze samples within this group. Compared to children in the mild to severe groups, only two consonants /m/, and /n/, emerged in 50% of the children as early as 15 months. However, all phonemes except /ð/,/dƷ/,/Ʒ/ were produced by 50% of the children with cochlear implants by age five, just like the severe hearing loss children who used hearing aids. At the age of 7, 80 percent of the children failed to produce the six phonemes /n/, /tʃ/, /dƷ/,/ ʃ/, /Ʒ/, /v/. The milestones were achieved later as the severity of hearing loss rose. The age at which consonants emerged and were generated by 80% of the children with severe hearing loss who used hearing aids was comparable to that of children with profound and severe hearing loss who wore cochlear implants.

2.7.1 Indian studies on articulatory characteristics of children using HA:

Sreedevi and Anusmitha (2022) investigated a total of seven 3- to 7-year-old monolingual Malayalam speaking children who were diagnosed with a spoken-language disorder related to congenital hearing impairment (> 70 dB HL bilaterally). They identified frequently misarticulated vowels and consonants in recorded voice samples. The most often misarticulated vowels were the short /u/ and long /i:/. Consonant trills (/r/), affricates (/ʤ/, /ʤ/), and fricatives (/ʂ/, /ʃ/) were the most prone to error. The majority of errors were substitution-related. Place and place-manner errors were more common than other kinds of errors. More substitution errors occurred in the initial and medial places for the velar stop /k/. Its voiced counterpart, /g/, had evident omissions in the initial position and substitution errors in the medial position. When compared to the medial position, the initial word position of the retroflex stop consonant (/ʈ/) and its voiced counterpart (/ɖ/) exhibited more substitution errors than omissions. Substitution errors were more evident in the medial position for the palatal affricate /ʧ/ and its voiced equivalent, /ʤ/.

In another study by Sreedevi, Anusmitha, and Reshma (2022) on Kannada speaking children with hearing impairment using digital hearing aids, reported that dental place of articulation was most often substituted for alveolar, retroflex, palatal and velar places of articulation. Based on the manner of articulation, stops were largely substituted for affricates, fricatives, trills, laterals. And voicing errors were more seen for stops (/g/, /ɖ/)

and affricates (/ʤ/). Place, manner and voicing errors were observed to be more predominant in the medial than in the initial word position.

2.8 Comparison of Articulatory errors and phonological processes across CI and HA

Van Lierde. (2005) compared six children with severe pre-lingual hearing loss using HA and nine prelingually deaf children using CI. Both objective (DSI, nasalance scores) and subjective (perceptual evaluations) assessment methods were applied. The voice quality and resonance of the CI and HA children were normal. However, both had articulation difficulties. When compared to the HA children, intelligibility was markedly better in the CI children. Children with HA had more phonological and phonetic problems noticeably. The findings of this study indicate that HA children's intelligibility is lower than that of CI children, which is caused by the presence of much more phonetic and phonological problems. The study revealed that distortions were both groups' most frequent error type. The number of distortions, substitutions, and omissions in relation to the incorrect consonants was significantly different between the CI and HA children. The proportion of distortions to all consonant errors was substantially higher in CI children. On the other hand, the relative number of substitutions and omissions occurred significantly more in HA children.

In a study by Baldock et al. (2009), distortions, substitutions, and omissions were identified in both CI and HA groups, with distortions being the most common error type. As a result, contrary to previous research, the findings show that omissions are no longer the most common error in the speech of hearing-impaired children fitted with modern hearing aids before the age of two. There were very significant phonetic and phonological differences between HA and CI groups. HA children had a larger mean total of consonant errors. They have much more substitutions and omissions. The CI group has a higher number of distortions than the HA group.

Perceptual evaluation of speech production by children using unilateral and bilateral cochlear implants and hearing aids with normal children was done by Baudonck et al. (2011). Participants included 11 NH children, 10 hearing aid-using HA children, 13 biCI children, and 14 uniCI children. And the results were for overall intelligibility, phonation, and resonance, the biCI children did not exhibit statistically significant differences from the NH children. But when compared to NH children, significantly greater distortions and consonant cluster reductions were seen in the biCI children. The NH and the biCI children received a better evaluation for phonation, resonance, and consonant articulation when compared to the uniCI and HA children. Children using unilateral CI and children using HA had significant distortions when compared to children using bilateral CI. The number of substitutions and omissions was comparable between the uniCI and the HA group. Following substitutions, omissions were the frequent error produced by children using unilateral CI and HA. Children using bilateral CI had more distortions when compared to normal hearing children.

With respect to phonological processing, the only phonological process that was noticeably more prevalent in biCI children than NH children was cluster reduction. The HA group, followed by the uniCI group, had the highest prevalence of all phonological processes. In contrast to the HA group, stopping was rarely observed in both the uniCI and biCI CI groups.

2.8.1 Comparison of Articulatory errors and phonological processes across CI and HA:

Mathur. (2019) evaluated and contrasted the phonological processes present in the speech of Hindi-speaking hearing-impaired children who used cochlear implants and hearing aids. The study included a total sample of 40 hearing-impaired children, divided into two groups: 20 used cochlear implants with a mean age of 7.71 and 20 used behind-the-ear hearing aids with a mean age of 7.37. The results of comparing the error percentage of speech in children using HA and children with CI found that the phonological processes, initial consonant deletion, final consonant deletion, stopping, gliding, vocalization, neutralization, the substitution of /l/ for /r/, prevocalic devoicing, monophthongization, and vowel lengthening were more prevalent in HA. The phonological processes, partial cluster reduction, epenthesis, fronting, affrication, palatalization, depalatalization, alveolar assimilation, postvocalic devoicing, medial consonant deletion, vowel backing, vowel lowering, and deaspiration, however, were more frequent in the speech of children with a cochlear implant. These results suggest that both subject groups' most prevalent phonological processes were different.

Ramadevi (2006) studied 60 Kannada-speaking children aged 5 to 9; 30 had hearing loss, and 30 had normal hearing. The study's findings showed a substantial difference between the two groups, and children with hearing loss scored worse due to their smaller vocabulary and slower language learning. Fifty-four phonological processes were detected in children with hearing loss, and 32 phonological processes were found in children with normal hearing. Epenthesis, gliding of liquids, and medial vowel deletion were phonological processes that occurred in less than 20% of hearing-impaired children, while affrication, alveolar assimilation, backing, partial cluster reduction, final vowel deletion, lateralization, monophthongization, stopping of glides and liquids, voicing, vowel backing, and vowel deletion frequently occurred, occurring in 20% to 60% of subjects. Cluster reduction, deaspiration, denasalization, devoicing of consonants, fronting of palatals and retroflexes, deletion, nasal deletion, stridency deletion, and vowel lowering were the processes that occurred the most frequently, or at a rate of >60%. The author correlated these findings with auditory perception issues in hearing-impaired children and the phonetic structure of Kannada.

2.9 Vowel production in children using Cochlear implants and children using Hearing aids

Joy and Sreedevi (2019) investigated vowel production in 30 Malayalam-speaking children using cochlear implants. All the participants were implanted before the age of 3 years with (Nucleus Freedom C124RE - bimodally) and had at least two years of therapy experience. Mid-central vowel /a/, high front vowel /i/, and high rear vowel /u/ with the three corner vowels are used in three intelligible Malayalam bisyllabic words in a CVCV combination target vowel in a CVCV combination's word-initial location were chosen for the investigation. Acoustic analysis of the first three Formants was carried out and in contrast to TDC, children with CI had higher mean and standard deviation for F1 and F2 values for the vowels /a/, /i/, and /u/ as well as the vowel space area. The results of the study showed a variety of outcomes that pointed in the direction that auditory information provided by a cochlear implant aid in the development of speech production abilities in children with hearing loss which is established in their acoustic characteristics.

Baudonck et al. (2010) compared vowel production of children using cochlear implants, hearing aids, and normal children. In this study, thirty-one were using Cochlear implants, and thirty-four of the children were using conventional hearing aids. All the children were fitted with amplification devices before the age of 3 years and had at least 2 years of therapy experience. The children were asked to name the black and white pictures presented and acoustic analysis of three formant frequencies of the vowels /a/,/i/, and /u/ revealed that Children in the cochlear implant group did not show any difference in formant frequencies of vowel /a/,/i/ and /u/ comparing with typically developing children, whereas children using hearing aids show lower F2 variations for vowel /a/,/statistically i/ and for /u/ low F2 and F3 values when compared with typically developing children.

Jafari et al. (2016) compared vowel production of 20 Persian children using Cochlear implants and children with normal hearing. Children in the cochlear implant group received their amplification device at three years and had an experience of at least six months. The stimuli /i/, /e/, /æ/, /u/, /o/, and /a/. Using Praat software, they analyzed the averages of the first three formants of these six vowels. And the results revealed significantly high F1 for vowel /a/ and /i/ and F2 for vowel /a/ and /o/ for children using cochlear implants. These results revealed a centralized vowel space area for children using cochlear implants. Based on the results, it has been shown that children using Cochlear implants produced the sounds which are anterior (Front sounds or front vowels) more posteriorly, which was attributed to reduced auditory feedback.

To summarize literature reports, substantial improvement in all aspects of speech production skills are well reported in CI and HA users. However, there exists a variation in the developmental trajectory for language and speech sound acquisition by CI and HA recipients. This could be due to various reasons such as hearing and implant age, quality and quantity of speech therapy provided. From the established literature it is noted that the articulatory errors exhibited by CI and HA users varied to a large extent, for example, production of fricatives were noted to be the most difficult phoneme class in children using CI and HA but production of trills, laterals were not affected in CI. In addition, there has been a significant increase in the number of HA and CI recipients due to evidence of better outcomes and government programs that offer to fund for surgery and intervention for a predetermined amount of time. It is important to note that there has only been a limited amount of study done on comparing articulatory features of children using CI and HA in Indian languages. Such research is crucial from a theoretical and clinical perspective because it can provide insight on the phonetic and phonological traits that distinguish particular languages. As a result, the current study's aim to examine the and compare the articulatory errors of children with cochlear implants and digital hearing aids was that such knowledge can enhance their speech intervention for reaching enhanced speech intelligibility.

Chapter 3

METHODS

Aim of the study

The aim of the study is to examine and compare the articulation abilities of Telugu-speaking children with hearing impairment using Digital hearing aids or are fitted with Cochlear implants and typically developing children.

Participants

A total of 15 Telugu-speaking children aged 4 to 6 years were recruited for the study. Participants were divided into three groups. Group-1 consisted of 5 children using digital hearing aids and they had a hearing age of minimum of 2 years, and Group-2 consisted of 5 children using cochlear implants fitted with multichannel cochlear implants and had an implant age of a minimum of 2 years. Group-3 consisted of 5 typically developing children. Both group of participants were recruited from ENT hospitals and private clinics from the state of Telangana, India. Group-3 participants consisted of age-matched typically developing children recruited from kindergartens in Telangana, India.

Participant Selection Criteria

Inclusion Criteria for Clinical Group-1

a. Native speakers of Telugu and reared in an ambient environment of Telugu.

b. Diagnosed as congenital severe to profound hearing loss by an audiologist

c. No history of persisting middle ear problems

d. Fitted with suitable Digital hearing aids (Bilateral- behind the ear) of a minimum of 4 to 6 channels before 3 years of age.

e. Had speech language therapy experience of at least 1.6 years.

Inclusion Criteria for Clinical Group-2

a. Native speakers of Telugu and reared in an ambient environment of Telugu.

b. Diagnosed as congenital severe to profound hearing loss by an audiologist

c. No history of persisting middle ear problems

d. Unilateral cochlear implantation (fitted with Cochlear Nucleus 22 channel cochlear implant)

e. Bimodal fitting (use of a cochlear implant in one ear and a hearing aid in the opposite ear)

g. Cochlear implantation by the age of 3 years

h. Minimum of one and a half to two years of CI use

i. Undergone a minimum of one and a half to two years of Speech therapy at the time of participation in the study.

j. Uses 2–3-word sentences and expressive vocabulary of 50-70 words which was assessed using the Assessment Checklist for Speech and Language Skills- (ACSLS given by Dr. Swapna et al, 2015).

F. Absence of any comorbid syndromic conditions, orosensory, motor, intellectual, or visual deficits

Inclusion Criteria for Control Group.

a. Native speakers of Telugu

b. Hearing sensitivity within normal limits with no persisting middle ear pathologies

C. No other comorbidities.

Research Design

The present study was a standard group comparison, wherein a Qualitative analysis of articulation of children using a cochlear implant, hearing aids and typically developing children were compared.

Stimuli

For all the groups of participants revised norms of the Test of Articulation and Discrimination in Telugu-(Padmaja,1988), by Usha and Sreedevi (2010) were administered, and speech samples were recorded for further analysis. The Telugu articulation test consists of 80 items in total for checking the articulatory proficiency.

Procedure

Informed consent was obtained from each participant's parents before administering the test. The assessment was carried out through a virtual model by using feasible applications. For the assessment, all participants were requested to use their mobile phones to log in and the researcher used a laptop to log in. The parents or the caregivers of the participants were provided with the stimuli and asked to present them to the child verbally and the child was asked to repeat the words after keenly listening to the same.

Data Analysis

The recorded speech sample was transcribed using symbols and diacritics from the International phonetic alphabet (2015). From the recorded speech sample, the consonant productions were compared to target productions and error categories were identified at the segmental level and distortions, substitutions, omissions, and additions of consonants were distinguished. Cluster error analysis and Place, voice, and manner analysis were carried out.

Qualitative Analysis.

For qualitative analysis, only one target word for each phoneme was considered as per the stimulus of the Telugu Articulation test.

SODA (Substitution/omission/Distortion/Addition) Analysis:

The participant's consonant errors were grouped into substitution, omission, distortion, and addition errors (SODA). Substitution errors were further subjected to place, manner, and voicing (PMV) analysis to identify specific articulatory error patterns.

PMV (Place -Manner-Voicing) Analysis:

The PMV analysis involved classifying substitution errors according to place, manner, and voicing characteristics to identify error patterns. In this analysis, only substitution errors are considered. Distortions, omissions, and additions are not explained by this method.

Procedure: Consonants were listed under various places and manners of articulation. Substitution errors of each phoneme were identified separately for various phoneme positions (initial, medial & final). The phoneme and the corresponding place of articulation with which a particular phoneme is substituted were profiled. The percentage of substitutions with a particular place was calculated. For e.g. if phoneme /g/has four substitutions; 3 with /b/ (bilabial) and 1 with /t/ (dental), then 75% of the time /g/is substituted with a bilabial and 25% with a dental. Further, the overall percentage of substitutions for each place of articulation (combining all phonemes of that POA) was calculated. Similarly, substitutions were subjected to manner error analysis.

Statistical Analysis

The obtained data were tabulated and subjected to appropriate statistical analysis using SPSS (Statistical Package for Social Sciences) version 25.

Chapter 4

RESULTS

The aim of the study was to examine and compare the articulation abilities of Telugu-speaking children with hearing impairment using Digital hearing aids or are fitted with Cochlear implants and typically developing children.

A total of 15 Telugu-speaking children aged 4 to 6 years were recruited for the study. Participants were divided into three groups. Group-1 consisted of 5 children using digital hearing aids and they had a hearing age of minimum of 2 years, and Group-2 consisted of 5 children using cochlear implants fitted with multichannel cochlear implants and had an implant age of a minimum of 2 years.

The Test of Articulation and Discrimination in Telugu (Padmaja, 1988), norms revised by Usha and Sreedevi (2010), were administered to test the articulatory skills of the participants. The recorded speech sample was transcribed using symbols and diacritics from the International Phonetic Alphabet (2015). Vowels, consonants, and consonant clusters were qualitatively analysed and profiled. The recorded samples were subjected to SODA analysis, and the substitution errors were further subjected to Place Manner and voicing analysis. The obtained results were tabulated and subjected to appropriate statistical analysis.

The normality of the data collected was tested using Shapiro Wilk test of normality, the results indicated that the data was non-normally distributed. Descriptive statistics and non-parametric tests such as Kruskal-Walli's test and Mann-Whitney U test were carried out to infer the articulatory performance of children using Hearing aids, cochlear implants, and typically developing children. Inter and intra-judge reliability tests were carried out to check the reliability of the articulatory analysis.

To check for the different articulatory errors made by the participants in the three groups, the speech sounds were classified further. Vowels were classified as short and long, the consonants were classified according to their place and manner of articulation, and the results were tabulated separately. Additionally, the frequent phonological processes exhibited by the three groups were also documented.

4.1 Inter-judge reliability and Intra-judge reliability

To determine the reliability of the data, inter and intra-reliability testing was carried out. For intra-judge reliability, the researcher randomly selected five participants' data irrespective of the group and reanalysed it within a 4-week time interval. For inter-judge reliability, randomly selected 5 participants' data, regardless of the group, were analysed by three experienced speech and language pathologists who are proficient speakers of Telugu, and had a minimum of one year of experience working with children having childhood communication disorders. The researcher also served as one among the three judges. The judges carried out phoneme-by-phoneme analysis. They were instructed to score ‘1’ for correct responses, ‘0.5’ for substitution errors, ‘0.75’ for distortion errors, and ‘0’ for addition and deletion errors. Table 4.1 shows Cronbach's alpha values for the total scores computed from the articulatory analysis of the data of five randomly selected participants from the three groups.

Table 4.1

Cronbach's alpha values for Intra judge and Inter judge reliability of articulatory analysis

	Cronbach's Alpha (α)
Intra-judge	0.997
Inter-judge	0.982

Analysis of the results in table 4.1 revealed that the level of agreement for inter and intra judge reliability was excellent. The results obtained in the statistical analysis are explained in the under the following sections:

4.2 Qualitative Analysis and statistical comparison of vowels and diphthongs across HA, CI, and TDC.

4.3 Qualitative and statistical comparison of consonants across HA, CI, and TDC.

4.4 Qualitative and Statistical comparison of SODA errors across HA, CI, and TDC.

4.5 Qualitative comparison of phonological processes across HA, CI and TDC.

4.2 Qualitative analysis and statistical comparison of vowels and diphthongs across HA, CI, and TDC.

Total of 10 vowels, five short (/a/, /i/, /u/, /e/, /o/) and five long (/a: /, /i: /, /u: /, /e: /, /o :/) and two diphthongs /ai/ and /ou/ were tested. Out of these ten vowels, short vowels /a/, /i/, and /u/ were tested in initial, medial, and final positions. The vowels (/a: /, /i: /, /u: /, /e/, /e: /, /o/, /o :/) and the diphthong /ai/ were tested in initial and medial positions. Diphthong /ou/ was only tested in the medial position. Descriptive statistics were computed for the production of vowels and diphthongs across the children using Hearing aids (HA), cochlear implants (CI), and typically developing children (TDC). The mean, standard deviation, median, and interquartile range of vowels and diphthongs for HA, CI, and TDC are depicted in Table 4.2

Table 4.2

Mean, standard deviation, median, and interquartile range of articulatory scores for vowels and diphthongs in HA, CI, and TDC

Sounds	HA				CI				TDC			
	Mean	SD	Median	IQR	Mean	SD	Median	IQR	Mean	SD	Median	IQR
Vowels	22.7	0.44	23.0	0.8	22.8	0.44	23.0	0.5	23.0	0.0	23.0	0.0
Diphthongs	3.80	0.20	3.75	0.38	3.95	0.11	4.00	0.13	4.00	0.0	4.00	0.0

The qualitative analysis revealed that, for both vowels and diphthongs, as expected TDC performed better when compared to HA and CI groups. The non-parametric Kruskal-Wallis test was employed to examine the overall statistical difference in the vowel and diphthong production across the HA, CI, and TDC. No statistically significant difference was obtained across the groups. Hence no further statistical analysis was carried out. Although no statistical difference was obtained, few noticeable errors were made by participants in HA and CI groups. In the HA group, an atypical error was observed; in the initial position, one participant substituted short back vowel /u/ with the bilabial stop /p / for the word /ulipa:ya/ and the long back vowel /u:/ was substituted with the mid-central vowel /ə/. Substitution of back vowel /u/ by /o/ was also observed in one participant. Concerning the CI group, one participant substituted the back rounded vowel /u/ with the back vowel /o/, in the initial position. With respect to the temporal aspects of the vowels, participants in both HA and CI group had difficulties producing clear distinctive differences between short and long back vowels (/u/, /u: /, /o/, /o :/), however, such difficulties were not observed for the front vowels (/i/ and /i:/) and (/e/ and /e :/).

Concerning production of diphthongs across HA and CI groups, 2/5 of participants in the HA group and 1/5 participant in the CI group produced distorted diphthong /ai/ in the medial position. For the diphthong /ou/, which was tested only in the medial position, 2/5 participants in the HA group had more distortion errors. Contrarily participants in the CI group produced the diphthong /ou/ accurately.

4.3 Qualitative analysis and statistical comparison of consonants across HA, CI, and TDC.

The consonants tested were classified based on place of articulation for ease of description. The articulatory performance scores for the consonants were computed using the scoring criteria as follows; Correct response =1, Distortion =0.5, Substitution =0.5, Addition/omission = 0. Higher scores indicated better performance in terms of articulatory proficiency. The mean scores of the consonants across HA, CI, and TDC revealed that TDC had the highest scores, followed by CI and HA groups respectively. In terms of consonants based on their place of articulation, for bilabials, participants in both HA group and CI group was similar. However, for other places of articulation like dentals, alveolars, palatals, velars, glottal, and clusters, the participants in the CI group had better scores than the HA group. One of the salient findings is that the scores obtained for the labiodental phoneme were higher for the HA group when compared to CI. Detailed descriptions of the errors are discussed in the following sections. The mean, standard deviation, median, and interquartile range of consonants for HA, CI, and TDC are depicted in Table 4.3

Table 4.3

Mean, standard deviation, median, and interquartile range for articulatory scores of consonants in HA, CI, and TDC

Sounds	HA				CI				TDC			
	Mean	SD	Median	IQR	Mean	SD	Median	IQR	Mean	SD	Median	IQR
Bilabials	7.45	0.54	7.25	1.00	7.00	0.88	7.00	1.75	8.00	0.00	8.00	0.00
Alveolar	10.55	0.27	10.50	0.38	11.75	0.25	11.75	0.50	12.0	0.00	12.0	0.00
Palatals	8.70	0.95	8.50	1.75	10.45	0.51	10.50	0.88	12.00	0.00	12.00	0.00
Dental	5.25	0.50	5.00	0.88	5.75	0.35	6.00	0.63	6.00	0.00	6.00	0.00
Velar	5.15	1.05	5.50	1.88	6.05	0.79	6.25	1.50	7.00	0.00	7.00	0.00
Labio-dental	1.90	0.22	2.00	0.3	1.50	0.35	1.50	0.5	2.00	0.00	2.00	0.0
Glottal	1.00	0.00	1.00	0	1.00	0.00	1.00	0	1.00	.000	1.00	0.0
Cluster	2.80	0.83	3.00	1.50	4.40	0.33	4.25	0.63	4.80	0.20	4.75	0.38
Total	69.30	1.20	69.25	1.88	74.6	1.71	75.0	3.13	79.80	0.20	79.75	.38

Inferential statistics using the non-parametric Kruskal-Wallis Test was computed to study the differences in the consonant production across the three groups of participants. The results reveal that, at least one group had significant differences when compared with others. Hence, pairwise comparison was carried out using Mann-Whitney U test to find which among the three groups had significant differences. Table 4.4 shows the result of the Kruskal-Wallis Test and table 4.5 shows the results of pairwise comparison using Mann-Whitney U test across HA, CI, and TDC.

Table 4.4

Results of comparison of articulatory scores for overall consonant production between HA, CI, and TDC.

Kruskal-Wallis Test	H value	P value
Bilabials	6.195	.045*
Alveolars	11.784	.003*
palatals	12.582	.002*
Dental	6.872	.032*
Velar	9.310	.010*
Labiodental	7.425	.024*
Cluster	11.077	.004*
Total	12.567	.002*

Note. *$p<0.05$

Table 4.5

Results of Pair-wise comparison across HA, CI and TDC for consonants.

Mann-Whitney-U test	HA vs TDC		CI vs TDC		HA vs CI	
Pairwise comparison	|Z|	p value	|Z|	p value	|Z|	p value
Bilabials	4.100	.116	6.400	.042*	2.300	.377
Alveolars	9.000	.025*	3.000	.261	6.000	.025*
Palatals	9.800	.000*	5.200	.060	4.600	.096
Dental	6.500	.009*	2.500	.318	4.600	.110
Velar	8.200	.003*	5.300	.052	2.900	.287
Labiodental	1.400	.551	6.100	.009*	4.700	.045*
Cluster	9.200	.001*	3.400	.224	5.800	.038*
Total	10.00	.000*	5.00	0.76	5.000	0.76

Note. *p<0.05

Details of the results of pairwise comparison across the three groups based on place of articulation are explained below

Bilabials (/p/, /p^h/, /b/, /b^h/, /m/)

The non-parametric Mann-Whitney U test revealed no significant difference between the articulatory performance of participants of HA and TDC groups. Significant differences between articulatory performance were present across participants using CI and TDC (| Z |=6.400, p=.042 < 0.05). No significant difference was present for bilabials across HA and CI.

Alveolar (/t/, /d/, /n/, /l/, /s/, /r/, / ɾ /)

The findings of Mann-Whitney U test showed a significant difference between the articulatory performance of participants using HA and TDC for alveolar sounds (|Z|=9.000, p=.025 < 0.05). No discernible difference between participants in the CI group and TDC were obtained. The outcome showed a statistical difference between participants in HA and CI groups in terms of their articulatory performance for alveolar sounds (|Z|=6.000, p=.025 < 0.05).

Palatals (/tʃ/, /dʒ/, /j/, /ʃ/)

As per the results obtained from the Mann-Whitney U test, there is a statistically significant difference between participants in HA and TDC groups (|Z=9.800, p=.000 < 0.05). No statistically significant difference was found between participants in CI and TDC groups and between HA and CI groups.

Dentals (/t̪/, /d̪/, /dh/)

For dental consonants using Mann-Whitney U test reveals statistically significant difference between participants in HA group and TDC (|Z|=6. 500, p=009<0.05. With respect to participants in the CI group and TDC, no statistically significant differences were obtained. Similarly, no significant differences were obtained when comparing participants in HA and CI groups.

Velars (/k/, /g/, /k^{h}/, /g^{h}/)

The results from the Mann-Whitney U test indicates that there is a statistically significant difference for the articulatory performance between participants in HA and participants in TDC group (|Z|=8.200, p=003<0.05). For participants in CI and TDC, no statistically significant difference was obtained. Similarly, no significant differences were obtained when comparing the articulatory performance of participants in HA and CI groups.

Labiodental (/v/)

The results from the Mann-Whitney U test reveals that no statistically significant difference between participants in HA and TDC. A statistically significant difference between participants in CI and TDC ($|Z|=6.100$, $p=.009 < 0.05$) and across HA and CI were found ($|Z|=4.700$, p.045 < 0.05).

Clusters (/bl/, /sk/, /kʃa/, /ʃra/, /kʃ/)

A Statistically significant difference using the Mann-Whitney U test was found between participants in HA and TDC ($|Z|=9.200$, $p=.001<0.05$). No statistically significant difference was obtained between participants in the CI group and TDC. Significant differences were obtained when comparing the articulatory performance between participants in the HA group and CI ($|Z|=5.800$, $p=.038<0.05$).

Total score

The comparison of the total score obtained by the three groups indicates a statistically significant difference between participants in HA and TDC groups ($|Z|=10.00$, $p=.000<0.05$). There was no statistically significant difference between participants in CI and TDC groups. Similarly, no significant differences were obtained when comparing the articulatory performance of participants in HA and CI groups.

4.4 Qualitative analysis and Statistical comparison for SODA errors across HA, CI, and TDC.

Descriptive statistics were computed for the SODA errors, namely substitution, omission, distortion, and addition exhibited by the participants in HA, CI, and TD groups. The raw scores obtained were converted to percent scores on all the sound classes. The mean, standard deviation, median, and interquartile range for SODA errors are represented in table 4.6.

The results obtained for the SODA errors for the three groups of participants revealed that substitution, omission and distortion errors were more prominent among participants in the HA group when compared to other two groups. One of the asserting findings is that omission errors were prevalent only among participants in the HA group. Contrarily participants in the CI group exhibited more substitution errors. Distortion errors were prevalent among both groups of participants, where as participants in the HA group obtained a high median value for distortion error, when compared to CI and TDC groups. TDC also exhibited few distortion errors. Addition errors were not observed in any of the three groups of participants.

Table 4.6

Mean, standard deviation, median, and interquartile range of SODA errors in HA, CI, and TDC

Error pattern	HA			CI			TDC		
	Mean	Median	SD	Mean	Median	SD	Mean	Median	SD
Substitution	11.75	11.25	2.59	9.00	8.75	2.98	0.00	0.00	0.00
Omission	5.00	5.00	1.76	0.00	0.00	0.00	0.00	0.00	0.00
Distortion	9.00	7.50	3.35	6.75	6.25	1.89	1.25	1.25	0.88
Addition	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Correct response	74.25	75.00	2.87	84.25	82.50	3.13	98.75	98.75	0.88

4.4.1 Statistical Comparison of SODA errors across HA, CI and TDC

Inferential statistics using the non-parametric Kruskal-Wallis Test were computed to compare the substitution, omission, distortion, and addition (SODA) errors across TDC, HA and CI groups. Table 4.7 shows the result of the Kruskal-Wallis test for the SODA errors and correct responses across the three groups. The results revealed that there is a significant difference across the three groups, hence pairwise comparison using Mann-Whitney U test was employed to check which among the three groups had significant differences and the results are represented in table 4.8. The figure 4.1 depicts the correct responses obtained by the participants in HA, CI and TDC and figure 4.2 represents the SODA errors and correct responses obtained by the three group of participants.

Table 4.7

SODA errors and correct responses across the three groups.

Kruskal-Wallis Test	H value	P value
Substitution	10.446	.005*
Omission	13.427	.001*
Distortion	10.678	.005*
Correct response	12.635	.002*

Note. *p<0.05

Concerning the substitution error across the HA group and TDC participants, the results revealed a statistically significant difference (|Z|=8.600, p=.002 < 0.05). Similarly, a significant difference (|Z|=6.400, p=.021<0.05) was obtained between CI and TDC group participants. Further, no statistically significant difference was obtained between HA and CI group participants.

Regarding the omission errors, there was a significant difference (|Z|=7.500, p=0. 002 < 0.05) between participants in the HA group and the TDC group. Contrary to these results, no statistical difference was obtained between participants in CI and TDC groups. A statistically significant difference (|Z|=7.500, p=0.002 < 0.05) was also obtained between participants in HA and CI groups.

A statistically significant difference in terms of distortion errors across HA and TDC (|Z|=8.800, p=0.001 < 0.05) and across CI and TDC groups (|Z|=6.200, p=0.025< 0.05) were obtained. However, no significant difference was obtained between participants in HA and CI groups.

In terms of correct responses obtained by the three groups of participants, a statistically significant difference was only present between HA and TDC group (|Z|= 10.00, p=.000 < 0.05).

Table 4.8

Results of Pair-wise comparison of SODA errors across three groups.

Man-Whitney U test	HA vs TDC		CI vs TDC		HA vs CI	
Pairwise comparison	|Z|	P value	|Z|	P value	|Z|	P value
Substitution	8.600	.002*	6.400	.021*	2.200	.426
Omission	7.500	. 002*	.000	1.000	7.500	.002*
Distortion	8.800	.001*	6.200	0.025*	2.600	.347
Correct responses	10.00	.000*	5.00	.076	5.00	.076

Note *p<0.05

Figure 4.1

Shows correct responses obtained by the participants in HA, CI and TDC.

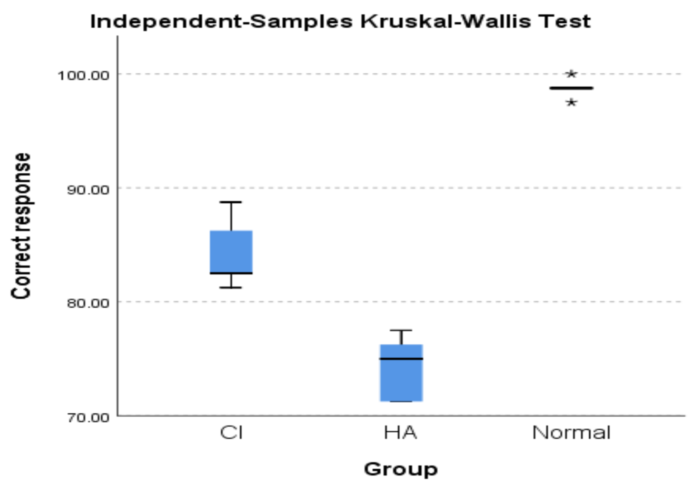
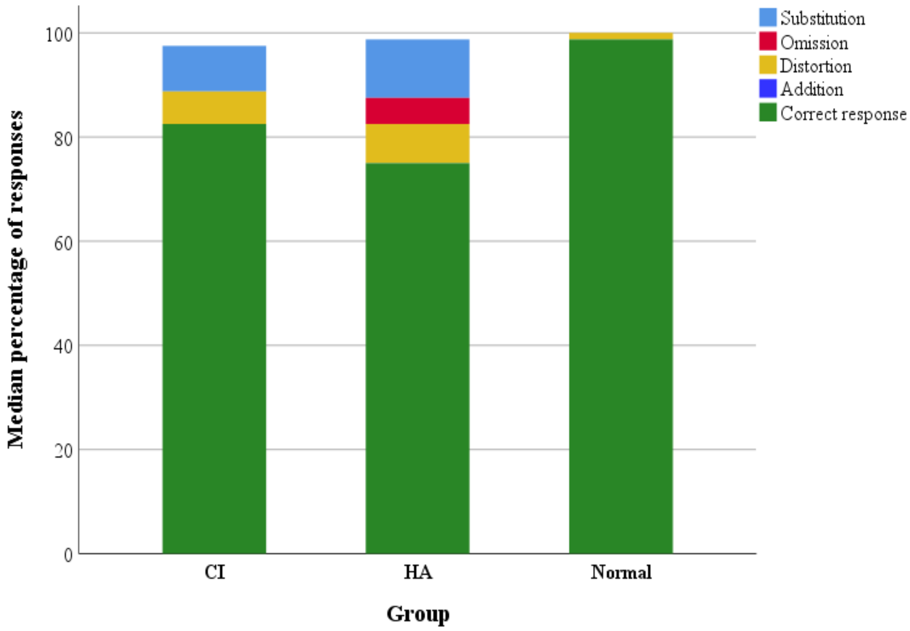


Figure 4.2

Shows SODA errors and correct responses of HA, CI and TDC groups.



The results from the qualitative and statistical analysis shows that substitution errors were more prevalent in HA and CI groups and no substitution errors were present in typically developing children. Hence, further the substitution errors in HA and CI were subjected to Place-Manner-Voicing analysis (PMV) to obtain a comprehensive picture of the substitution errors made.

4.4.2 PMV analysis for substitution errors in HA group

The substitution errors made by the participants utilizing hearing aids (HA) were further analysed on the basis of errors of Place, Manner and Voicing (PMV) to explore which type of substitution errors (PMV) were more prevalent among the participants in HA group.

Bilabials

Under stop consonants, five bilabial phonemes tested included (/p/, /p^h/, /b/, /b^h/, /m/). The unaspirated bilabial stops (/p/, /b/, /m/) were tested in initial and medial positions and the aspirated stops (/p^h/, /b^h/) were tested in initial positions only. All participants in the HA group were able to accurately produce the phonemes /p/ and /m/ in initial and medial positions. No errors with respect to place of articulation was observed. Deaspiration errors for the unvoiced aspirated stop /p^h/ and its voiced cognate /b^h/ were substituted with unaspirated stops /p/ and /b/.

Manner and voicing errors of bilabials

HA group were able to produce the consonants without any manner errors for bilabials. Devoicing errors were observed for the voiced bilabial stop /b/.

Table 4.9

PMV analysis of bilabial phonemes in children using HA.

Target phonemes		HA				
Phoneme	Position	NPS	SP	POA	MOA	Voicing
p	I M	0	-	-	0	-
b	I	1	/p/	Bilabial	Stop	Devoicing
	M	1	/p/	Bilabial	Stop	Devoicing
p^h	I	1	/p/	Bilabial	Stop	-
b^h	I	1	/b/	Bilabial	Stop	-
m	I M	0	-	-	-	-

Note. NPS-number of participants with substitution errors, SP- substituted phoneme, POA- the place of articulation, MOA-Manner of articulation.

Labiodental

The labiodental fricative /v/ was tested only in the initial and medial positions. No place error was observed in the initial position. However, in the medial position one participant substituted the phoneme /v/ with unvoiced velar stop /k/.

Manner and voicing errors of labiodental

The voiced labiodental fricative /v/ was substituted with the unvoiced velar stop /k/ indicating both manner and devoicing errors as in table 4.10

Table 4.10

PMV analysis of Labiodental phoneme in children using HA.

Target phonemes	HA					
Phoneme	Position	NPS	SP	POA	MOA	Voicing
v	I	0	-	-	0	-
	M	1	/k/	Velar	Stop	Devoicing

Note. NPS-number of participants substituted, SP-Substituted phoneme substituted with, POA- the place of articulation, MOA-Manner of articulation.

Dentals

Three phonemes were tested under dentals (/t̪/, /d̪/and /d^h/) in the initial and medial position. Analysis of the substitution errors based on the place of articulation reveals that the unvoiced dental stop /t̪/ was substituted with the unvoiced velar stop /k/ in initial position by 1/5 participants. The voiced dental stop /d̪/ was substituted with the unvoiced alveolar stop /t/ in the initial position by one out of five participants and in final position it was substituted with the palatal glide /j/ by 1/5 participants. The voiced aspirated dental stop /d^h/, was substituted with unvoiced alveolar stop /t/ by one participant in both initial and medial positions.

Manner and voicing errors of dentals

Few apparent manner errors such as substitution of the glide /j/ for the voiced dental stop /d̪/ in the final position by one participant was observed. Devoicing errors for voiced dental phoneme /d̪/ when substituted with unvoiced alveolar phoneme /t/ in the initial position was seen. Similarly, the voiced aspirated dental stop /d^h/ was substituted with the unvoiced /t/ in both initial and medial positions by one of the five participants. The results are compiled and represented in table 4.11

Table 4.11

PMV analysis of dental phonemes in children using HA.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
t̪	I	1	/k/	Velar	Stop	-
	M	0	-	-		
d̪	I	1	/t/	Alveolar	Stop	Devoicing
	M	1	/j/	palatal	Glide	
d^h	I	1	/t/	Alveolar	Stop	Devoicing
	M	1	/t/	Alveolar	Stop	Devoicing

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Alveolars

Six alveolar phonemes that includes (/t/, /d/, /n/, /l/, /r/, /s/, / ɾ /) were tested across initial, medial positions. The alveolar trill /r/ and the fricative /s/ were tested in initial and final positions and the alveolar flap /ɾ/ was tested only in the initial position. Participants in the HA group produced the unvoiced alveolar stop /t/ and nasal stop /n/ and the lateral /l/ accurately.

With respect to the errors of place of articulation reveal that, the alveolar voiced stop /d/ was substituted with bilabial voiced stop /b/ by one among the five participants and 2/5 participants substituted fricative /s/ with bilabial stop /p/ and with the voiced alveolar stop /d/ in the initial position. Substitution of the phoneme /s/ with the unvoiced dental stop /t/ by 4/5 participants and with unvoiced velar stop /k/ by 1/5 participant were observed. For the voiced alveolar trill /r/ in the initial position 2/5 participants substituted with unvoiced velar stop /k/, and it was substituted with the voiced alveolar lateral /l/ in the medial position by 1/5 participants, and in the final position by 4/5 participants. One participant substituted the alveolar flap / ɾ / with the lateral /l/ in the initial position. Thus, it can be observed that production of the alveolar trill /r/ was most difficult in the final position followed by initial and medial positions. The production of fricative /s/ was more difficult in the final position followed by medial and initial positions. The results are compiled and represented in the table 4.12.

Manner and voicing errors of alveolars

Prominent errors in the manner of articulation were observed for the unvoiced alveolar fricative /s/, which was predominantly substituted with other unvoiced stop consonants /p/ and /k/. Substitution of the alveolar trill /r/ with the lateral approximant /l/ was more evident in the final position. Devoicing errors were observed where the voiced trill /r/ was substituted with the unvoiced velar stop /k/, and fricative /s/ was substituted with voiced alveolar stop /d/.

Table 4.12

PMV analysis of alveolar phonemes in children using HA.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
t	I M	0	-	-	0	-
d	I M	1	/p/	Bilabial	Stop	Devoicing
n	I	0	-	-	-	-
l	I	0	-	-	-	-
	M	0	-	-	-	-
	F	0	-	-	-	-
s	I	2	/p/	Bilabial	Stop	-
			/d/	Alveolar	Stop	Voicing
	F	4	/t/	Dental	Stop	-
			/k/	Velar	Stop	-
r	I	2	/k/	Velar	0	-
	M	1	/l/	Alveolar	Lateralization	-
	F	4	/l/	Alveolar	Lateralization	-
ɾ	I	1	/l/	Alveolar	Lateralization	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Palatals

Four palatal sounds were tested in initial and medial positions (/tʃ/, /dʒ/, /j/, /ʃ/). The glide /j/ was tested only in the initial position. Participants in the HA group produced the palatal glide /j/ accurately. Concerning the substitution errors in the place of articulation the unvoiced palatal affricate /tʃ/ was substituted by unvoiced alveolar stop /t/ in the initial position by 1/5 participants and by unvoiced alveolar fricative /s/ in the medial position by 1/5 participants.

Voiced palatal affricate /dʒ/ was produced correctly in the initial position, but in the medial position /dʒ/ was substituted with unvoiced alveolar stop /t/ by 1/5 participants. The palatal fricative /ʃ/ was substituted with alveolar fricative /s/ by four of five participants in initial position. And 3/5 participants substituted /ʃ/ with the alveolar fricative /s/ in the medial position.

Manner and voicing errors of Palatals

From the results, it was apparent that the affricates were substituted with other stops, fricatives and other affricate sounds. Devoicing of the voiced palatal affricate /dʒ/ was seen when substituted with the unvoiced fricative /s/. Table 4.13 depicts the results of error of place, manner and voicing features in HA participants for palatal phonemes.

Table 4.13

PMV analysis of palatal phonemes in children using HA.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
	I	1	/t/	Alveolar	Stop	-
tʃ	M	1	/s/	Alveolar	Fricative	-
dʒ	I	0	-	-	0	-
	M	1	/t/	Alveolar	Stop	Devoicing
j	I	0	-	-	0	-
ʃ	I	3	/s/	Alveolar	Fricative	-
		1	/ tʃ/	Palatal	Affricate	-
	M	3	/s/	Alveolar	Fricative	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Velars and Glottals

Velar phonemes tested were unvoiced stop /k/, voiced stop /g/, their aspirated cognate /k^h/ was tested in initial and medial positions. The voiced aspirated velar /g^h/ and glottal phoneme /h/ were tested only in the initial position.

Participants in HA group produced the unvoiced velar stop /k/ and glottal /h/ accurately. With regard to place of articulation, the production of the voiced velar stop /g/ and unvoiced aspirated velar stop /k^h/ in initial and medial positions were difficult. In the initial position, 1/5 participants substituted the phoneme /g/ with its unvoiced cognate /k/ and also substituted the phoneme /g/ with the voiced labiodental fricative /v/ in the medial position. The unvoiced aspirated velar stop /k^h/ was substituted with its unaspirated cognate /k/ in both initial and medial position by 1/5 participants. Table 4.14 shows the results of substitution errors for the velar phonemes by children using HA.

Manner and voicing errors of velars and glottals

Substitution of fricatives for the stops was observed, where the voiced velar stop /g/ was substituted with labiodental fricative /v/ in the final position. Devoicing errors of substitution of voiced consonant /g/ with unvoiced /k/. Also, the voiced aspirated velar stop /g^h/ substituted with /k/ was observed in the initial position.

Table 4.14

PMV analysis of velar phonemes in children using HA.

Phoneme	Position	NPS	SP	POA	MOA	PS
k	I	0	-	-	0	-
	M	0	-	-		
g	I	1	/k/	Velar	Stop	Devoicing
	M	1	/v/	Labiodental	Fricative	-
k^h	I	1	/k/	Velar	Stop	Devoicing
	M	1	/k/	Velar	Stop	Devoicing
g^h	I	2	/k/	Velar	Stop	Devoicing
v	I	0	-	-	0	-
	M	1	/k/	Velar	Stop	Devoicing
h	I	0	-	0	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulatin

Clusters

Five clusters tested in the study were /bl/, /sk/, /kʃa/, /ʃra/, /kʃ/ in which /bl/, /sk/ were tested in the initial position and /kʃa/, /ʃra/, /kʃ/ were tested in medial positions. Overall, the production of clusters was difficult when compared with singleton consonants. No participant in HA group was able to produce the cluster /ʃra/ correctly. Substitution of /kʃa/ with /tʃ/ for the word /rikʃa/ was observed in 2/5 participants. The cluster /sk/ in the word /ske:lu/ was substituted with bilabial stop /p/ and produced as /pe:lu/ by 1/5 participants. Other cluster errors such as initial cluster reduction, deletion and distortion were more prominent and the results are represented in the respective subsections.

4.4.3 PMV analysis for substitution errors in CI group

The substitution errors made by the participants in the CI group was subjected to PMV analysis and the results are discussed in the following sections.

Bilabials

In participants in the CI group, the bilabial unvoiced stop /p/ and nasal stop /m/were accurately produced. Analysis of errors of place of articulation reveals that the voiced bilabial stop /b/ was substituted with unvoiced velar stop /k/ by 1/5 participants in the medial position. Further, the voiceless aspirated bilabial stop /p^h/ and its voiced cognate /b^h/ were substituted with their unaspirated counterparts /p/ and /b/ respectively.

Manner and voicing errors of Bilabials

No errors concerning the manner of articulation was observed**.** Devoicing of the voiced consonants such as the voiced bilabial stop /b/ was substituted with unvoiced cognate /p/ in initial position.

Table 4.15

PMV analysis of bilabial phonemes in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
p	I M	0	-	-	0	-
b	I M	3 1	/p/ /k/ /p/	Bilabial Velar Bilabial	Stop Stop Stop	Devoicing Devoicing Devoicing
p^h	I	1	/p/	Bilabial	Stop	
b^h	I	1	/b/	Bilabial	Stop	
m	I M	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Labiodental

The labiodental fricative /v/ was tested only in the initial position. Despite its anterior production and more visible articulatory features, 1/5 participants in the CI group substituted it with unvoiced bilabial stop /p/ in the initial position. In the medial position 2/5 participants substituted the phoneme /v/ with unvoiced velar stop /k/, and 1/5 participants substituted it with unvoiced bilabial stop /p/.

Manner and voicing errors of labiodental

Substitution of stops for the fricatives were predominantly observed i.e., substituting the fricative /v/ with bilabial stop /p/ or velar stop /k/ respectively. Devoicing errors were observed for voiced fricative /v/ which was substituted with unvoiced stop consonants /p/ and /k/.

Table 4.16

PMV analysis of labiodental phoneme in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
	I	1	/P/	Bilabial	Stop	Devoicing
v	M	3	/k/	Velar	Stop	Devoicing
		1	/p/	Bilabial	Stop	Devoicing

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Dental

In participants in CI group, the voiced dental /d̪/ was produced correctly among the other dental phonemes. The unvoiced dental /t̪/ was substituted with the unvoiced velar stop /k/ by 1/5 participants in the initial position. The voiced unaspirated dental stop

/d^h/ was substituted with voiced alveolar stop /d/ by one participant in the initial position was noted.

Manner and voicing errors of dentals

No errors with respect to manner and voicing features for dental consonants were observed. Thus, it can be stated that for dental consonants errors of place of articulation is more prevalent in participants in CI group.

Table 4.17

PMV analysis of dental phonemes in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
t̪	I	1	/k/	Velar	Stop	-
	M					
d̪	I	0	-	-	-	-
	M					
d^h	I	1	/d/	Alveolar	Stop	-
	M					

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Alveolar

Six alveolar phonemes which includes (/t/, /d/, /n/, /l/, /r/, /s/, /ɾ/) were tested across Initial, Medial positions. The alveolar trill /r/ and the fricative /s/ were tested in Initial and final positions. The participants in CI group were able to produce the unvoiced alveolar stop /t/, the lateral /l/, nasal stop /n/, fricative /s/ and flap /ɾ/ accurately. The alveolar trill /r/ was substituted with the alveolar lateral approximant /l/ in the final position by 3/5 participants. Thus, it is evident that the production of alveolar trill /r/ was significantly difficult for participants in CI group.

Manner and voicing errors of alveolars

The alveolar trill /r/ were substituted by lateral /l/ was the only error concerned with the manner of articulation. Devoicing of the voiced alveolar stop /d/ when substituted with unvoiced alveolar stop /t/ by 2/5 participants were observed in the initial position.

Table 4.18

PMV analysis of alveolar phonemes in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
t	I M	0	-	-	-	-
d	I M	2	/t/	Alveolar	stop	Devoicing
n	I	0	-	-	-	-
l	I M F	0	-	-	-	-
s	I F	0	-	-	-	-
r	I M F	0 0 3	- - /l/	- - Alveolar	- - Lateral	- - -
ɾ	I	0	-	-	-	

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Palatals

Four palatals were tested in Initial and medial positions (/tʃ/, /dʒ/, /j/, /ʃ/). The glide /j/ was tested only in the initial positions. The participants in CI group were able to produce the voiced and unvoiced affricates (/dʒ/, /tʃ/), and the glide /j/ accurately. The palatal fricative /ʃ/ was substituted with alveolar fricative /s/ in the initial position by 1/5 position.

Manner and voicing errors of palatals

No errors with respect to manner and voicing were observed for palatal sounds.

Table 4.19

PMV analysis of palatal phonemes in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
	I	0	-	-	-	-
tʃ	M					
dʒ	I	0	-	-	-	-
	M					
j	I	0	-	-	-	-
ʃ	I	1	/s/	Alveolar	Fricative	-
	M	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation.

Velars and Glottal

Velar phonemes tested were unvoiced stop /k/, voiced stop /g/, their aspirated cognates /k^h/ and /g^h/ and labiodental phoneme /v/ were tested in initial and medial positions. The glottal phoneme /h/ was tested in the initial position. The participants in CI group were able to produce the voiced velar stop /g/ and the glottal phoneme /h/

accurately. Regarding the place errors, the unvoiced velar stop /k/ was substituted with unvoiced bilabial stop /p/ in the initial position by 2/5 participants was noted. Unvoiced aspirated stop /k^h/ was substituted with its unaspirated cognate /k/. The voiced aspirated velar stop /g^h/ was substituted with its unaspirated voiced cognate /g/ by 3/5 participants in the initial position.

Manner and voicing errors of velars and glottals

No errors with respected to voicing and manner of articulation was observed.

Table 4.20

PMV analysis of velar and glottal phonemes in children using CI.

Phoneme	Position	NPS	SP	POA	MOA	Voicing
k	I	2	/p/	Bilabial	Stop	-
	M	0	-	-		
g	I	0	-	-	-	-
	M	0	-	-	-	-
k^h	I	2	/k/	Velar	Stop	-
	M	2	/k/	Velar	Stop	-
g^h	I	3	/g/	Velar	Stop	-
	M					
h	I	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation

Clusters

Among the five clusters /bl/, /sk/, /kʃa/, /ʃra/, /kʃ/ distorted production of the clusters was a noticeable error occurred in participants in CI group. 3/5 participants were able to accurately produce the cluster /bl/, /sk/ in the initial position. Production of the cluster /ʃra/ was particularly difficult, only 1/5 participants able to produce it accurately. Distortion errors were prominent in participants in CI group, which are represented in the respective subsections.

4.4.4 Comparison of PMV errors across CI and HA

The substitution errors made by the participants in both HA and CI group were analysed based on the PMV analysis and the results are compared to obtain the similarities and differences in the errors exhibited by both group of participants.

Bilabials

The results of the substitution error analysis of bilabial phonemes in both groups are shown in table 4.21. In both HA and CI groups the most correctly produced phonemes were the unvoiced bilabial /p/ followed by nasal /m/. With reference to place errors, revealed that in both CI and HA groups, the voiced bilabial /b/ was substituted with its unvoiced cognate /p/ in both initial and medial positions by one participant in each group. In addition, the unvoiced aspirated /p^h/ and its voiced cognate /b^h/ were substituted with unaspirated /p/ and /b/. In both CI and HA groups, the production of the voiced bilabial /b/ was noticeably difficult.

Manner and voicing errors of bilabials

No errors with respect to manner of articulation for bilabial consonants were observed in both groups of participants. Devoicing of the voiced bilabial stop /b/, when substituted with its unvoiced counterpart /p/ has been noticed in conjunction to voicing errors in both HA and CI group. From these observations it can be concluded that in terms of substitution errors, there is no noticeable difference between the CI and HA groups. In both the groups, errors concerning the place of articulation was more when compared to manner and voicing errors.

Table 4.21

Comparison of PMV analysis of bilabial phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
p	I M	0	-	-	-	-	0	-	-	-	-
b	I	1	/p/	Bilabial	Stop	Devoicing	1	/p/	Bilabial	Stop	Devoicing
	M	1	/p/	Bilabial	Stop	Devoicing	3	/k/ /p/	Velar Bilabial	Stop 0	Devoicing -
p^h	I	1	/p/	Bilabial	Stop	-	1	/p/	Bilabial	Stop	-
b^h	I	1	/b/	Bilabial	Stop	-	1	/b/	Bilabial	Stop	-
m	I M	0	-	-	-	-	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, V-Voicing features.

Labiodental

Participants in HA group were able to produce the labiodental fricative /v/ accurately in the initial position. Concerning the place of articulation, the phoneme /v/ was substituted with velar consonant /k/ in the medial position by both HA and CI group. In participants of CI group, the labiodental phoneme /v/ was substituted with the bilabial phoneme /p/. Table 4.19 represents the substitution errors based on place, manner and voicing analysis for HA and CI groups.

Manner and voicing errors of labiodental

Both HA and CI group participants substituted the labiodental fricative /v/ with the stop consonants /k/ and /p/ respectively. Devoicing errors were observed in both CI and HA groups. The participants in HA group performed better when compared with CI group in terms of labiodental production.

Table 4.22

Comparison of PMV analysis of labiodental phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
	I	0	-	-	0	-	1	/P/	Bilabial	Stop	Devoicing
v	M	1	/k/	Velar	Stop		3	/k/	Velar	Stop	Devoicing
							1	/p/	Bilabial	Stop	Devoicing

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, V-Voicing features.

Dentals

The participants in CI group were able to produce correctly the voiced dental /d̪/ in all the targeted positions. And in HA group none of the participants were able to produce the dental consonants correctly. Voiced dental /d̪/ in both initial and medial position was significantly difficult for children using HA. Substitution of velar /k/ for the dental /t̪/ in the initial position was observed in both HA and CI groups. In both the groups, most frequently the dental phonemes were substituted with alveolar phonemes in both initial and medial positions. Table 4.23 represents the substitution errors for dental consonants based on PMV analysis by HA and CI groups.

Manner and voicing errors of dentals

No manner and voicing errors were observed in CI group**.** In HA group the aspirated dental stop /d^h/ was substituted with palatal glide /j/ was the only error concerning the manner of articulation was observed. Devoicing errors prevalent only in the HA group. Hence, the production of dental sounds was better in CI group when compared to HA group.

Table 4.23

Comparison of PMV analysis of dental phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
t̪	I	1	/k/	Velar	Stop	-	1	/k/	Velar	Stop	-
	M										
d̪	I	1	/t/	Alveolar	Stop	Devoicing	0	-	-	-	-
	M		/j/	palatal	Glide	-					
d^h	I	1	/t/	Alveolar	Stop	Devoicing	1	/d/	Alveolar	Stop	-
	M	1	/t/	Alveolar	Stop	Devoicing	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, V-Voicing features.

Alveolars

The unvoiced alveolar sounds /t/ and /n/ were accurately produced in both the HA and CI groups. Both in the initial and final positions, producing the alveolar /r/ was difficult for both participant groups. The children utilising CI were able to accurately produce the alveolar /s/ while the HA group had difficulty doing so. According to the observations made above, the individuals in the HA group had considerably more difficulty with the alveolar /s/ and alveolar /r/ than those in the CI group.

Manner and voicing errors of alveolars

The substitution of the stops (/p/, /t/, /d/, /k/) for the fricative /s/ was predominant in participants in HA group. In both CI and HA group the substitution of the alveolar trill /r/ with the lateral /l/ was a prominent error. Devoicing errors were observed in both the group of participants, where the voiced alveolar /d/ was substituted with unvoiced bilabial stop /p/ and unvoiced alveolar stop /t/. Voicing of the unvoiced consonant was observed in HA group were the unvoiced fricative /s/ was substituted with the voiced alveolar stop /d/. More substitution occurred in the final position of the word than initial and medial position for both the group of participants. Thus, the errors concerning place of articulation was more when compared to errors of manner and voicing features. The table 4.24 represents the substitution errors based on PMV analysis for alveolar consonants for HA and CI groups.

Table 4.24

Comparison of PMV analysis of Alveolar phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
t	I M	0	-	-		-	0	-	-	-	-
d	I M	1	/p/	Bilabial	Stop	Devoicing	2	/t/	Alveolar	Stop	Devoicing
n	I	0	-	-	-	-	0	-	-	-	-
l	I M F	0	-	-	-	-	0	-	-	-	-
s	I F	2 4	/p/ /d/ /t/ /k/	Bilabial Alveolar Alveolar Velar	Stop Stop Stop Stop	- Voicing - -	0	-	-	-	-
r	I M F	2 1 4	/k/ /l/ /l/	Velar Alveolar Alveolar	Stop Stop Lateral	Devoicing	0 0 3	- - /l/	- - Alveolar	0 0 3	-
ɾ	I	1	/l/	Alveolar	-	-	0	-	-	0	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, V-Voicing features

Palatals

The palatal /j/ was produced accurately by participants in HA and CI groups and participants in the CI group produced the voiced palatal /dʒ/ correctly in all the positions. Overall, the participants in the CI group had fewer substitution errors when compared to the HA group. Production of the palatal /ʃ/ in both initial and medial positions were noticeably difficult for both group of participants.

Manner and voicing error of palatals

In both group of participants, the palatal affricates were substituted with stop consonants. In participants in HA the palatal fricative /ʃ/ was substituted with alveolar fricative /s/ was observed in the initial position by 4/5 participants. Correspondingly, in participants in CI, the palatal fricative /ʃ/ was substituted with the alveolar fricative /s/ in the medial position. Devoicing errors were observed in participants in HA. Contrarily the participants in CI did not exhibit voicing errors with respect to targeted palatal consonants.

To summarize, in both the groups the substitution of palatals with alveolars was majorly observed in terms of place of articulation. The affricate consonants were substituted with stops and fricatives. Devoicing errors were observed only in HA participants. Hence it can be concluded, place errors were more prominent than manner and voicing errors in both HA, and CI with respect to palatal consonants.

Table 4.25

Comparison of PMV analysis of palatal phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
	I	1	/t/	Alveolar	Stop	-	1	/t/	Alveolar	1	-
tʃ	M	1	/s/	Alveolar	Fricative		0	-	-	0	-
dʒ	I	0	-				0	-	-	0	-
	M	1	/t/	Alveolar	Stop	Devoicing	0	-	-	0	-
j	I	0	-	-	Stop	-	0	-	-	0	-
ʃ	I	4	/s/	Alveolar	Fricative	-	0	-	-	-	-
			/tʃ/	Palatal	Affricate	-	1	/s/	Alveolar	Fricative	-
	M	3	/s/	Alveolar	Fricative	-	0	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, V-Voicing features

Velars and Glottal

Concerning the velar and glottal production, the glottal phoneme /h/ was produced accurately by participants in both groups. In HA group the unvoiced velar /k/ was accurately produced and in CI group the voiced velar consonant /g/ was accurately produced. For both HA and CI group the production of /k^h/ and its voiced cognate /g^h/ were significantly difficult.

Manner and voicing errors of velars and glottals

The substitution of labiodental fricative /v/ for the voiced velar stop /g/ was observed in participants in HA group. Devoicing errors were prevalent only in the HA group. The voiced velar stop /g/ was substituted with its unvoiced cognate /k/ was observed. Participants in CI group had less errors when compared to participants in HA group. Both the group of participants substituted the velar (back consonants) with the bilabial (front consonants). And in both the group of participants the production of aspirated consonants (/k^h/, /g^h/) were more difficult and these consonants were frequently substituted with its unaspirated counterparts (k/, /g/).

Table 4.26

Comparison of PMV analysis of velar and glottal phonemes in children using HA and CI.

Target phonemes		HA					CI				
Phoneme	Position	NPS	SP	POA	MOA	V	NPS	SP	POA	MOA	V
k	I	0	-	-	Stop	-	2	/p/	Bilabial	Stop	-
	M	0	-	-	Fricative		0	-	-	0	-
g	I	1	/k/	Velar			0	-	-	0	-
	M	1	/v/	labiodental	Stop	Devoicing	0	-	-	0	-
k^h	I	1	/k/	Velar	Stop	-	2	/k/	Velar	Stop	-
	M	1	/k/	Velar			2	/k/	Velar	stop	
g^h	I	2	/k/	Velar	Stop	Devoicing	3	/g/	Velar	Stop	-
		1	/g/	Velar	Stop	0	-	-	-	-	-

NPS-number of participants substituted, SP- substituted phoneme, POA- place of articulation, MOA – Manner of articulation, Voicing features

Followed by the substitution errors, distortion errors were more prevalent in HA and CI. TDC group also demonstrated few distortion errors. The distortion errors in the three groups of participants are discussed under the following sections.

4.4.7 Qualitative comparison of distortion errors across HA, CI and TDC.

The comparison of the distortion errors exhibited across participants of HA, CI and TDC groups revealed that participants in the HA group had more distortion errors. The participants in the TDC group had distortion only for the cluster sounds. Hence in the following section, the distortion errors made by the participants in HA and CI group are represented.

Among bilabials, both the groups had distorted production of the voiced bilabial stop /b/ in the initial and medial position. In the HA group distortion of unvoiced aspirated stop /p^h/ and its voiced cognate /b^h/ in the initial position were observed. For the dental consonants, the participants in the CI group had distortion errors for the voiced dental stop /d̪/ in the initial position and the HA group produced voiced dental stop /d̪/ distortedly in the medial position.

With regard to the alveolar consonants, the CI group had distortion errors only for the alveolar trill /r/ in the final position. The participants in the HA group had distortion errors for the alveolar fricative /s/ and the alveolar trill /r/ in both initial and final positions.

For both groups of participants, it was difficult to produce palatal sounds correctly. Both group of participants produced the unvoiced and voiced palatal affricates /tʃ/ and /dʒ/ distortedly in initial and medial positions. The participants in the HA group had distorted production of palatal fricative /ʃ/ in the medial position and the CI group had distortion errors for the same in both initial and medial positions. In producing the velar consonants, the HA group had more distorted errors and the CI group exhibited distortion of the unvoiced aspirated velar stop /k^h/ in the initial position. Distorted production of the voiced velar stop /g/ in both initial and medial position, and the unvoiced aspirated velar stop /k^h/ in medial positions were more prevalent in the HA group.

Few distortion errors were made by the TDC for the clusters /ʃra/, /kʃ/ by two out of the five participants. For CI group the clusters /bl/, /sk/, /ʃra/, /kʃ/ had more distortion errors. However, deletion of clusters was more prevalent in HA group and the results are discussed in following sections.

4.4.8 Qualitative comparison of omission errors between HA and CI

One of the salient findings is that, the omission of the targeted phonemes was prevalent only with the participants in the HA group. Hence, the following section explains the sound classes that had omission errors by the participants in the HA group.

Omission of the voiced palatal affricate /dʒ/ in the medial position by 2/5 participants, and the palatal glide /j/ in the initial and medial position by 1/5 participants, the alveolar trill /r/ initial and medial position by 1/5 participants, the alveolar flap /ɾ/ by 1/5 participants in the initial position, the unvoiced aspirated velar stop /k^h/in the initial position by 1/5 and by 2/5 in the medial position.

Omission of the initial clusters /bl/ in the word (/bledu/) by 3/5 participants, and /sk/ in the word (/skelu/) by 2/5 participants were observed. The medial cluster /ʃra/ in the word /aʃramam/ was omitted by 3/5 participants and /kʃa/ in the word /rikʃa/ was omitted by 1/5 participants.

4.5 Qualitative comparison of phonological processes in participants in HA, CI and TDC.

The phonological processes frequently exhibited by the three groups of participants were documented. In participants belonging to HA group, the most frequently occurring phonological processing were the rhotacism (E.g. /kala/ for /karra/), velar fronting (E.g. /pappu/ for /kappu/) stopping (E.g. /Pu:di/ for /su:di/) , deaspiration (/palam/ for /p^halam/), Initial consonant deletion (/o:li/ for /go:li/), deaffrication (/taku/ for /tʃa:ku/), total and partial cluster reduction (/kelu/ for /skelu/) were commonly observed in all the five participants.

On the other hand, in participants belonging to CI group, partial cluster reduction, deaspiration, depalaitization, deaffrication, rhotacism and fronting were predominant in all the five participants. It's noteworthy to mention, phonological processes such as initial consonant deletion and stopping were not observed in any of the participants who were using CI. Further, the typically developing children exhibited only partial cluster reduction in 3/5 participants, depalatalization, and affrication by 1/5 participants were present.

Hence, the following conclusions may be made from the results:

- Both CI and HA groups exhibited substitutions and distortion errors for vowels and diphthongs.
- CI group performed better in terms of consonant production than HA group. They exhibited less number and variety of SODA errors when compared to HA groups. However, in terms of consonants bilabials and glottals, both groups performed similarly.

- Among SODA errors, substitution errors was most predominant among both HA and CI groups. This was followed by distortion errors. On the contrary, omission errors were only exhibited by HA group. Similarly, none of the participants in both the groups made any addition errors.
- With respect to Phonological process, initial consonant deletion and stopping was seen only in HA group. Partial and total cluster reduction was most commonly seen in both CI and HA group.

The findings are quite enlightening and points to the need to carry out such studies on larger groups. The results are discussed with suitable support from the literature in the following chapter.

Chapter-5

DISCUSSION

The present study aimed to examine and compare the articulation abilities of Telugu-speaking, typically developing children with hearing impairment using Digital hearing aids or are fitted with Cochlear implants.

The main objectives of the study were

1) To document the articulation errors and frequent phonological processes used by children with hearing impairment using digital hearing aids and compare them with age-matched TDC.
2) To document the articulation errors and frequent phonological processes used by children with hearing impairment using cochlear implants with age-matched TDC.
3) To compare the articulation errors and frequent phonological processes used by children with hearing impairment using digital hearing aids and cochlear implants.

The results of the study are discussed in the following sections:

5.1 Comparison of the articulatory performance of children across HA and TDC for vowels, diphthongs, and consonants.

5.2 Comparison of the articulatory performance of children across CI and TDC for vowels, diphthongs, and consonants.

5.3 Comparison of the articulatory performance of children across HA and CI for vowels, diphthongs, and consonants.

5.4 Comparison of frequent phonological processes by children across HA, CI, and TDC groups

5.1 Comparison of the articulatory performance of children across HA and TDC across vowels, diphthongs, and consonants.

5.1.1 Comparison of vowels and diphthongs across HA and TDC.

The primary objective of computing and comparing the articulatory performance of children using Hearing aids with typically developing children is to provide a picture of the overall intelligibility of the speech of children using hearing aids and the type of errors made by them. Such analysis can give a picture of the hearing aid's amplification efficacy.

In participants using hearing aids, the production of vowels and diphthongs was better compared to consonant sounds. This is in agreement with the existing literature. Similar results were obtained by Sreedevi and Anusmitha (2022). They examined the articulatory errors in Malayalam and Kannada speaking children using digital hearing aids. Indian studies investigating vowel acquisition in different languages report the early acquisition of vowels in Malayalam (Divya, 2010; Vrinda & Sreedevi, 2011) and Kannada (Prathima & Sreedevi, 2009), Tamil (Thirumalai, 1972; Usha, 1986), Telugu (Padmaja, 1988; Usha & Sreedevi, 2011). In English, a study by Ambrose et al., 2014 revealed that vowel accuracy in children with hearing loss was on par with children who typically develop even at two years of age. Our results may be attributed to the following reasons. Firstly, the early acquisition of vowels in children speaking Telugu and other Indian languages can be inferred from the studies mentioned above. Secondly, vowels are more sonorous and produced for a longer duration, so they can be easily perceived by children using HA.

Concerning the overall vowel errors exhibited by participants in the HA group, producing short vowels/u/ and /o/ and the long vowel /u: / was significantly difficult. This finding contradicts the results of Sreedevi and Anusmitha (2022) in Malayalam-speaking children using HA, where the production of short vowel /u/ and long vowel /e: / was challenging to produce. Furthermore, with the results of Sreedevi et al. (2022) in Kannada-speaking children using HA, the production of short vowel /o/ and long vowel /e:/ were more difficult. Although the languages tested belong to the same Dravidian family, differences were seen among participants in terms of articulatory proficiency. The variations across studies could result from using different stimuli and the participant’s language age and developmental differences.

The substitution errors made by the participants in the HA group, vowel /u/ being substituted for the vowel /o/ are in coherence with the previous research findings, which suggest that neutralization to a central vowel and substitution of vowels among the neighbouring vowels in the quadrilateral, which McCaffrey and Sussman, (1994) reported; Smith. (1975). Indian studies done in Malayalam by Sreedevi and Anusmitha (2022), Joy (2020), and in Kannada by Sreedevi et al. (2022) also reported similar results. The outcome can be attributed to two main reasons. First, it can be due to the posterior production and reduced visibility of the vowels /u/ and /o/. Secondly, it can be due to the similar articulatory configuration made while producing the vowels /u/ and /o/. The participants in the HA group also had difficulty producing the apparent, distinct differences between the production of the temporal aspects for the long and short vowels, which can be attributed to the poorer perception of the temporal cues of children utilizing hearing aids (Banik, 2003). Concerning the production of diphthongs HA group had more distortion errors in the medial position. This can be attributed to the rapid tongue advancement and retraction seen in the coarticulation for diphthong production.

5.1.2 Comparison of consonant production across HA and TDC.

Based on the place of articulation, dental, alveolars, palatals, velars, and clusters had statistically significant differences between HA and TDC groups, and bilabials and labiodentals had no significant difference. This observation shows a difference in the production of the consonants between the two groups.

The production of bilabial consonants was better in the HA group compared to other consonants. This is in agreement with the existing literature reported in English. In a study by Smith (1975), the children utilizing hearing aids were able to produce bilabial consonants relatively better when compared to other consonants. In a similar study by Wiggin et al. (2013), the authors investigated the development of consonants in English-speaking children with hearing impairment using hearing aids and cochlear implants. This study examined 269 hearing-impaired children between the ages of 15 and 84 months for consonant development in the English language across different age groups and degrees of hearing loss. The results revealed that in children with hearing impairment utilizing hearing aids, the stop consonants, including the bilabial stops, were produced accurately. Indian studies exploring the articulatory errors made by children using hearing aids also report similar results. Sreedevi and Anusmitha (2022) investigating the articulation errors in Malayalam and Kannada speaking children using digital HA, the bilabial consonants were produced correctly. These results can be attributed to two main reasons. First, the more anterior and visible production of the bilabial consonants makes it easier for children with hearing impairment using hearing aids to utilize the visual cues provided by them. Secondly, the ease of the motoric action required to produce bilabial consonants can also serve as a reason.

Production of the alveolars /s/ and palatal consonants /ʃ/, /tʃ/, /dʒ/ were significantly difficult for the participants in HA group. Similar findings were made in a study by Blamey et al., 2001, who concluded that the production of alveolars and palatals (/t/, /s/, / ʃ /, /c/, / ɟ /, / θ /) for English speaking children with hearing impairment using hearing aids continues to be impeded by errors like distortions, substitution, and omissions because of the concentration of energy at relatively high frequencies and low-intensity levels. In the Indian context, studies conducted by Sreedevi and Anusmitha (2022) in Malayalam and Kannada-speaking children using HA also reported similar results, where the production of the fricatives, affricates, and trills was frequently misarticulated. The difficulties experienced by the children using HA while producing fricatives can be because of their inability to perceive high-frequency auditory cues like the noise spectrum. Hence, children with high-frequency HI frequently have difficulty perceiving fricatives. Concerning the production of affricates, the inherent complexity of these sounds and the temporal properties of affricates can also be attributed to errors in the production of the speech sounds /tʃ/, /dʒ/.

The results from the qualitative and statistical analysis of the SODA errors across the HA and TDC revealed that substitution errors were a more common error exhibited by children using HA, followed by distortion and omission. No addition errors were observed in the HA and TDC group. These results agreed with the studies in Indian literature by Sreedevi and Anusmitha (2022) on Malayalam and Kannada speaking children using HA, where the substitution errors were more prevalent. Further, these results contradict the earlier study by Smith et al. (1975), where the omission errors were reported to be more prominent among HA users. The reason for these findings can be due to the early identification and intervention provided for the participants recruited for the study.

In participants in the HA group, errors in the place of articulation were more when compared to the manner and voicing errors. This result aligns with the findings of Sreedevi and Anusmitha (2022). As cited by the authors mentioned above, the present study's findings may be attributed to Jakobson's (1941) structuralist model of phonological acquisition, wherein children first distinguish vowels from consonants followed by consonantal contrast (nasal/oral) and then by place variations during speech acquisition.

Both initial and medial clusters had more omission errors. This can be due to three reasons. First, the complex nature of the clusters compared to singleton consonants would be difficult for the children using hearing aids to perceive and produce. Secondly in the development of speech sounds late acquisition of clusters when compared to singleton consonants and thirdly, it can be due to the coarticulatory effort and rapid changes in the articulators could be difficult for the children using HA.

5.2 Comparison of the articulatory performance of children using CI and TDC across vowels and consonants.

Cochlear implants have become one of the primary treatment sources in children with hearing impairment. The direct neural stimulation provided by the cochlear implant bypasses the damaged OHC and IHC caused by severe sensory neural hearing loss, leading to better amplification.

Provision of early implantation leads to better speech and language development. Hence it is inevitable to compare the articulatory performance of children using cochlear implants and typically developing children to get an overall picture of the differences in the articulatory performance and to measure the cochlear implants efficacy in speech production skills children with hearing impaired individuals.

5.2.1 Comparison of vowel and diphthongs production between CI and TDC groups.

The analysis of vowel production results reveals that participants in the CI group could accurately produce the back vowel /a/ and the other front vowels /i/ and /e/. And they had difficulty in producing the back vowel /o/ and producing clear distinctive differences between short and long back vowels (/u/, /u: /, /o/, /o :/). These findings are supported by a study done by Joy (2020) comparing the articulation skills of children using cochlear implants; the participants were sub-grouped into two groups based on the years of cochlear implant use (2-3 years and 3-4 years, respectively). Both the subgroup of participants could produce the front vowel and mid-central vowel accurately. However, the production of back vowels /u/ and /o/ was most difficult. Other western literature, such as studies carried out by (Blamey et al., 2001; chin & Pisoni, 2000; Waener-Czyz &Davis, 2008) reported the same results; production of the front and central vowels was better than back vowels. These findings in the present study can be attributed to two reasons. First, the early acquisition of vowels in Telugu and other Indian languages could serve as a reason. Secondly, the intense and sonorous nature of the vowel would provide better perception for the children using cochlear implants.

From the analysis of the vowel errors, vowel substitution errors were significant, and other errors such as vowel omissions were absent. Similar results were reported by Joy (2020), where the substitution errors were more prevalent. The results are also in consonance with Paschall (1983) noted a shift from vowel omissions to substitutions after two to three years of CI experience. As implant experience increased, substitutions and error variability were primarily reduced.

5.1.2 Comparison of consonant production between CI and TDC groups

Better production of bilabials, when compared with other consonant productions, was observed. However, participants in the CI group had difficulty producing the voiced bilabial /b/ in the medial position, which was frequently substituted with unvoiced /p/ observed for the word /kobbarika:ja/. These results are in consonance with the findings of Joy (2020), where the author reported voicing errors for phonemes (/p/ & /b/). Furthermore, the bilabials are frequently substituted with other bilabials concerning the place errors. Substitution with the same place of articulation can be positively correlated with improved auditory feedback provided by CI. The devoicing bias for the bilabial stops reported in this study was in consonance with the study by Rodvik et al. (2019); their study revealed one of the distinguishing characteristics of cochlear implant users is perceptual confusions between identical consonants. Consonants with a different way and inverse voicing were the least frequently confused sounds. This may be due to two main problems: (1) implants do a poor job of conveying the F0 in voiced sounds because most implant models lack temporal information in the electrical signal, and the electrode's insertion depth may be too shallow to cover the entire cochlea; (Hamzavi & Arnoldner, 2006; Svirsky et al., 2015; Caldwell et al., 2017) and (2) the VOT makes the unvoiced stops much more accessible to perceive than the voiced stops because of the aspirated pause between the voiced and unvoiced stops.

In children using CI, the alveolar phonemes like /t/, /n/, /l/, /s/ and /ɾ/ were correctly produced. The phoneme /d/ was difficult to produce in the initial position. These findings are supported by Joy (2020), where the author cited that late acquisition of the alveolar phoneme /d/ (>5 years) results in error production. The production of alveolar trill /r/ was difficult to produce in the final position. It can be attributed to the fact reported by (Lass, 2014) that the centre of the mouth produces more noise than the back may contribute to compromised alveolar production.

Concerning the production of the palatal consonants, the children using CI could correctly produce the palatal consonants /tʃ/, /dʒ/, and/j//. Early acquisition of the glide /j/ can be a factor for accurate production (Warner-Czyz et al., 2010). The palatal fricative /ʃ/ production was difficult in the initial position. These findings are in agreement with Baudonck et al. (2010) who compared the articulation abilities of HA, CI, and TDC. Their results indicated, the children using CI frequently substituted /ʃ/ for /s/. This could be attributed to the poorer frequency resolution of higher frequencies by CI, which affects the perception and production of the fricatives.

Concerning the production of velar consonants, the frequent substitution of the unvoiced velar stop /k/ with the bilabial stop /p/ agrees with the previous studies. This can be attributed to the posterior production and poor visibility of the velar phonemes. This supports the hypothesis made by Warner-Czyz et al. (2010) and Tobey et al. (2007) that phonemes that are less prominent and distinct via the CI signal may be more challenging to discriminate, recognize, and produce appropriately. Unlike bilabials, the articulatory movements for both alveolar and velar sounds are visibly unclear.

The substitution errors were more prevalent in the CI group, followed by distortion errors. These findings are in par with a study by Joy (2020), where the author indicated that even with 3-4 years of implant experience, children with hearing impairment exhibited substitution errors. Further, the findings from the present study contradicted Baudonck et al. (2010), where the authors reported distortion errors were more prevalent among Dutch children using cochlear implants. The difference in the stimuli used, the participant's language age and the implant age may be attributed to these differences in the results.

From the PMV analysis, in CI participants place errors were followed by voicing and manner errors. Similar results were also obtained in the study by Joy (2020). Joy (2020) cited Jakobson's (1941) structuralist model of phonological acquisition, which states that children initially identify vowels from consonants, then consonantal contrast (nasal/oral), and finally place variations throughout speech acquisition.

5.3 Comparison of articulatory performance of HA and CI.

The comparison of the overall articulation abilities of the children using HA and CI revealed that the participants in CI performed better than the HA group. However, the types of errors exhibited by both groups of participants varied significantly. Concerning the vowel and diphthong production, participants in the CI group performed better than the HA group. This can be attributed to the cochlear implant’s better amplification and auditory feedback than hearing aids.

When comparing the overall performance for the production of the consonants, participants in CI performed better than HA. However, it is noteworthy to establish that consonants are produced in the anterior portion of the mouth, which provides more visual cues such as bilabials and labiodentals. Both HA and CI groups performed similarly. This can be attributed to the early acquisition of these consonants and the amplification provided by HA sufficient for children with hearing impairment to perceive these consonants. However, the consonants produced in the middle and posterior portion of the mouth, like the alveolars, palatals, and velars, the children using CI performed better than HA. This shows that rigorous articulatory training is required for the children using HA to produce these consonants than those using CI.

In comparing the type of error produced by the children using HA and CI, the substitution, omission, and distortion errors were more prevalent in children using HA. Comparing the errors within the HA group revealed that omission is no longer the standard error made by children using HA. This result is supported by a study by Baudonck et al. (2010) comparing the consonant production of Dutch children using HA and CI. They found that children with HA had more substitution errors followed by omission than the CI group. Another study done by Van Lierde. (2005) comparing overall intelligibility in Dutch children using HA and CI revealed that the number of distortions, substitutions, and omissions with incorrect consonants was significantly different between the CI and HA children. The prevalence of omission errors compromises the overall intelligibility of children using HA (Van Lierde et al.,2005).

5.4 Comparing the frequent phonological processes that occurred in HA, CI, and TDC.

In participants in HA and CI groups, the most frequently occurring phonological processing was rhotacism, deaspiration, and total and partial cluster reduction. Notably, phonological processes such as initial consonant deletion and stopping were not observed in any participants using CI. The results align with a study by Mathur. (2019), in which the author reported the differences in the phonological process exhibited by Hindi-speaking children in HA and CI groups. The children utilizing cochlear implants did not exhibit phonological processes such as initial consonant deletion, final consonant deletion, and vocalizations which were more prevalent in the HA group. However, the number of phonological processes reported in the study done by Mathur. (2019) were comparatively higher. This may be attributed to the difference in number of participants and hearing age.

Chapter 6

SUMMARY AND CONCLUSIONS

Providing amplification devices early in life is paramount for children with hearing impairment. Currently, digital hearing aids and cochlear implants are the options recommended for the intervention of children with hearing impairment. However, very few studies have compared the articulation abilities of children using cochlear implants and hearing aids. Hence, there is a need to compare the articulatory errors across children using digital HA and CI to understand their articulatory abilities better.

The present study investigated the articulatory errors of Telugu-speaking children with hearing impairment using digital hearing aids and cochlear implants. A total of 15 Telugu-speaking children aged 4 to 6 years were recruited for the study. Participants were divided into three groups. Group-1 consisted of 5 children using digital hearing aids and they had a hearing age minimum of 2 years, and Group-2 consisted of 5 children using cochlear implants fitted with multichannel cochlear implants and had an implant age of a minimum of 2 years. Group -3 consisted of 5 typically developing children. Test of Articulation and Discrimination in Telugu was administered for detailed articulatory analysis. For detailed articulatory profiling, vowels, consonants, and consonant clusters were analysed qualitatively (SODA and PMV analysis for consonants).

Statistical analysis for vowels, diphthongs and consonants (classified based on place of articulation) were made using the non-parametric Kruskal Wallis test across the HA, CI and TDC groups. No significant difference was obtained for vowels and diphthongs across the three groups. However, few apparent errors were seen between CI and HA groups. Participants in the CI group performed better than the HA group, and both groups had prominent substitution errors for vowels. On the contrary, there was a statistically significant difference for the consonants across the three groups. In the HA group, for consonants, the most to least accurately produced are as follows bilabial>labiodental>dentals>palatal>velar>alveolar>clusters. Similarly, for the CI group, the most to least accurately produced were bilabials>dentals>alveolar>labiodentals>palatals>clusters. Production of consonants was better in CI participants when compared to HA.

Statistical comparison for the SODA errors revealed a statistical difference across the three groups. The qualitative and statistical analysis of the SODA errors reveals that substitution errors were more prevalent in HA and CI (HA>CI). However, the omission errors were only prevalent in the HA group only. Also distortion errors were more prevalent in HA, followed by CI, and minimal errors were observed in TDC (HA>CI>TDC). From PMV analysis, it was observed that in HA and CI groups place errors were more, followed by voicing and manner errors (Place>voicing>manner). A comparison of phonological processes analysis across the three groups reveals that partial and total cluster reduction, rhotacism, and deaspiration are commonly observed in both HA and CI groups. Initial consonant deletion and stopping were present only in the HA group. Deaffrication was only observed in the CI group. And in TDC, partial cluster reduction was more commonly seen.

6.1 Implications of the study

- The study's outcome will help speech language pathologists to classify the articulation errors and the phonological processes exhibited by children using digital hearing aids and cochlear implants.
- The results would augment the speech language pathologist in understanding of differences between the errors produced by children using CI and digital Hearing Aids, which aids in providing appropriate intervention.
- The effectiveness of hearing aids and cochlear implants in improving speech intelligibility, naturalness, and acceptance can be documented.
- The study gives detailed information on the phonemes that are most frequently produced correctly and erroneously. This would assist SLPs in developing effective articulation training intervention strategies to promote speech intelligibility in children who use HA and CI.
- The study emphasizes on the need for speech therapy to be available at school and district levels and to focus on speech intelligibility at the early phases of speech intervention.

6.2 Limitations

- The number of participants considered in the study are less.
- Only the target phoneme present in the stimulus word was analysed.

6.3 Future directions

- The study can be replicated in other languages, providing language-specific information about the articulatory abilities of children using HA and CI.
- The abilities of the HA and CI can be investigated regarding narration/ conversation abilities.

- Can investigate the effect of facilitating phoneme position/context on speech sounds in HA and CI.

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