ACOUSTIC CHARACTERISTICS OF VOWELS IN CHILDREN WITH COCHLEAR IMPLANT IN NEPALI

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Register No: 18SLP016

A Dissertation Submitted in Part Fulfillment of Degree of Master of Science

(Speech-Language Pathology)

University of Mysore

Mysuru

ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSURU—570 006

July, 2020

CERTIFICATE

This is to certify that this dissertation entitled "**Acoustic Characteristics of Vowels in Children with Cochlear Implants in Nepali**" is a bonafide work submitted in part fulfillment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 18SLP016. 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.

Mysuru
July 2020

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DECLARATION

This is to declare that this dissertation entitled "**Acoustic Characteristics of Vowels in Children with Cochlear Implants in Nepali**" is the result of my own study under the guidance of Dr. N. Sreedevi, Professor & 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 award of any other Diploma or Degree.

Mysuru ***Registration Number: 18SLP016***

July 2020

Dedicated to

God,

Guide,

Baba, Maamu, Daji

&

My Well-wishers….

ACKNOWLEDGEMENTS

I would like to thank my Guide Dr. N, Sreedevi, for constant supervision and guidance. You are my inspiration and ideal person. You are such a wonderful person with extensive knowledge and sweetest heart. You are the best teacher, mentor and a wonderful guide.

I would like to thank my respected teacher Mr. S. L Karna Sir, for helping me in all the ways of data collection and increasing me interest in taking this topic as my dissertation. Sir you are my true inspiration. I would like to thank Kabiraj khanal sir for arising all interest to carry my career and arising my interest in speech language pathology, your efforts in data collection and all life guidance are immeasurable. My sincere thanks to wonderful Susmita maam who have help me a lot in her possible way, you are not only my teacher but more like my elder sister and caring mom. I will like to thank Prava maam, Bebek dai, Anil dai and Team IOM with full heart for all support. I will also like to thank Namrata maam for support during data collection.

Thank you Vasanthalaksmi maam for helping me to learn statistics and clearing my doubts. My immense thanks for all the support and help to Deepthy maam.

Words are less to express thanks to my parents, brother, sisters and sister-in-law for their love, care support and motivation each day of my life. You people are my greatest wealth of life. I could not imagine how tough it would have been without you all people. My gratitude are extreme to innumerous list of reasons. My success and everything till now is dedicated to you all. Adhu baby you are my every time mood freshener and your videos were enough to come out from all my low moods. You are my love little champ.

I would like to thank my best friend Sammy for all the wonderful support. The journey of here was made easier with your company too. Thank you for understanding me in all ways and *motivating to work hard each day. Your unfailing support throughout the rollercoaster of these years are really admirable.*

I can't forget, Simrin diju for the timely help, it really meant a lot. Thank you aunty and uncle for really caring me. Thank you Sameer bhattarai sir for handling my doubts. Thank you Deepak dai, Santosh dai and Prem bhai for being there for me always and for yours wonderful support, you all mean a lot to me. Thank you Narayan maam, Sabitra sanima and Devendra uncle for unforgettable help that you all did during my journey of AIISH. Thank you all my relatives for believing in me and supporting in some or other way.

Thank you Shradha for making each days of Kapila ladies hostel wonderful. Thank you Sabin, Sapana and Prasanna you were always wonderful and helpful friends for lifetime.

Thank you Dilli, Prabuddha, Biraj, Anup, Ashish dai and Sashish bhai. Our mini-Nepali family in Aiish for all support.

I can't express my thanks and love to Hina and Swaliha, you both are my wonderful friends to make this two years journey worth. My sincere thanks to Madhu and Apoorva for helping and listening me always.

I would like to thank my sweet dissertation Partners for always being there for me. You guys are the sweetest people and helpful souls. The memories of our data analysis are irreplaceable. Thank you Lily and 'N' number.

Thank you all the faculties of AIISH, for making me a better version of myself.

Thanks to my classmates and batch mates "Brainiacs" for unfailing support throughout and making the PG life more memorable one.

Last but not the least I will express my thanks to all my participants without whom this study would have been impossible. Thanks to the Renu maam, Rama aunty (sweetest and lovely aunt) and parents of all my participants for helping me out.

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CHAPTER I

Introduction

Speech is the articulatory movement which is made audible. It is defined as an auditory-vocal channel that has a rapid fading broadcast transmission, specialized to convey meaning with arbitrary sound symbols. It is composed of discrete units or elements that can be formed into an infinite number of messages (Kent & Read, 2002). Speech is a wonderful outcome of the interaction of various energy from the different systems in the vocal tract modified further by different articulators and thus form consonants and vowels.

"Vowels are described as speech sounds produced without any constriction in the vocal tract" (Ladefoged & Maddieson, 1996). Vowels production differ from consonants in terms of the shape of the vocal tract and the positions of the articulators which generate different acoustic energy between consonants. Vowels are classified acoustically based on the formant frequencies, spectrum, shape of the vocal tract, and duration. Formants are the peak of the sound spectrum (Fant, 1960), and the corresponding frequencies are termed as formant frequencies. Frequency regions amplified significantly for a continuous band on a wideband bar type spectrogram are formant frequencies (Singh & Singh, 1979). Format frequencies are dependent on the tongue height and advancement. The fundamental frequency is defined as the lowermost frequency component of a complex waveform. Temporal parameters of the vowels are also an important cue to differentiate among vowels as well as consonants. Differences between vowels and consonants are described better acoustically.

Acoustic analysis was one of the latest advancements, which had been systematic using analog filter banks in the 1940s along with the development of acoustic spectra analysis of phonemes (Koenig, Dunn, & Lacy, 1946). It is appropriate to test any hypothesis about developmental changes in anatomy, motor control, and phonological functions (Sreedevi, 2007). Acoustic analysis is easier, safer, and convenient than ultrasound, EMG, X-ray, EMMA, etc., since it is noninvasive, relatively simple concerning instrumentation. Various spectral parameters corresponding to fundamental frequency, formant frequencies, formant bandwidth, etc. can be analyzed by acoustic analysis. Furthermore, we can also investigate the temporal features corresponding to vowel duration, consonant duration, word duration, etc., of speech segments using acoustic analysis. The speech samples are recorded and analyzed using spectrogram and other computerized ways to investigate various spectral and temporal parameters. Acoustic parameters of vowels vary across age, gender, language, disorders, etc. Acoustic parameters of speech are profoundly altered in individuals with hearing impairment.

Hearing is the special sense that allows processing, perceiving, and distinguishing sounds with the help of ears. With normal hearing and other body functions, a child drives the road of successful communication from as soon as they are born. The child is able to acquire language through continuous auditory stimulation of speech and other environmental sounds (Whetnall & Fry, 1964). If an individual has a hearing impairment, both speech perception and production get affected, which directly alters oral communication.

Hearing impaired children have inaccurate speech production in several aspects, which reduces speech intelligibility (Abberton, Hazan, & 1990; Monsen, 1976). Investigations have revealed the reason to be the compromised listening abilities: the process of receiving and understanding the words (Hamaguchi, 1995), inadequate acoustic cues (Angelocci, Kopp, & Holbrook, 1964; Monsen, 1976) and also inadequate information present in the environment. Children with significant difficulty in hearing are restricted to auditory feedback and have a negative impact on speech production and language development (Verhoeven, Hide, Maeyer, Gillis & Gillis, 2015). The overall oral communication efficacy is reduced because of inadequate auditory feedback, which even affects the proper articulatory movements resulting in various errors of consonants and vowels. The common vowel errors seen in individuals with hearing impairment are substitution, neutralization or centralization of vowels, diphthongization of vowels, nasalization, and distortion of a vowels (Levitt & Stromberg, 1983; Markides. 1974, Smith, 1975). These inaccurate productions are due to inaccurate tongue positions (low/high, front/back) and posture (shape & tension) as stated by Ertmer et al., (1996). Supra-segmental errors such as improper intonation, irregular rhythm, and other prosodic features are also observed. Language development fails, and communicative competency in terms of spoken language is difficult to be achieved with impaired hearing sensitivity.

WHO (2019) estimated 466 million people with hearing impairmentm, which is 6.1 % of the global population and out of this, 34 million (7%) are children. According to Nepal's census (2011), among all the disabilities, 15% are found to have a hearing impairment. Census reports of India (2011) showed that of 121 crore population, 2.21% of the total population was found to have some kind of disability, of which 19% were diagnosed with a hearing impairment. Pre-lingual hearing impaired participants produces inaccurate vowels and consonants os(Jaferi et al. 2016). These children also had difficulties in learning vowels and consonants (Jaffari et al., 2016). The children with pre-lingual hearing impairment also reported errors such as diphthongization and neutralizations (Smith, 1975). Osberger and McGarr (1982) reported various prosodic problems like reduced rate of speech with labored articulation, longer and more frequent pauses, monotonous intonation with higher pitch and distorted suprasegmental and temporal parameters in hearing-impaired compared to normal children, which has directly influence the overall intelligibility of speech throughout all stages of life.

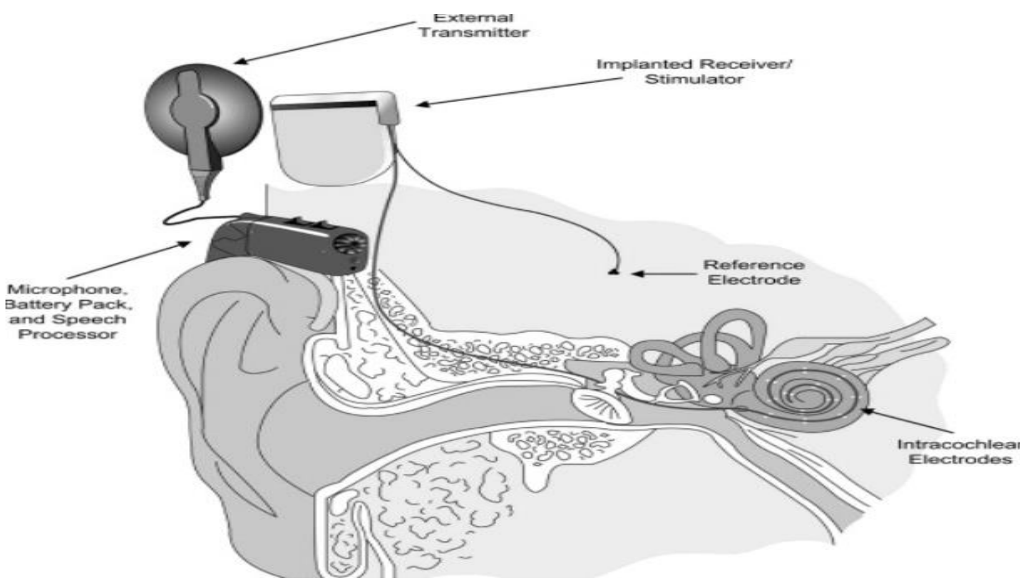
Early identification and appropriate intervention of hearing impairment by the age of 6 months can increase the chance of normal speech-language development in children with hearing impairment (Pimperton & Kennedy, 2012; Holzinger, Fellinger, & Beitel, 2011). Options for the appropriate intervention for individuals with extensive hearing-impairment include cochlear implantation or hearing aid fitting followed by proper auditory-verbal therapy, speech-language therapy, and effective educational strategies.

1.1 Cochlear Implant: A Better Option for Intervention

ASHA defined a cochlear implant as "A surgically implanted, complex electronic prosthetic device that directly provides electrical stimulation to nerve fibers in the cochlea, bypassing damaged hair cells to deliver useful sound to an individual." It consists of the external sound processor (worn behind the ear), which receives sound information, processes the sound signal, and transmits electromagnetically to surgically implanted electrodes in the cochlea (internal receiver). The auditory nerve receives these signals and directs them to the brain. Figure 1.1 shows the cochlear implant fitted in the ear.

Figure 1.1

Various Parts of a Cochlear Implant.



Source: *Retrieved from Wilson and Dorman (2008).*

The cochlear implant has been a standard treatment option for pre-lingual deaf children for almost 30 years. The ultimate goal of implanting pre-lingual pediatric patients is adequate hearing and better speech performances (Ganek et al. 2012). Throughout the following decades, rapid development throughout technology and many advanced types of research have facilitated the development of cochlear implants with sophisticated speech processing capacities, allowing patients not only to hear environmental sounds but also to communicate effectively through spoken language (Balkany et al . , 2002; Clark, 2012).

Early implanted children who get appropriate rehabilitation show improved speech intelligibility and fluency when compared to the hearing aid users (Geers, 2002). In contrast, considerable variability in performance is noted across individuals within cochlear implants (Pisoni, Cleary, Geers, & Tobey, 2000). Fryuf-Bertschy et al., (1997) have reported that most of the children with CI showed improvement in speech perception, few others demonstrate drastic progress, and some have reduced perceptual abilities in-spite of few years of cochlear implant usage (Geer, 2002). Despite numerous advantages of cochlear implants, deviant speech characteristics such as poor voice performance, the erroneous output of segmental features, imprecise prosody, and reduced intelligibility are seen. It may be due to inadequate articulation and inappropriate neural decoding, as demonstrated by DIVA model (Guenther & Vladusich, 2012).

1.2 Nepali Language

Nepali is the national language of Nepal and belongs to the Indo-Aryan family of languages and is spoken by 16 million people in Nepal. It is an important language for around 7 million speakers of other Nepalese having different mother tongue, including Tibeto-Burman. It is also one of the 22 scheduled languages in India and one of the commonly spoken languages in Bhutan. Hindi is a very close language to Nepali and is one of the cousin languages of it. Both languages share Devanagari as the written script (Hutt, 1997). Nepali language consists of 6 main vowels /ʌ/, /a/, /i/, /u/, /e/, /o/ and 29 consonants. The Nepali language is transcribed in the Devanagari script, where there are 36 graphemic variations; nevertheless, only 29 consonant sounds are phonemic (Pokharel, 1989). Geierson (1916) reported a lack of contrastive vowel length in the Nepali language (Source: M Hutt, University of London, London, UK. @ Elsilver 2006).

The subtle differences between vowels of different languages can be studied by subjecting them to acoustic analysis (Ladefoged, 1975). Therefore, the study of the acoustic characteristics of vowel sounds of a language becomes essential.

1.3 Need for the study

Vowels are sounds with a steady-state acoustic pattern, simplest to analyze and describe acoustically. These are associated with definite formant patterns that determine their phonetic quality and reflect the articulatory configurations in it (Stevens, 1998). Many studies have reported the difference in acoustic characteristics of vowels in children with a cochlear implant and normal hearing children. Also, there is a considerable variation in the acoustic characteristics of speech sounds across languages and geographical locations. It is crucial to study and analyze the acoustic characteristics of speech sounds of different languages to understand their speech production and perception (Savithri, 1989).

There are several studies on various characteristics of consonants on Nepali speakers (Pokharel, 1989; Lageford & Maddieson, 1996; Clements, George, & Khatiwoda, 2007; Chalise, 2015). But there is a dearth of adequate information on the acoustic characteristics of vowels in Nepali language, particularly in children. Even the acoustic characteristics of disordered speech in Nepali is highly under explored.

The number of individuals seeking cochlear implant in Nepal is increasing due to early identification and new government schemes; several NGO's and INGO's assistance in cochlear implantation and post-rehabilitation have become more affordable, economical and accessible to majority of the hard of hearing population. Thus, knowledge of acoustic characteristics of vowels in CI can augment SLP's understanding of the deviances in speech characteristics and intervene more scientifically for aural- oral rehabilitation. This information can also aid audiologists in CI mapping. Hence, the present study is a preliminary attempt to investigate the acoustic characteristics of vowels in cochlear implantees in comparison to age and gender matched typically developing native Nepali speaking children.

1.4 Aim of the Study

To investigate the acoustic characteristic of vowels in native Nepali speaking children with cochlear implants and children with normal hearing.

1.5 Objectives

1. To investigate the spectral and temporal characteristics of vowels in children with a cochlear implant.

2. To investigate the spectral and temporal characteristics of vowels of age and gender matched typically developing children.

3. To compare the acoustic characteristics of vowels of children with a cochlear implant and typically developing children.

1.6 Hypothesis

1. There will be no significant differences in the spectral parameters of vowels between children with cochlear implant and typically developing children.

2. There will be no significant difference in the temporal parameters of vowels between children with cochlear implant and typically developing children.

CHAPTER II

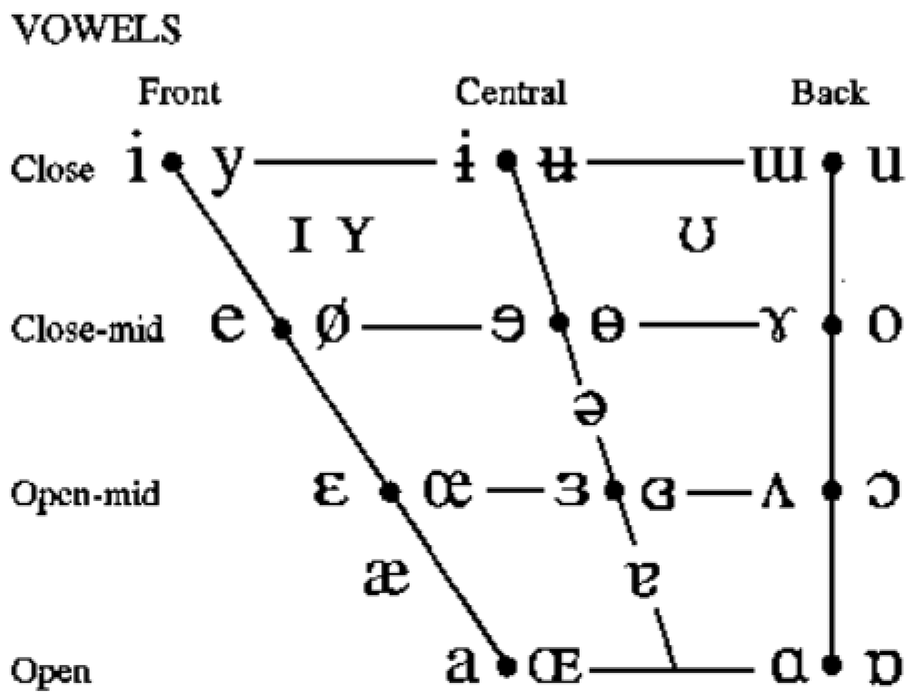
Review of Literature

Adequate hearing abilities play an essential role in speech and language development. The children born with congenital profound hearing impairment seem to have a significant impact on the overall speech and language development. Cochlear implantation has been a promising option to overcome the issues of speech sound errors and improve language development. Early intervention of hearing impairment leads to better language development and improved speech intelligibility. This benefit is due to the neuroplasticity of the brain in younger children (Colletti et al., 2005; May-Mederake & Shehata-Dieler, 2013). Despite implantation, there are multiple parameters like consonants and vowels, which are not perceived accurately, which results in inappropriate production. Vowel errors in individuals with cochlear implants are found in spectral and temporal parameters like formant frequencies, fundamental frequencies, vowel duration, and word duration. Numerous studies have focused on the acoustic parameters of vowels.

Vowel sounds are created by a source at the glottis, through acoustic excitation of the vocal tract. The vocal tract is considered an acoustic circuit. The acoustic disturbances in this path are generally defined in terms of sound pressure and air vibration volume velocities at different points in the circuit (Kenneth & Arthur, 1961). The articulatory definition of vowels was found to be of limited use by Jones (1965) and developed a perceptual scale of vowel classification to illustrate the distinction between vowels of different languages. Further, Jones (1965) defined that cardinal vowels can be independent of any particular language and are located at the periphery of the vowel field.

Figure 2.1

Illustration of Primary and Secondary Cardinal Vowels



Maddieson (1984) classified vowels based on tongue positions (e.g., front vowels, central vowels, back vowels, etc), based on lip rounding (rounded vs. unrounded), nasality (oral vs. nasal) and based on the muscular effort (tense vs. lax vowels).

Vowels are primarily characterized by the first three formants (F_1, F_2, and F_3). The most critical acoustic cues for perception of vowels lie in the frequencies and the patterning of the speaker's formants. A formant is a preferred resonating frequency of an acoustical system. It is distinguished by its center frequency and the range of frequencies on both sides having amplitudes within 3 dB of the central frequency. The first three formants are called the F-pattern (F_1, F_2, and F_3) for a vowel (Hixon, Weismer, & Hoit, 2008).

It is known that various acoustic parameters are altered in participants with hearing impairment. This inaccurate production in participants with auditory deprivation are explained by several models. One of them, the DIVA model well explains how auditory-related information is interpreted and how speech movements are processed within the brain.

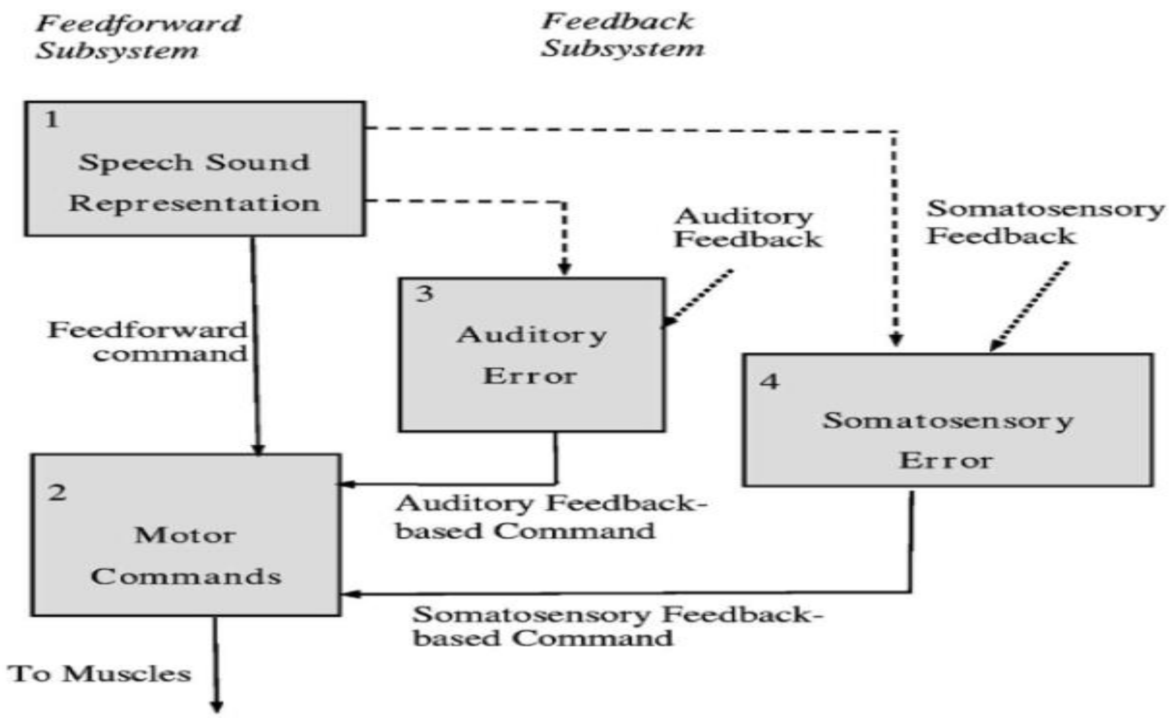
The DIVA MODEL

The DIVA model was introduced in the 1990s, and as recently as 2012, revised versions were released (Guenther, 1994, 1995a, 1995b; Guenther & Vladusich, 2012; Tourville & Guenther, 2011).

The DIVA model (Directions in Velocities of Articulators) offers a theoretical, computer-based paradigm that explains how auditory-related information is interpreted and how speech movements are generated within the brain. This model explains that in the left operculum frontal, all speech sounds are depicted in a "Speech Sound Map." This "speech sound map" is constantly matched with "auditory state map" and "somatosensory state map." Deviations in matching are constantly recorded in auditory or somatosensory "error maps" to improve articulatory abilities and accuracy.

Figure 2.2

Schematic Representation of the DIVA Model. (Retrieved from Lane et al. 2005)



Note: Boxes represent the cortical neurons. Dashed lines reflect the direction of predicted sensory signals (premotor projections to sensory cortices). Dotted lines display the afferent projection of information to the sensory cortex, and solid lines suggest effective information regulating motor movements.

In participants with hearing impairment, auditory deprivation, and inadequate speech stimulation alters the speech sound representation. Also, reduced auditory feedback produces errors in auditory maps, so comparing the speech sound map is not appropriate. The errors in various temporal and spectral parameters in participants, even after cochlear implantation, may be due to a longer duration of deprivation before implantation and insufficient gain after implantation.

The review is discussed under the following headings:

2.1 Description of Formant Frequencies, Fundamental Frequency, and Duration

2.1.1 Formant Frequencies F_1 and F_2

As the air puffs generated by the vibration of the vocal folds passes through the vocal tract, some frequencies get damped, and some others pass through the vocal tract. Those frequencies which pass and are similar to the resonant frequencies and are termed as formant frequencies. The frequency of the formant depends upon the shape and size of the vocal tract. Fant (1960) described formant as the sound spectrum's spectral peak. Formants are the frequency peaks in the spectrum of a vowel with a higher degree of energy (F_1, F_2).

Sunberg (1969), noted different vocal tract structures give rise to different formant frequency ranges. The formant frequency shifts occur by

- Variations in tongue shape and tongue position,
- Configuration of lips, soft palate, and mandible.

It is noted that F_1 varies inversely with the height of the tongue, and F_2 varies with the advancement of the tongue (Fant, 1973). It means low vowels have higher F_1, and high vowels have low F_1. F_2 is noted higher in front vowels, whereas smaller F_2 is noted for back vowels.

2.1.2 *Fundamental Frequency (F_0)*

Fundamental frequency (F_0) defined as the lowest frequency band in a given sound signal, analogous to pitch perception. According to the acoustic theory and the source filter models of speech production, this characteristic is related to the vocal tract's laryngeal tone, i.e., vocal folds tightness in response to laryngeal muscle contraction (Fant, 1971). From the history of auditory feedback studies, it is clear that regulation and production of F_0 is somewhat dependent on auditory feedback; however, anatomical changes in the vocal tract and vocal cords also play a role (Mugitani & Hiroya, 2012). Iyer and Oller (2008) listed the studies related to F_0 concisely, as depicted in Figure 2.2.

Figure 2.2

Studies related to F_0 in Typically Developing Children.

Studies on F_0 in typically developing infants.

Study	Design	n	Ages	Mean F_0 (Hz)**	Range (Hz)	SD (Hz)
Delack and Fowlow (1978)	L	19 (10: 1 mo–1 yr; 9: ≤ 6 mo)	1 mo–1 yr (biweekly)	355	NA	NA
Kent and Murray (1982)	C–S	21	3, 6, 9 mos	3 mo: 445 6 mo: 450 9 mo: 415	350–500	NA
Laufer and Horii (1977)	L	4	1–24 wks (bimonthly)	335	317–342	utterance: 217–423
Robb and Saxman (1985)	C–S	14	11–25 mos	357	164–1366	session: 105 (45–238)
Robb, Saxman, and Grant (1989)	L	7	begin: 8–14 mo end: 19–26 mo	mono: 396 di: 399	mono: 289–642 di: 281–652	session: mono: 106 (23–307); di: 86 (18–202)
Sheppard and Lane (1968)	L	2	0–5 mos	429	384–481	utterance: ≤ 10% of mean F_0
Whalen, Levitt, Hsiao, and Somodinsky (1995)	L	12	6, 9, 12 mos	362	NA	NA

L= longitudinal; C–S= cross-sectional;

** mono= monosyllables; di= disyllables.

Note: *Retrieved from Iyer and Oller (2008).*

2.1.3. Vowel Duration (VD) and Word Duration (WD)

Sreedevi (2007) defined vowel duration as the duration from the onset of a vowel to the offset of the vowel. This acoustic feature is one of the measures relating to acoustic characteristics that cause prosodic variations in speaking. Studying various acoustics measures, such as vowel duration, provides insight into speech motor regulation and the articulators ' performance.

The duration of vowels is affected by the nature of the segment (manner of production), its phonetic context, and the tongue's height. High vowels are found to be produced with longer duration and shorter durations for low vowels. Also, vowel duration is found to be higher in the stressed syllables compared to unstressed.

Word duration is the time difference between the onset and offset of the target word. Word duration is found to be longer in long words. It is also dependent upon the duration of the segments in words—consonants and vowels.

2.2. Formant Frequencies in Cochlear Implantees

Svirsky and Tobey (1991) investigated the effect of auditory stimulation of vowels in pre-and post-implantation in hearing-impaired adults. They analyzed the formant frequencies with the implant processor on and off condition. Stimuli used were prepared in /hVd/ context. Subjects were asked to repeat the word after the researcher. Participants utilized the auditory input and also used lip reading. Recorded output was transferred, and formant frequencies were analyzed using Kay Elemetric software. Results revealed that formant frequencies were neutralized post-implantation.

Perkell et al. (1992), evaluated the vowel characteristics of nine vowels spoken in /hVd/ context in the carrier phrase of 4 post-lingual hearing-impaired individuals with cochlear implant in pre and post-implant condition. The speech stimuli were read three times and were digitized, and data extraction and analysis were using MITSYN (MITSYN = MIT Synergy) command language script. Results revealed a significant difference in F_1, F_2, F_0, and duration in pre-to post evaluation. F_1 and F_2 were decreased in post-implantation compared to pre-implantation in all the participants.

Kishon-Rabin et al. (1999), conducted a longitudinal study and analyzed the changes in the speech of 5 adult (age range 35 to 61 years) cochlear implantees (post-lingual), before the implant, after one month, after six months and after 24 months post-implant. Stimuli used were 50 monosyllabic, minimal pair consisting of 17 consonants and five vowels of Hebrew language, 12 sentences, and spontaneous speech. Acoustic parameters analyzed were F_0, F_1, F_2 of vowels in word-in-isolation and word in a sentence, word duration, and sentence duration. Following effective rehabilitation, significant changes occurred within two years. They found that F_0 decreased significantly after six months of the implant in both males and females and approached average values after two years after implantation. There was a significant decrease in word duration and utterance duration from pre-implant to post-implant after two years. The pre-implant F_1 value, which was abnormally high, decreased significantly after implantation within six months for /e, i, u/. There was no significant difference in F_2 except for vowel /i/.

Seifert et al. (2002), studied the F_0 and formant frequencies F_1, F_2, and F_3 in Swiss-German vowel /a/ in 20 children with a cochlear implant and compared with normal hearing children in the age range 3.8 to 10.3 years. The sample was recorded during the standardized playing situation in which they had to name the picture shown, which were recorded for analysis. Acoustic parameters were analyzed by using CSL (4300B) using spectrographic and LPC analysis. The study revealed that the F_0 of children implanted before four years were similar to those of average age and matched peers. In contrast, there was a significant difference in F_0 of children who were late implanted. F1: F_2 ratio was found to be more centralized in late implanted children, and no significant deviation was found between early implanted and normal children.

Ryalls, Larouche, and Giroux (2003) analyzed syllable duration, fundamental frequency (F_0), and first three formant frequencies (F_1, F_2, F_3) of vowels of French-speaking 10 children with the cochlear implant of average age 9.4 years. Speech stimuli used were 18 basic monosyllables in which speakers were asked to read from the written card and make five repetitions. The analysis was done by digitizing at 20 kHz, after low-pass filtering at 9 kHz using BLISS software. Results revealed the longer syllable durations, higher fundamental frequency, and more centralized formant frequency. Similarly, F2 of /i/ was found to be highest among all vowels.

Horga and Liker (2006) conducted a comparative study among cochlear implant users, hearing aid users, and normal hearing individuals. Each group consisted of 10 age matched participants. Participants were instructed to repeat the heard stimulus and read it on the screen along with the picture. F_1 and F_2 for vowels /i/, /a/, and /u/ were obtained by acoustical analysis using Praat and PCquirer software. The acoustic analysis showed significantly reduced formant values (F_1 & F_2) for the hearing aid users compared with cochlear implant users and hearing controls. Twelve months after cochlear implantation, F_1 and F_2 values showed a significant shift towards normative values. They also reported vowel clustering. Vowel intelligibility test revealed vowel /a/ to be slightly less intelligible among cochlear implant users than hearing aid users.

Kim and Ko (2007) compared the acoustic characteristics of vowels produced by 20 children with cochlear implants and 20 normal hearing under the age of 10 years and further grouped the cochlear implantees as under and over four-years. They analyzed the three corner vowels /a/, /i/, and /u/ in isolation produced five times. Fundamental frequency (F_0) and formant frequencies (F_1, F_2) were analyzed with Multi-Speech (Kay Elemetrics, model 3700). They found a significant difference in F_0 and F_1 in late implantees compared to those implanted under four years and normal hearing children. No significant difference was noted in F_2 among implanted groups. Vowel space area was also found to be smaller in cochlear implantees compared to normals. Thus, they suggested that surgery before four years leads to productive outcomes.

Liker et al. (2009) studied Croatian vowels, fricatives, and affricates in a longitudinal study among 18 children with cochlear implants and age and gender matched normal hearing children of the age range 9.5 to 15.2 years over 20 months. Recordings were done three times during the period and analyzed the F_1 and F_2 of vowels. The results revealed reduced F_1 and F_2 values. Fronted and smaller vowel space, which improved steadily over 20 months, was also reported that suggested early implantation and rehabilitation of the subjects.

Neumeyer et al. (2010) studied formant frequencies and vowel space area of 10 cochlear implantees and ten age-matched standard hearing groups. Five German vowels occurring in the first syllable of a word in bilabial and labial context were considered stimuli of study (e.g., bude, boten, etc.). Results revealed no difference between the two groups on F_1, whereas F_2 of the CI group was smaller than typical hearing participants. Also, the vowel duration was found to be longer in cochlear implantees compared to typical hearing peers.

Lofqvist et al. (2010) studied vowel production in 12 cochlear implantees and 11 normal hearing adolescents and analyzed the F_1 and F_2 in 9 long Swedish vowels. Vowels occurred in the Swedish word /rVta/ with stress on the first vowel; nine words were thus recorded and found a significant difference in the vowel space area of two groups. Vowel space was obtained by formant measures using PRAAT software, first by average Euclidean distance in the F_1–F_2 plane between the nine vowels and the mean F_1 and F_2 values of all the vowels and second was by finding the mean Euclidean distance in the F_1–F_2 plane between all the vowels. The size was smaller for cochlear implantees, irrespective of receptive and productive linguistics skills. F_2 values were found to be more constricted in the CI group.

Jafari et al. (2016), compared the formant frequency F_1 and F_2 of six Persian vowels in 40 deaf and hard of hearing (20 hearing aid users, 20 cochlear implant users) and 20 normal hearing children. F_1 and F_2 values were analyzed and extracted from the isolated repetition of vowels with average loudness, pitch, and quality from the middle 25% of each vowel's duration and found a significant difference in F_1 value of /i/ and F_2 of /a/ among CI, NH and HA users. However, cochlear implant users showed F_1 and F_2 values closer to the values obtained by NH children. After one year of implantation, there was a shift in formant frequency closer to NH groups, and even the vowel space was expanded.

Verhoeven et al. (2012) investigated the acoustic parameters, formants, the surface area of vowel space, and acoustic differentiation between 12 Dutch vowels and compared across three groups of children with normal hearing, hearing aid users and cochlear implantees. Results revealed significantly reduced vowel space and smaller acoustic differentiation between vowels in hard of hearing children, i.e., hearing aid and cochlear implant users. Three sets of different consonantal contexts were chosen because plosives, laterals, and trills provide a sharp spectral transition with the adjacent vowel, and this would considerably facilitate acoustic segmentation. In the first set, stimuli context was /pVt/, the second context consisted /lVt/, and the third set consisted /tVr/, in which participants had to make three repetitions after hearing recorded sample. F_1 in the CI group was reduced as compared to the NH and HA group. F_2 in the CI group was significantly different from the NH group for all vowels except /I/, /e/ and /ø/. The HA group was significantly different from the NH for all vowels except /e/, /a/ and /ø/. In both cases, the direction of the F_2 difference was consistent with vowel neutralization, i.e., a lower F_2 for front vowels and a higher F_2 for back vowels and a significantly reduced vowel space in children with hearing impairment.

Zamani et al. (2016), conducted a cross-section study on 69 children with cochlear implants. Participants were divided into three groups based on the age of implantation as children who received CI before the age of 1 year (n = 21), children who received implantation at the age of 3 to 4 years (n = 29) and children who received implantation at five years (n = 19). Speech stimuli consisted of nonwords consisting of vowels three Persian vowels /a/, /i/ and /u/ in standard phonetic context (/had, /hud/ and /hid/) associated with three two-syllable Persian meaningful words /færhud/, /færhad/, and /nahid/. Samples were recorded using a recorder, and acoustic analysis was done using SFS (Speech Filing System) software at 30 ms of each vowel spectrum. Results indicated that F_1 and F_2 in all the vowels /a/, /i/ and /u/ were significantly different among participants of three groups included. F_1 for vowel /a/, /i/ was found to be increased as the age of implantation increases. They argued that the participants who had a longer auditory deprivation duration were unable to maintain the normal tongue rising as expected. F_2 was also found to be less in the participants who were implanted after three years of age as they tend to maintain more posterior tongue placement during vowel articulation. They concluded that implantation at an early age (before 2) would lead to correctness in vowel production.

2.3. Fundamental Frequency in Cochlear Implantees

Szyfter et al. (1996) investigated five cochlear implantees (2 children and three adults) by acoustic analysis, a week before implantation and after three months of implantation. The analysis was done using the KAY Electronics (Model, 4300) instruments and the MDVP program. Results revealed a decrease in F_0 value on the phonation task after the cochlear implant surgery in all the patients and increased mean values of jitter and shimmer.

Poissant, Peter, and Robb (2006) studied the fundamental frequency, formant frequencies (F_1 & F_2), and word duration. Participants were asked to produce the speech samples in the cochlear implants off and on condition. Speech stimuli consisted of five monosyllabic words and two bisyllabic words. The participants were instructed to label the pictures as well as to repeat the same words in a carrier phrase (I see a…) and was audio recorded. Acoustic analysis was done using the Kay CSL (4300B). Results indicated F_0 was significantly higher in the CI-off condition for four participants among six whereas, two participants showed significantly higher F_0 on CI-on condition. Also, word duration and formant frequencies were found to be higher in CI-off conditions. They have justified that the increase in the fundamental frequency is due to increased loudness in CI-off condition (as intensity is directly related to frequency).

Evans, and Deliyski (2007), analyzed the change in voice and speech of three prelingually hearing-impaired adults, who went under cochlear implantation. The objective evaluation was carried out in Computerized Speech Lab (CSL model 4400 Kay PENTAX) before and after six months of implantation. The participants were instructed to sustain the vowel, which was recorded using MDVP software. Pre and post-implantation comparison revealed decreased F_0 and increased nasalance after surgery, and some even showed a low percentage of accuracy of vowel production.

Hamzavi et al. (2009), studied the short term effect of cochlear implantation on fundamental frequency among 13 hearing-impaired individuals who later underwent cochlear implant surgery. Acoustic analysis was carried out using X-Tools software at pre- and three months post-implantation. Results showed a significant decrease in F_0 after three months of implantation, and no significant difference was noted on vowel duration. This study also revealed no correlation between speech recognition and production.

Baudonck et al. (2011), conducted a comparative study to analyze the perceptual speech qualities among 13 bilaterally implanted children (biCI), 14 unilaterally implanted children (uniCI), ten children using hearing aids (HA), and 11 normal-hearing children (NH). Here, the participants were asked to name 25 common objects, repeat seven sentences based on a picture, and repeat a short story using four consecutive illustrations. Perceptual evaluation of voice and resonance was done using the GRBAS scale. The overall speech intelligibility, voice characteristics, and the pitch parameters of biCI and NH did not show any significant difference. The voice quality of uniCI and children using HA were significantly different. The study suggested bilateral implantation for better intelligibility, phonation, and resonance.

Milijkovic et al. (2014), studied the acoustic characteristics of voice in children with a cochlear implant and age-matched typical hearing peers. A total of 60 participants speaking Serbian language were included in the study, 30 in each group (cochlear implantees and normal hearing children). The participants of the age range 6 to 13 years were included in the study. The objective voice assessment was carried out using the Dr. Speech software, and 13 acoustic parameters were analyzed. Frequency related parameters included in the study were mean (mean F_0), maximum (max. F_0), and minimum fundamental frequency (min. F_0), along with other perturbation measures. The study stated that the measures of the fundamental frequencies were significantly higher in cochlear implantees than typical hearing peers. The frequency-related parameters were found to be higher in girls compared to boys in both groups. They argued that the increase in F_0 in CI participants was due to auditory deprivation following hearing impairment, which resulted in an inability to control the vocal parameters.

Knight et al. (2016) conducted experimental research, including a total of 19 participants (9 cochlear implantees and ten normal hearing children) speaking African language. Among cochlear implantees, the participants were divided into two groups pre-lingual (age range 0- 2 years, n = 4) group and peri-lingual group (age range 2-4 years, n = 5). The acoustic analysis of phoneme /a/ was carried out using the MDVP (Multi-Dimensional Voice program in CSL model 4500; KayPANTAX) software. It revealed that the fundamental frequency of vowel /a/ was higher in the pre-lingual group than peri-lingual. The fundamental frequency of cochlear implantees did not show any significant difference (the values were similar to the typical hearing participants).

2.4. Vowel and Word Durations

Tye-Murray et al. (1996) examined the sound production abilities of 20 children with a cochlear implant age range of 2.7 to 15.3 years with two years of listening experience. The stimuli were 14 monosyllabic words produced in a carrier sentence. The participants were instructed to name the pictures shown with three repetitions. The stimuli were presented in both the conditions-- cochlear implant on and off conditions. The results revealed that CI children nasalized vowels sometimes but were not consistent, and also the consonants were inappropriately aspirated. Their tendency to nasalize vowels and aspirate initial consonants might reflect an attempt to increase proprioceptive feedback, which would provide them with a greater awareness of their speaking behavior. Similarly, the duration of the word produced was significantly longer than usual.

Lane and Matthies (2001) examined the effect of the hearing status in co-articulation, formant frequencies, and duration by comparing seven cochlear implantees and two normal hearing individuals in 8 English vowels in /bVt/ and /dVt/ syllable context. The study revealed significantly shorter mean vowel durations.

Uchanski and Geers (2003) compared the acoustic characteristics of 181 young cochlear implant users with those of 24 normal hearing and analyzed the VOT, F_2, spectral moment and duration of vowels, words, and sentences. The study reported that the large percentage of young cochlear implantees had acoustic values within the range of normal hearing children except the sentence duration and vowel duration measured for monosyllabic, CVC-type words in sentence-initial and sentence-final positions. Vowel duration, as well as the sentence duration, was longer by 132ms in cochlear implantees compared to normal hearing peers.

VanDam et al. (2011) compared duration among 27 children (12 with NH, 7 with HAs, 8 with CIs) of age range 4-5 years. 18 CSIT words containing the point vowels /æ, α, u, i/ were selected as stimuli. Participants were asked to listen and repeat words and vowels in isolation, and the data was analyzed in PRAAT. Vowel duration was examined by hearing status (HL, NH), device type (HA, CI), age (4-years, 5-years), and vowel type (/æ, α, u, i/). The results obtained suggested a longer vowel duration in children using a hearing aid and cochlear implant than children with normal hearing. Vowel duration by device type, i.e., HA and CI, were not significantly different. Vowel duration among children of 4 years and five years of age was not significantly different from CI users. In contrast, a marginally significant effect of age was seen on vowel duration with HA user children. A significant difference was noted in vowel type; mean vowel duration was shorter for older children for high vowels /i, u/ compared to low vowels /æ, α/.

Nicolaidis and Sfakiannaki (2016) compared the acoustic parameters like formant frequencies and duration of 5 Greek vowels among six hearing impaired and six normal-hearing young adults. Speech material was presented in /pVCV/ form with six vowels and in the context of four consonants C=/p, t, k, s/ embedded in a carrier phrase, and was repeated six times. So, 1440 words were recorded and analyzed using PRAAT software. The results revealed a longer vowel duration in hearing-impaired groups compared to the normal hearing children. This difference is because of the prolonged transition or steady-state movements from one articulatory position to another. Also, the vowel space area was found to be reduced.

Jafari et al. (2017), studied the six Persian vowels among three groups of participants (15 CI users, 15 HA users, and 15 NH). The participants' age range was 54-106 months, and the average duration of implantation for CI participants was three years. Stimuli considered to measure the vowel duration were words with syllabic shape /C_bVC_d/ (/bid/, /bed/, /bæd/, /bud/, /bod/, /bad/) with vowels

/i/, /e/, /æ/, /u/, /o/ and /a/. To calculate the F_0, the participants were instructed to maintain a stable production of vowel /a/. The participants were asked to make a repetition in the same way as the examiner. The production was audio recorded, and the acoustic analysis was carried out using the PRAAT software. F_0 in children with CI was higher compared to normal hearing participants. It could be because the children with hearing impairment tried to compensate for the auditory deprivation by changing the voice quality, which would increase the F_0. Vowel duration was significantly higher in both hearing impaired participants (CI users and HA users) than normal hearing children. Vowel duration was longest in vowel /a/ followed by /o/ > / æ/ > /u / > / e/ >/ i/.

Ghayedlou et al. (2020) conducted a comparative study in children with a cochlear implant and normal hearing in the age range of 9 to 12 years. The mean implant age for participants with cochlear implant was 32.5 months. A total of 52 age and gender matched participants were involved in the study. The participants were instructed to read the stimuli written separately on an A4 size paper. The production was recorded, and further acoustic analysis was done using the PRAAT software. Stimuli used were six Persian words with CVC syllable shape (/bid/, /bed/, /bæd/, /bud/, /bod/, /bad/). The study's findings suggested that children with cochlear implants produced vowels with a shorter duration, and the values were not significantly different. They considered these findings as the benefit of a cochlear implant on a long term perspective.

2.5 Acoustic Analysis of Speech of Children with CI in Indian languages

Anusha, Varsha, and Sreedevi (2010) compared the acoustic features of speech in children with CI and BTE users with their typical hearing peers. The parameters under study included vowel and word duration, the Voice Onset Time (VOT), and the formant frequencies. The authors concluded that all the parameters other than vowel duration showed similar results across children with CI and normal hearing children. Children using BTEs performed weaker than cochlear implantees.

Kant et al. (2012) compared the acoustic characteristics of CI and typically developing children in Hindi and found that VOT, formant frequencies of vowels (F_1 & F_2 -/e/, F_3- /u/) were affected in children with CI. Abhinaya, Reni and Catherine (2014) studied the vowel space characteristics of short vowels /a/, /i/ and /u/ in medial position in Tamil. Findings revealed a reduction in vowel space in children with CI indicating deviant vowel articulatory abilities in children with CI.

Sreedevi, Smitha, Irfana and Nimisha (2012) analyzed the F_2 locus equation of CV production in three different places of articulations, i.e., bilabials, alveolars and velars in the context of vowels (/a, i, u/) across cochlear implantees, hearing aid users and age-matched normals in Malayalam. Imitation tasks were carried out to elicit the speech samples. They found that co-articulation was closer to typically developing children in children with CI compared to BTE users.

Sebastian, Sreedevi, Lepcha, and Mathew (2015) compared nasalence in children with CI, HA users, and their typical hearing peers. A higher percentage of nasalence was observed in children using hearing aids. Children with CI showed a lower percentage of nasalence than children using hearing aids but did not match with their typical peers.

Joy, Deshpande, and Vaid (2016), compared the various acoustic parameters in the three groups of children using a cochlear implant. A total of 30 children using a cochlear implant in the age range of 4.1 to 6.7 years were compared with ten normal children of age range between 4 to 7 years. Objective voice analysis was done using Dr. Speech software in the three different time frames, six months, one year and two years following the implantation. The acoustic parameters like habitual fundamental frequency, jitter, and shimmer were analyzed for sustained Hindi vowels /a/, /i/ and /u/. The findings revealed that F_0 was higher in participants who had cochlear implantation at an age of six months and one year. However, children who used a cochlear implant produced the habitual fundamental frequency within the norms considered. They concluded these positive findings as to the positive outcome of rehabilitation training and auditory adaptation.

Deepthy and Sreedevi (2019) studied the acoustic characteristics of the vowel in cochlear implant users and compared them with the normal hearing participants in the age range of 4-8 years. Acoustic analysis of vowels /a/, /i/, and /u/ in the word-initial condition in a CVCV syllabic shape was performed using the PRAAT software and values of F_1 and F_2 were obtained at vowel midpoint.

Results revealed no significant difference between F_1 and F_2 of vowels /a/, /i/, /u/ across cochlear implantees and normal hearing children except for F_2 of /u/. Mean values of formant frequencies were found greater in CI users compared to TDC. Overall, intelligibility was found to be similar in both groups. The vowel space area did not show any significant difference between the two groups.

To summarize, numerous studies have reported on the spectral and temporal parameters of vowels in individuals with a cochlear implant in many languages, including some Indian languages. Most studies of acoustic analysis are limited to the exploration of the spectral parameters, whereas comparatively fewer studies are reported on temporal parameters of CI. Many studies review showed consistent F_1 compared to F2 and, F_2 was more affected. Durational parameters were significantly longer in CI. However, there are no published Nepali studies which have explored the acoustic characteristics of speech of cochlear implantees. Hence the present study attempted to explore the acoustic parameters in children with a cochlear implant and compare the findings with TDC in Nepali.

CHAPTER III

Method

The study aims to investigate the acoustic characteristics of vowels with a cochlear implant in native Nepali speaking children.

3.1 Participants

A total of 30 individuals participated in the present study. Among them, 15 children with pre-hearing impairment fitted with a multichannel cochlear implant (clinical group) and 15 age and gender-matched typically developing children (control group) in the age range of 4 to 8 years. They were matched with the chronological age and gender of cochlear implantees. The chronological age of all the participants ranged from 4 to 8 years, and for the clinical group, the implant age of a minimum of 2 years was considered. All the cochlear implantees were recruited from ENT hospitals and private speech and hearing clinics. Normal hearing children were from the kindergartens in Nepal. The demographic details of all the participants of the clinical and control groups are depicted in Table 3.1.

Table 3.1

Demographic Details of Clinical (CI) and Control group (TDC)

Group	Participants	Mean Age (Years)	Gender		Mean Implant age (Years)
			Male	Female	
CI	15	6.33	7	8	2.53
TDC	15	6.33	7	8	NA

Note: CI = Cochlear Implantees, TDC = Typically Developing Children, NA = Not Applicable

Both groups consisted of 15 participants, each with seven males and eight females. The mean age of the participants of both groups was 6.33 years. The mean age of cochlear implantation was 2.53 for the participants of the clinical group.

3.2 Research Design

The present study was a standard group comparison, wherein acoustic analysis of children using a cochlear implant is compared with typically developing children.

3.3 Participant Selection criteria

The following criteria were considered for the selection of participants of the clinical group in the present study:

3.3.1 Inclusion criteria for the clinical group

- Native Nepali speaker
- Children diagnosed with severe to profound hearing loss before CI surgery

- No middle ear or any other neurological disorders
- Cochlear implantation at least by the age of 4 years
- Not more than four inactive electrodes in cochlear implant
- Implant age of at least two years
- Undergone a minimum of two years of Auditory Verbal therapy(at the time of participation)
- No structural or functional deficits of orofacial structures
- Absence of any comorbid syndromic conditions, orosensory, motor, intellectual or any visual deficits

3.3.2 Inclusion criteria for the control group

- Native Nepali speaker
- Normal hearing sensitivity with no middle ear pathologies
- No structural or functional deficits of orofacial structures
- No language, motor, or neurological/cognitive impairments were confirmed by administering the 'WHO Ten-question disability screening checklist' (Singhi, Kumar, Malhi, & Kumar, 2007).

3.4 Test Stimuli

A total of six common words with VCVC/ VCV /VC syllable shapes were selected which included all the six Nepali vowels /ʌ/, /a/, /i/, /u/, /e/, /o/. Uniform syllable structure could not be maintained due to the unavailability of words in the required environment appropriate for the considered age participants. The first vowel of the combination was taken as the target vowel for analysis. The words were be selected from the wordlist (Dawadee, Prabhu, & Bhattarai, 2016) / Picture articulation test (Dawadee & Prabhu, 2015), which were picturable, unambiguous and within children's vocabulary. Colorful, clear, real, and pictures of appropriate size with the white background were chosen. Each of the six target words was presented three times randomly in the PowerPoint slides with one picture per slide. The responses elicited from the participants were audio-recorded. Thus, a total of 18 words (6 words x 3 trials) constituted the stimuli for the study.

Table 3.2

Nepali Words Containing Vowels under Study in the Initial Position

Vowel	Words (IPA)	Meanings(English)
/ʌ/	/ʌnar/	Pomegranate
/a/	/alu/	Potato
/i/	/inar/	Well/tank
/u/	/ukʰu/	Sugarcane
/e/	/ek/	Number one
/o/	/otʰa/	Lip

3.5 Procedure

Informed written consent was obtained from the parents or school administrators. The participants were made to sit comfortably in a quiet room, with minimum interference from the background noise and tested individually. The expected response was elicited by showing the stimuli word pictures on the laptop screen. For those children who were unable to name the picture shown, they were asked to repeat after the investigator. Each of the six target words was randomly displayed with three trials. The responses were audio-recorded with a recorder kept approximately 10 cm away from the mouth of the participant, and the pictures were presented in a gap of 4-5 seconds. Participants were encouraged to name the target picture, and appropriate verbal reinforcement was given for a correct response. Thus, 18 words (6 words x 3 trials) were recorded from each individual.

3.6 Instrumentation

The Olympus multi-track linear PCM recorder (Model No: LS 100) was used for recording the samples. Stimuli were be presented in PowerPoint using a 14-inch laptop (HP, Pavilion).

3.7 Data Analysis

The data were transferred to the personal computer for analysis. The acoustic analysis of the collected sample was carried out using the PRAAT software with 44.1 kHz sampling frequency (Boersma & Weenink, 2019) Version 6.1.01. The three recorded samples were analyzed, and the average of each stimulus was taken and further analyzed. Various acoustic parameters that were considered in the study are:

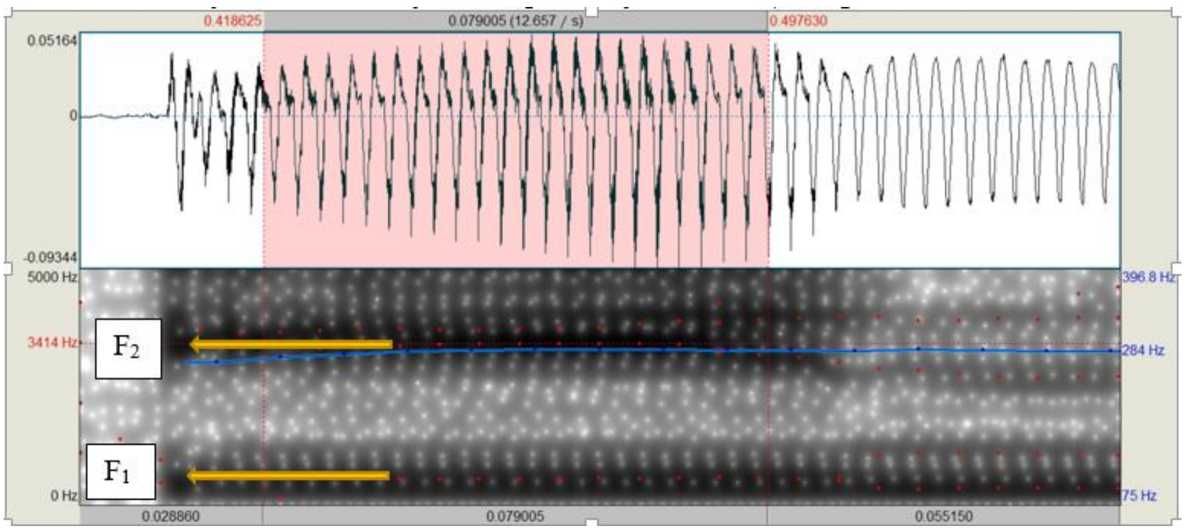
a. Formant frequencies F_1, F_2
b. Fundamental frequency
c. Vowel duration
d. Word duration

a) *First Formant and Second Formants Frequency:* Formants are the frequency peaks in the spectrum of a vowel with a higher degree of energy (F_1, F_2). The frequency of first

(F_1) and second (F_2) formants for each target vowel was measured at the midpoint of the vowel. Figure 3.1 illustrates the measurement of formant frequencies (F_1, F_2).

Figure 3.1

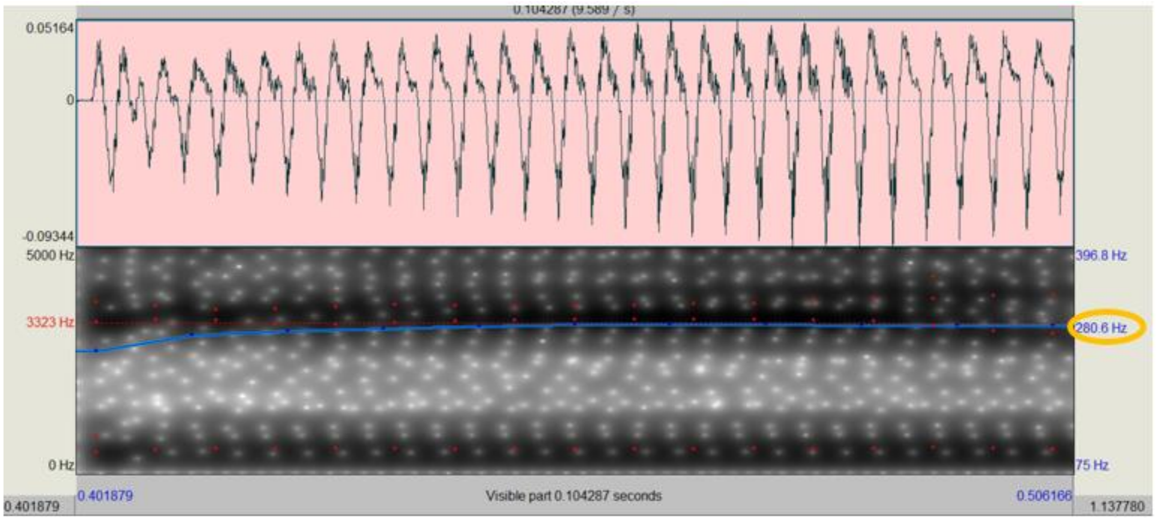
Illustration of Measurement of the Frequency of Formants (F_1, F_2)



b) *Fundamental frequency (F_0):* It is the frequency most often used by a person while speaking. A three-second segment with a stable pitch was considered for visual estimation of the pitch. The cursor will be placed on the pitch line (represented in blue color) in the spectrogram, and the frequency value shown for the selected point will be considered. Figure 3.2 illustrates the measurement of the fundamental frequency.

Figure 3.2

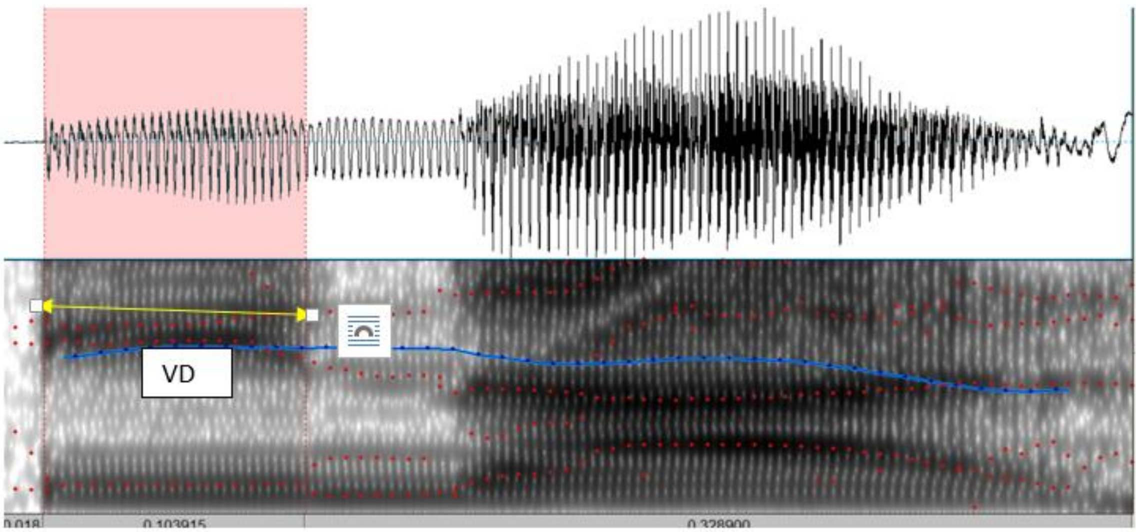
Illustration of Measurement of Fundamental Frequency of /i/



c) *Vowel Duration (VD):* VD is the time difference between the onset and offset of the vowel. On the waveform, vowel onset was determined by the first steady visible pulse of the steady. In contrast, vowel offset was determined similarly by the last steady visible pulse of the waveform. VD was measured in the word-initial position (VCV). Figure 3.3 illustrates the measurement of VD.

Figure 3.3

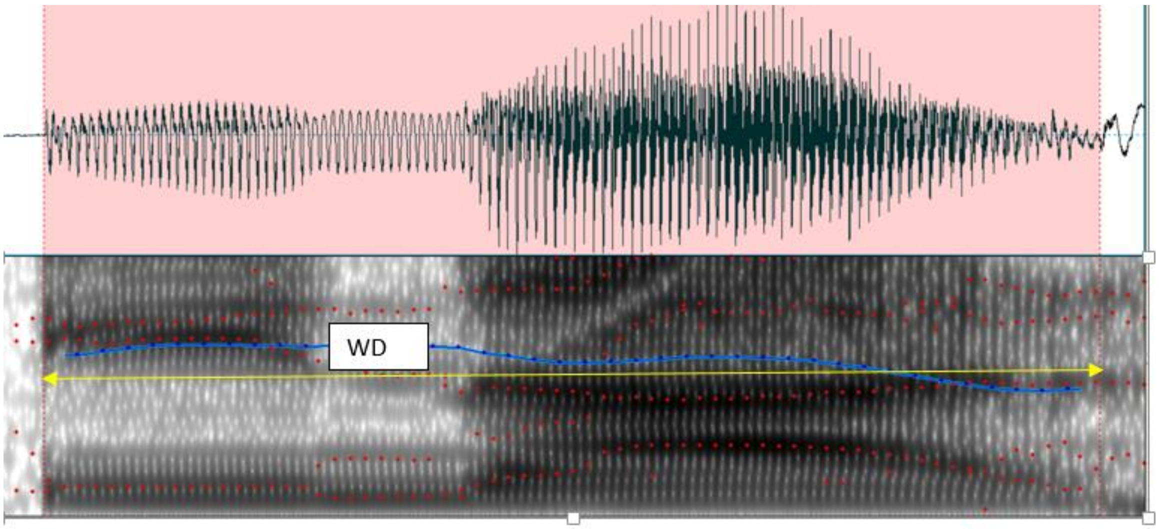
Waveform Showing Vowel Duration of /i/ in the Word /inar/



d) *Word Duration (WD):* WD is the time difference between the onset and offset of the target word. WD was measured by placing the cursor on the onset and offset of the target word on the waveform. Figure 3.4 depicts waveform showing waveform duration.

Figure 3.4.

Waveform Showing Word Duration of the Word /inar/



3.8 Statistical Analysis

The five acoustic parameters considered for the study among thirty participants (15 cochlear implantees & 15 typically developing children) were analyzed using PRAAT software. Statistical analysis was carried out using the Statistical Package for Social Science (SPSS) software (Version 20).

3.9 Inter and Intra judge reliability

Fifteen percent of the randomly selected samples were subjected to Inter and Intra judge reliability tests. To check the inter judge reliability, three speech-language pathologists, including the researcher, performed the acoustic analysis of the parameters independently. Whereas, for the intra-judge reliability, the investigator herself analyzed the randomly selected 15% of the samples at two different periods.

3.9.1 Intra and Inter-Judge Reliability in CI

The intra-judge and inter-judge agreement were analyzed using Cronbach's alpha test for all the spectral and temporal parameters of cochlear implantees (CI) considered in the study. Cronbach's alpha score for intra-judge reliability ranged from 0.71 to 0.999 for all the parameters indicating good internal consistency. Cronbach's alpha scores for inter-judge reliability ranged from 0.803 to 0.99 for the temporal and spectral parameters in CI, indicating good to excellent internal consistency across the measurements.

3.9.2 Intra and Inter Judge Reliability in TDC

The intra judge and inter-judge agreement were analyzed using Cronbach's alpha test for all the spectral and temporal parameters of typically developing children (TDC) considered in the study. Cronbach's alpha score for intra-judge reliability ranged from 0.78 to 0.999 for all the parameters indicating good internal consistency. Cronbach's alpha scores for inter-judge reliability ranged from 0.701 to 0.99 for the temporal and spectral parameters in TDC, indicating good to excellent internal consistency across the measurements.

CHAPTER IV

Results and Discussion

The current study aimed to analyze and compare the acoustic characteristics of vowels in native Nepali speaking children with cochlear implants and typically developing children. The acoustic parameters investigated in the present study included three spectral parameters (fundamental frequency, formant frequencies F_1 & F_2) and two temporal parameters (vowel duration & word duration). The three objectives of the present study are.

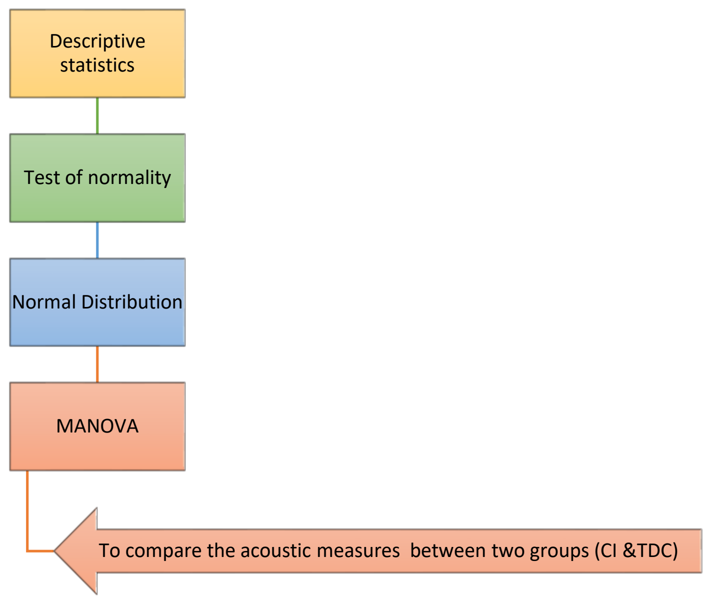
1. To investigate the spectral and temporal characteristics of vowels in children with a cochlear implant.
2. To investigate the spectral and temporal characteristics of vowels of age and gender matched typically developing children.
3. To compare the acoustic characteristics of vowels of children with a cochlear implant and typically developing children.

The obtained data in terms of spectral and temporal parameters of participants were subjected to a normality test using Shapiro-Wilk's test. A significant outlier was removed and replaced by another participant in the typically developing children group, following which the normality test was repeated. A normal distribution ($p>0.05$) was seen in all the parameters, except one variable F_2 /a/ (2^{nd} formant frequency of vowel /a/). Hence, parametric tests were adapted for all the spectral and temporal variables considered (non-parametric test was not applied for one variable F_2 /a/, as it would not have resulted in a realistic picture of the individual values). Mean, and Standard

Deviation (SD) were obtained for each parameter using descriptive statistics. Finally, MANOVA at a 95% confidence interval for mean was run to compare the considered parameters across Cochlear implantees (CI) and Typically Developing Children (TDC). MANOVA was applied as the number of dependent variables were more, and it also involves a comparison between two groups.

Figure 4.1

Flowchart of Statistical Analysis Performed on Acoustical Analysis of the Present Study.

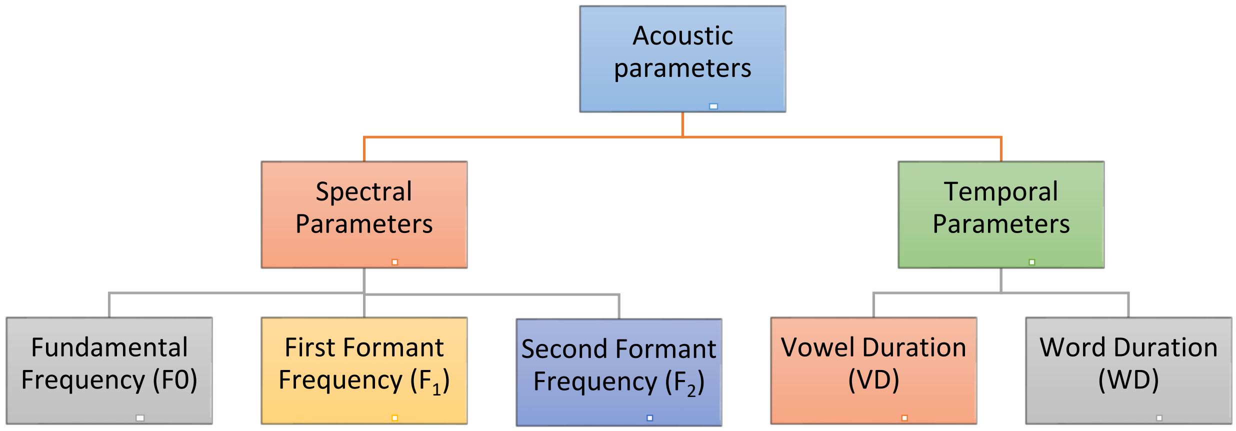


The findings of the present study are discussed under the following sub-headings:

1. First formant frequency (F_1)
2. Second formant frequency (F_2)
3. Fundamental frequency (F_0)
4. Vowel duration (VD)
5. Word duration (WD)

Figure 4.2

Acoustic Parameters of Vowels Investigated in the Present Study.



4.1 First formant frequency (F_1)

First formant frequency (F_1) of following Nepali vowels /ʌ/, /a/, /u/, /i/, /o/ and /i/ were measured among cochlear implantees and typically developing children (TDC). Descriptive statistics were applied to obtain the mean and standard deviation. Shapiro-Wilk's test was performed to check the normality. The result of the Shapiro-Wilk's test revealed that the analyzed speech samples of children with CI and TDC were both normally distributed. Hence, parametric test MANOVA was administered to check the significance, and the level of significance was obtained. The mean, standard deviation, F-value, and p-values are presented in Table 4.1, and the comparison of mean values of F_1 is depicted in figure 4.3.

Table 4.1

Mean, Standard Deviations, F-value, and p-value of F_1 for Vowels between CI and TDC

Vowel	CI		TDC		F-value	*P*
	Mean (Hz)	**SD**	**Mean (Hz)**	**SD**		
/ʌ/	984	137	857	109	7.85	0.009*
/a/	1309	188	1229	112	1.97	0.17
/u/	561	66	538	68	0.868	0.35
/i/	487	106	539	92	2.03	0.16
/o/	676	63	676	96	0.00	0.99
/e/	696	60	679	96	0.28	0.59

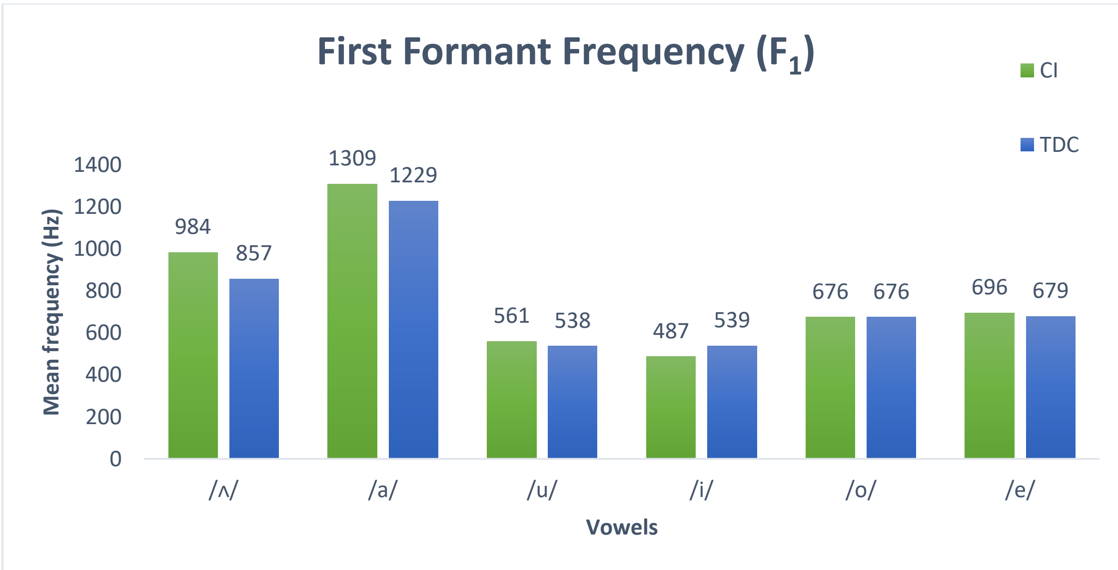
Note. SD = Standard Deviation, CI = Cochlear Implantees, TDC = Typically Developing Children, * indicates $p < 0.05$-values are significant.

Results indicated that mean first formant frequencies (F_1) for all the vowels were higher in cochlear implantees than typically developing children except for vowel /i/. As expected, the first formant frequency of vowel /a/ was higher than in other vowels in typically developing children (*M* 1229.42, *SD* 112.68) and cochlear implantees (*M* 1309, *SD* 188.27). This was followed by /ʌ/, /e/, /o/, /u/ and /i/ in both groups. CI demonstrated lower F_1 values in vowel /i/ than typically developing children (CI *M* 487 *SD* 106, TDC *M* 539 *SD* 92). Mean F_1 was found to be similar for both CI and TDC for vowel /o/ (*M* 676). The standard deviation was high for low vowels /ʌ/ (*SD*

CI=137, TDC=109) and /a/ (*SD* CI=188, TDC=112) in both groups compared to high vowels.

Figure 4.3

Comparison of F_1 in Children Using Cochlear Implant and TDC.



As it is clear from table 4. 1 and figure 4.3, the findings of the current study suggest that children with cochlear implants produced high vowels /i/, /u/,/e/, /o/ with lower F_1 and low vowels /a/and /ʌ/ are produced with higher F_1 compared to the typical group. Among all the vowels, only vowel /ʌ/ showed significant difference across the two groups [$F(1, 28) = 7.85$, $p < 0.05$]. Hence, the null hypothesis states there is no significant difference in F_1 across CI, and TDC is accepted for all vowels except for vowel /ʌ/.

Based on the results obtained in the present study, the mean F_1 of children with CI was higher than typically developing peers. Poissant found a similar result, Kimberly, Peter, 2006; Mahmoudi, Rahati, Ghasemi, et al. 2011; Narges Jaffari et al. 2016; and Deepthy and Sreedevi, 2019. The reason it as this increase in first formant frequency is due to lack of distinctions between the vowels, which is because of inadequate sensory feedback, i.e., auditory and kinesthetic.

In general, F_1 of vowel /a/ is higher and lower for vowel /i/. This is because vowel /i/ is an unrounded, front, close, and high vowel. Also, F_1 is inversely proportional to tongue height and /i/ is a high vowel which requires the mouth to be closed and the tongue touching the palate. Hence it is difficult to learn this articulatory gesture of vowel via visual feedback and are produced with much reliance on auditory feedback. However, vowel /a/ is produced by lowering the jaw, i.e., easier to get the visual feedback and requires minimal auditory control and depends on the vertical movement of the jaw with minimum tongue movement (Ozbic, Kogovsek, 2008).

Further, few more studies are found to have an agreement with the present finding. Baudonck et al. (2011) found higher F_1 values and argues that this increase in formant frequencies may indicate imitation of exaggerated articulatory movements of the therapist, parents, caregivers, and significant others. Also, because of the use of an effective hearing device, i.e., a cochlear implant, they get slightly recovered auditory feedback; as a result, their F_1 value was found to be close to those in TDC (Jaferi et al., 2016). However, Hocevar-Boltezar et al. (2008) found higher F_1 values of /i/, /u/. Svirsky and Tobey (1991) found higher F_1 of vowels /i/, /u/ and reasons that vowels /i/ and /u/ have more oro-sensory cues (tactile and proprioceptive) and also with the help of quantal properties of the sound processor system. Stevens (1972), scrutinized the point vowels /i/ and /u/ can have normalized values for F_1 and F_2. Also, for the production of the intermediate vowels like /e/, auditory information plays an important role than for point vowels. This could be taken into notice during the intervention of CI children.

In contrast to the finding of the present study, smaller F_1 among cochlear implantees has been reported in some earlier studies. Lofqvist et al. (2010) investigated 12 Swedish vowels, and Verhoeven et al. (2012) investigated Dutch vowels, they found CI children had lower F_1 values for vowels /ɛ/, /a/,/ɑ/ and higher for vowels /u/, /ɔ/, compared to TDC and HA children. Liker et al. (2007) found mean F_1 value of vowel /a/ significantly lower in CI children compared to normal hearing children among 4 Croatian vowels and comments this finding as an effect of decreased jaw movements and also the effect of more duration following surgery. Other investigators (Svirsky & Tobey, 1991; Perkell et al., 2001; Vick et al., 2001; Horga & Liker, 2006; Liker et al., 2007; Ibertsson et al., 2008; Neumeyer et al., 2010) hypothesized reduced F_1 among cochlear implantees and hearing-impaired population as a result of insufficient auditory feedback, which severely affects the vowel perception.

Some studies report that children with CI performed equally well as typical children; Eisenberg et al. (2004), Svirsky, Robbins, Kiron, Pision (2000). Also, Campisi, Low, Papsin, Mount, Harrison, 2006; Baudonck et al. (2011) found no significant difference in F_1 of vowel /a/ among CI and TDC. No apparent differences in F_1 among the CI and TDC participants are due to clear visibility of jaw height changes, i.e., CI participants can abstract phonetic height almost like typical hearing peers.

4.2 Second formant frequency (F_2)

Second formant frequency (F_2) in following Nepali vowels /ʌ/, /a/, /u/, /i/, /o/ and /i/ were measured for cochlear implantees and typically developing children (TDC). Descriptive statistics were applied to scores of both groups to obtain the mean and standard deviation. Shapiro-Wilk's test was performed to check the normality. The result of the Shapiro-Wilk's test revealed that the analyzed speech samples of children with CI and TDC were normally distributed. Hence, parametric test MANOVA was administered to check the significance, and the level of significance was obtained. The mean, standard deviation, F-value, and p-values are presented in Table 4.2, and the comparison of mean values of F_2 is depicted in figure 4.4.

Table 4.2

Mean, Standard Deviations, F-value and p-value of the Second Formant Frequency (F_2) for Vowels in CI and TDC

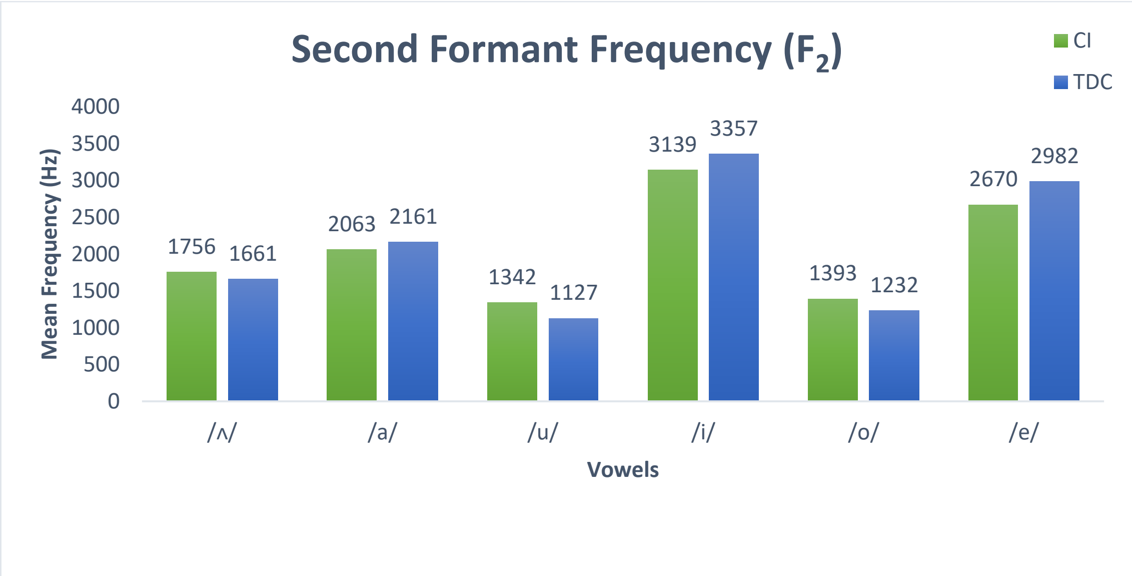
Vowel	**CI**		**TDC**		**F**	***P***
	Mean (Hz)	**SD**	**Mean (Hz)**	**SD**		
/ʌ/	1756	171	1661	181	2.176	0.151
/a/	2063	176	2161	124	3.09	0.090
/u/	1342	165	1127	138	14.865	0.001**
/i/	3139	241	3357	96	10.577	0.003*
/o/	1393	148	1232	137	9.512	0.005*
/e/	2670	360	2982	134	9.877	0.004*

Note. SD = Standard Deviation, CI = Cochlear Implantees, TDC = Typically Developing Children * indicates $p < 0.05$ - values are significant, ** p indicates < 0.001 - values are highly significant.

F_2 for all the vowels in word-initial position was measured in both cochlear implantees and normal children. The highest mean F_2 and the standard deviation was observed for vowel /i/ in both groups (CI *M*= 3139 Hz, *SD* 165.319, TDC *M*= 3357 Hz, *SD* 96.827) compared to all other vowels. This was followed by F_2 of /e/, /a/, /ʌ/, /o/, /u/. F_2 for /i/, /e/, /a/ were found to be higher in typically developing children, whereas F_2 of vowels /ʌ/, /u/, /o/ were higher in cochlear implantees. Lowest F_2 was observed for the vowel /u/ in both groups among all vowels as expected. However, CI participants depicted higher F_2 of /u/ than TDC (CI *M* = 1342 Hz, *SD* = 165, TDC *M* =1127 Hz, *SD* =138). The standard deviation was highest for vowel /e/ in CI (SD 360) and /ʌ/ in TDC (*SD 181*).

Figure 4.4

Comparison of F_2 in Nepali Speaking Children using Cochlear Implant and TDC.



F_2 of front vowels /a/, /i/, /e/ were found to be low and high for back vowels /ʌ/, /u/, /o/ in cochlear implantees than normal hearing peers. As Cochlear implantees produced front vowels with reduced F_2 values, a partial vowel neutralization phenomenon is observed, unlike in participants of TDC.

As it is clear from table 4.2, the results of the current study revealed that vowels /u/, /i/, /o/, /e/ showed significant difference across the two groups ($p < 0.05$) for F_2.

However, there was no significant difference for F_2 across two vowels /ʌ/, and /a/ (i.e., $p > 0.05$). Hence, the null hypothesis stating there is no significant difference in second formant frequency across CI and TDC is partially accepted.

As discussed above, F_2 was lower for front vowels and higher for back vowels in CI compared to TDC. Equivalent results were reported by earlier researchers Baudonck et al. (2011), and Verhoeven et al. (2015) state that this inconsistency in CI results is due to the less consistent realization of vowels in front-back dimension. Similar results are reported by Narges et al. (2015).

Back vowels were found to have higher values in cochlear implantees; the reason can be due to the inability of CI participants for optimum backing of the tongue, which lacks visibility. In the study by Narges et al. (2015), they found the significantly higher value of /o/ and argue that because of hearing impairment, they try to produce the back vowels with the more anterior placement of tongue compared to TDC. At the same time, the front vowel /i/ was found to have higher mean values in TDC.

Likewise, compressed F_2 value in CI participants for the back vowels is due to reduced opportunity to infer tongue backing visually and hence phonetic backness in the same way (Neumeyer et al., 2010). Lachs et al. 2001, conducted the study among cochlear implantees in two conditions, one providing both auditory and visual feedback. The other condition had only auditory feedback and found children performed better in audiovisual sensory mode.

In contrast to the present findings, Narges et al. (2015) and Baudonck et al. (2011) found higher F_2 for the vowel /a/ in the CI participants than TDC but was not significant.

This aligns with Kant et al. 2012, where she found higher F_2 for point vowels /i/, /u/ among CI and F_2 was greater in TDC for vowel /e/ and argued the finding as to the presence of more oro-sensory cues (tactile and proprioceptive) for the vowel /i/ and /u/ than for vowel /e/. However, for the production of vowel /e/ and other intermediate vowels, auditory stimulation plays a higher role, lacking in participants with cochlear implantees (Svirsky & Tobey, 1991). Also, Higgins et al. (2001) studied formant frequencies in pre-lingual hearing impaired girls of 6 years and found an increase in F_2 of /a/ and /i/. The authors concluded that insufficient auditory feedback might have resulted in inappropriate tongue placement of /a/.

Uchanski and Geers (2003), Baudonck et al. (2011) found no significant difference in F_2 of /i/ and /u/ among CI and TDC participants. This is supported by Deepthy and Sreedevi (2019) in Malayalam, i.e., F_2 of vowels /a/ and /i/ was not significantly different in CI though higher. Similarly, vowel /u/ was higher in TDC but not significant. It is hypothesized that the smaller F_2 of /u/ among CI participants was due to a reduced tendency towards a more dorsal articulation. In the present study also, few vowels were not significantly different for F2. The lack of significant difference across CI and TDC suggests the positive benefit from the cochlear implant. On similar lines, Kishon-Rabin et al. (1999) and Muller-Deile et al. (1991) analyzed post lingually deafened adults. They found relatively constant F_2 value for all the vowels, but F_2 of /i/ was found to be higher post-implantation.

4.3 Fundamental Frequency (F_0)

Fundamental Frequency (F_0) in Nepali vowels /ʌ/, /a/, /u/, /i/, /o/ and /i/ were measured among cochlear implantees and typically developing children (TDC).

Descriptive statistics was administered to obtain the mean and standard deviation. Shapiro-Wilk's test was performed to check the normality. The result of the Shapiro-Wilk's test revealed that the analyzed speech samples of children with CI and TDC were both normally distributed. Hence, parametric test MANOVA was administered to check the significance, and the level of significance was obtained. The mean, standard deviation, F-value, and p-values are presented in Table 4.3, and the comparison of mean values of F_1 is depicted in figure 4.5.

Table 4.3

Mean, Standard Deviations, F-value and p-value of the Fundamental Frequency (F_0) for Vowels in CI and TDC

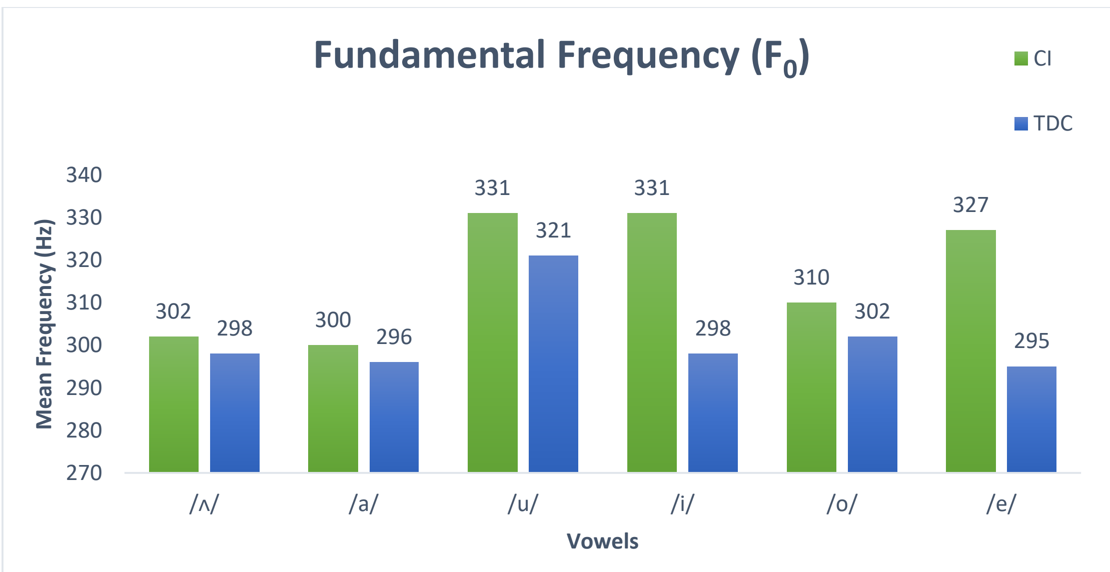
Vowel	**CI**		**TDC**		**F**	***P***
	Mean(Hz)	**SD**	**Mean(Hz)**	**SD**		
/ʌ/	302	33	298	38	0.096	0.75
/a/	300	38	296	12	0.14	0.70
/u/	331	47	321	52	0.28	0.60
/i/	331	50	298	48	3.36	0.77
/o/	310	34	302	42	0.31	0.57
/e/	327	33	295	35	6.67	0.01*

Note. SD = Standard Deviation, CI = Cochlear Implantees, TDC = Typically Developing Children * indicates $p < 0.05$ - values are significant.

The mean and standard deviation were compared across fundamental frequency (F_0) domain of spectral analysis in children with cochlear implants and children with normal hearing. Mean fundamental frequency (F_0) value was found higher for vowel /u/ (CI *M* = 331 *SD* = 47, TDC *M* = 321 *SD* = 52) followed by /i/, /e/, /o/, /ʌ/ and /a/ in both groups. Cochlear implantees had mean F_0 scores higher than typically developing children in all six vowels. F_0 was found lowest for vowel /a/ (*M* 300, *SD* 38) in CI participants and for /e/ (*M* 295, *SD 35*) for TDC. Standard deviation was found highest for vowel /i/ (*SD*, 50) in CI and /U/ (*SD* 52) in TDC.

Figure 4.5

Comparison of F_0 in Nepali Speaking Children Using Cochlear Implant and TDC.



As it is clear from table 4.3, the result of the current study revealed that vowel /e/ showed a significant difference between two groups [F (1, 28 = 6.67), $p < 0.05$]. However, there was no significant difference across other vowels ($p > 0.05$). Hence, the null hypothesis, which says there is no significant difference in fundamental frequency across CI and TDC, is accepted for all vowels except for vowel /e/.

The result from the present study revealed higher fundamental frequency among children with cochlear implants compared to TDC. This finding is in coherence with the finding of Hocevar-Boltezar et al. (2005) and contends that the cochlear implantation before the age of 4 years and implant exposure of more than 24 months enables a quicker and better auditory control of voice production and improves overall voice quality and speech compared to those implanted after four years or late. Higher fundamental frequency among the participants with hearing impairments (cochlear implantees) results in more considerable vocal efforts on the part of hearing-impaired.

In contrast to the present findings, Hamzawi et al. (2000), Kishon Rabin et al. (1999), Szyfter et al. (1996) Chouard et al. (1988), and Leder et al. (1987) documented reduced fundamental frequency in CI closer to the average value. Also, Mueller-Deile et al. (1991) found a decrease in the variability of F_0. Results of other studies (Leder et al., 1984; Hamzavi et al., 2000; Higgins et al., 2004) showed a significant decrease in F_0 after implantation. Spitzer et al. (2007) reported reduced F0 variations and stated this effect to be detrimental in the task of lexical segmentation.

Seifert et al., 2002 noted less deviation of F_0 in CI compared to typical hearing peers. Four participants were found with higher fundamental frequency for Swiss-vowel /a/ above the average mean, and 16 participants had F_0 lower than the normal after the implantation. Standard deviation was found to be less, and no significant difference was noted among the participants who received the implantation before the age of 4. Authors state that early implantation led to better functional auditory maturation and better stimulation.

4.4 Vowel Duration (VD)

The vowel duration was analyzed in the speech sample obtained from children using cochlear implant (CI) and typically developing children (TDC). Six Nepali vowels /ʌ/, /a/, /u/, /i/, /o/ and /i/ were considered and vowel duration was measured for cochlear implantees and typically developing children (TDC). Descriptive statistics was administered in both groups to obtain the mean and standard deviation. Shapiro-Wilk's test was performed to check the normality of the data. The Shapiro-Wilk's test revealed that the analyzed speech samples of children with CI and TDC were normally distributed. Hence, the parametric test MANOVA was administered to check the significance and the level of significance. The mean, standard deviation, F-value, and p-values across groups are depicted in Table 4.4, and a comparison of mean values of vowel duration is depicted in figure 4.6.

Table 4.4

Mean, Standard Deviations, F-value, and p-value of the Vowel Duration for Vowels in CI and TDC

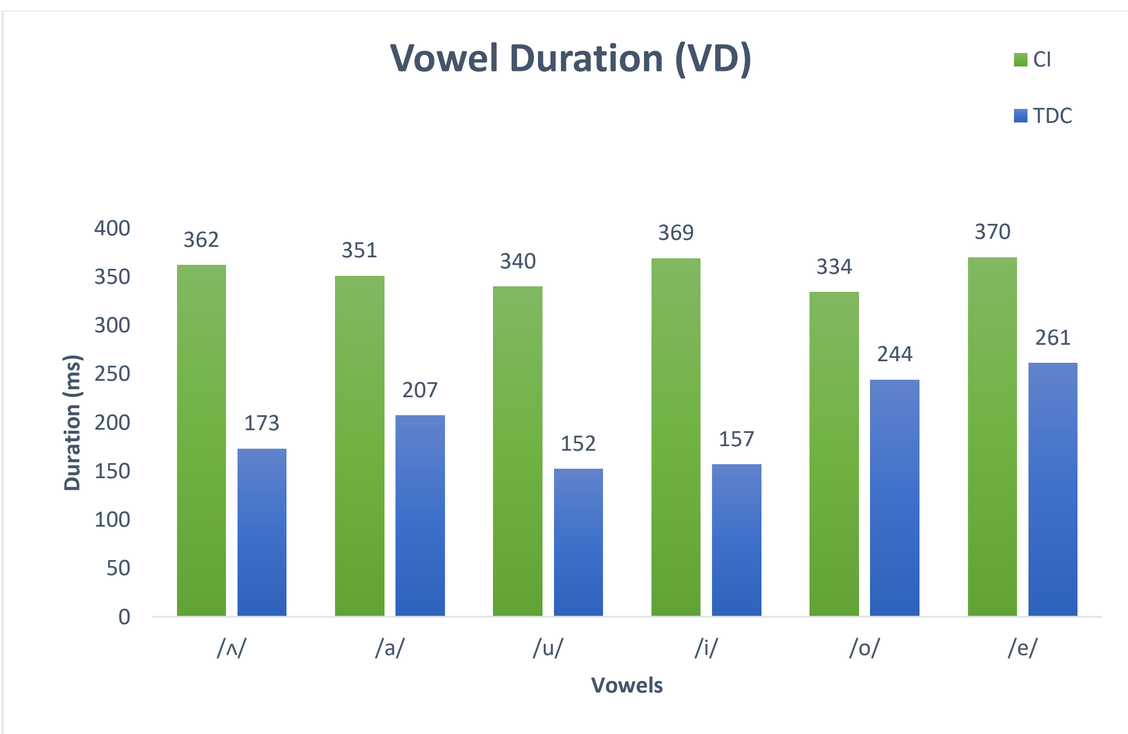
	CI		**TDC**			
Vowel	**Mean (ms)**	**SD**	**Mean (ms)**	**SD**	**F**	***P***
/ʌ/	362	82	173	34	67.04	0.00**
/a/	351	82	207	45	34.96	0.00**
/u/	340	79	152	41	66.43	0.00**
/i/	369	96	157	41	50.95	0.001**
/o/	334	70	244	56	14.71	0.001**
/e/	370	107	261	61	11.78	0.002*

Note. SD = Standard deviation, CI = Cochlear Implantees, TDC = Typically Developing Children, ** indicates p<0.01-values are highly significant, * indicates p < 0.05, values are significant.

According to descriptive statistics, mean vowel duration value was found to be longer in CI children compared to TDC. It was observed that vowel /e/ had longest duration among all vowels in both groups (CI *M* = 370.69 *SD* = 107.18, TDC *M* = 261.61 *SD* = 61.56) followed by vowels /i/, /ʌ/, /a/, /u/ and /o/ in cochlear implantees and /e/, /o/, /a/, /ʌ/, /i/, /u/ in typically developing children. In CI participants, vowel duration ranged from 334 ms for /o/ to 370 ms for /e/. Whereas, for participants with normal hearing, vowel duration ranged from 152 ms for /a/ to 261 ms for vowel /e/. Lowest vowel duration was found for vowel /o/ in CI group and /u/ in TDC group. Cochlear implantees had mean vowel duration scores higher than typically developing children for all six vowels studied. Standard deviation was found to be highest in vowel /i/ in both the groups (*SD*, CI = 107, TDC = 61).

Figure 4.6

Comparison of Vowel Duration in Cochlear Implantees and TDC.



The parametric test, MANOVA, was administered to analyze and compare the significance of vowel duration across groups (CI vs. TDC). Results indicated a significant difference between vowel durations of CI children and TDC (Table 4.4). The vowel duration of CI children was significantly longer compared to TDC.

To summarize, the findings of the current study suggest that children with cochlear implants produced all six vowels with a significantly longer duration compared to TDC ($p < 0.001$ & $p < 0.05$). Hence, the null hypothesis, which states there is no significant difference in vowel duration across CI and TDC, is rejected for all six vowels.

Researchers (Smith, 1978; Kent & Forner, 1980; Robb & Saxman, 1990) have concluded that shorter segmental duration signifies more mature articulatory movements and speech production, which indicates better linguistic abilities and effective planning, and motor practice.

Overall, in the present study children with cochlear implant had longer and more variable vowel durations than typically developing children, which is consistent with earlier published literature on cochlear implantees, hearing aid users among hearing-impaired children (Monsen, 1974; Osberg & Levitt, 1979; Ryalls & Laroche, 1992; Uchanski & Geers, 2003, VanDam et al., 2011).

Similarly, longer vowel durations among the hearing-impaired population were also reported in the study by Whitehead and Jones (1976), these prolongations are seen in transitory movement from vowels to consonants (i.e., from one articulatory movement to another) or in the steady states (within vowel portion). Deepthy and Sreedevi (2018) found longer vowel duration among CI than TDC except for vowel /i/. Also, Whitehead and Jones, 1976; Lane et al. 1995; Uchanski and Geers, 2003, found partially longer vowel duration and remarks this finding as to the result of Lombard effect induced by average hearing listeners through binaural masking which produces an increase in vowel duration (Garnier et al., 2006; Junqua, 1993; Lane and Tranel, 1971; van Summers et al., 1988).

The finding of the present study, which showed participants with CI had longer vowel duration compared to TDC is consistent with the other previous studies also (Monsen, 1974; Uchanski & Geers, 2003; Yang et al., 2015; Yang & Xu 2017). They explained that participants with CI might need more time to form the articulatory gestures for vowel production and travel from one articulatory target to the next in the context of words of the multi-target phonemic segment. Earlier research also suggests the increased vowel duration as a compensatory strategy to increase the clarity and intelligibility of their speech. Similarly, Neumeyer, Harrington, and Draxler, 2010, reported individual vowel duration of /i:/ and /e:/ in German-speaking adult CI users more than average.

Nicolaidis and Sfakiannaki (2016) found durational differences in the degree of openness of the oral cavity for participants with hearing impairment. They found the most prolonged vowel duration in open vowel / ɐ / and shortest in close vowel /i/. Kent and Rosenbek (1983) reasoned that the vowels are produced with lengthier durations to compensate for reduced proprioception.

4.5 Word Duration (WD)

The word duration values for cochlear implantees (CI) and typically developing children (TDC) was calculated in words containing following vowels /ʌ/, /a/, /u/, /i/, /o/ and /i/ in word-initial position. Descriptive statistics across both groups were applied to obtain the mean and standard deviation. Shapiro-Wilk's test was performed to check the normality. Results of the Shapiro-Wilk's test revealed that the analyzed WD of children with CI and TDC were both normally distributed. Hence, the parametric test MANOVA was administered to check the significance and the level of significance. The mean, standard deviation, F-value, and p-values of WD are presented in Table 4.5, and a comparison of mean values of word duration is depicted in figure 4.7.

Table 4.5

Mean, Standard Deviations, F-value and p-value of the Word Duration (WD) for Vowels in CI and TDC

Words	**CI**		**TDC**		**F**	***P***
	Mean (ms)	**SD**	**Mean (ms)**	**SD**		
/ʌnar/	1007	151	565	78	100.81	0.000**
/alu/	883	250	559	92	22.20	0.000**
/ukhu/	878	190	595	83	27.859	0.000**
/inar/	1020	115	564	109	122.43	0.000**
/oth/	829	173	629	173	10.01	0.004**
/ek/	696	125	578	120	6.84	0.014*

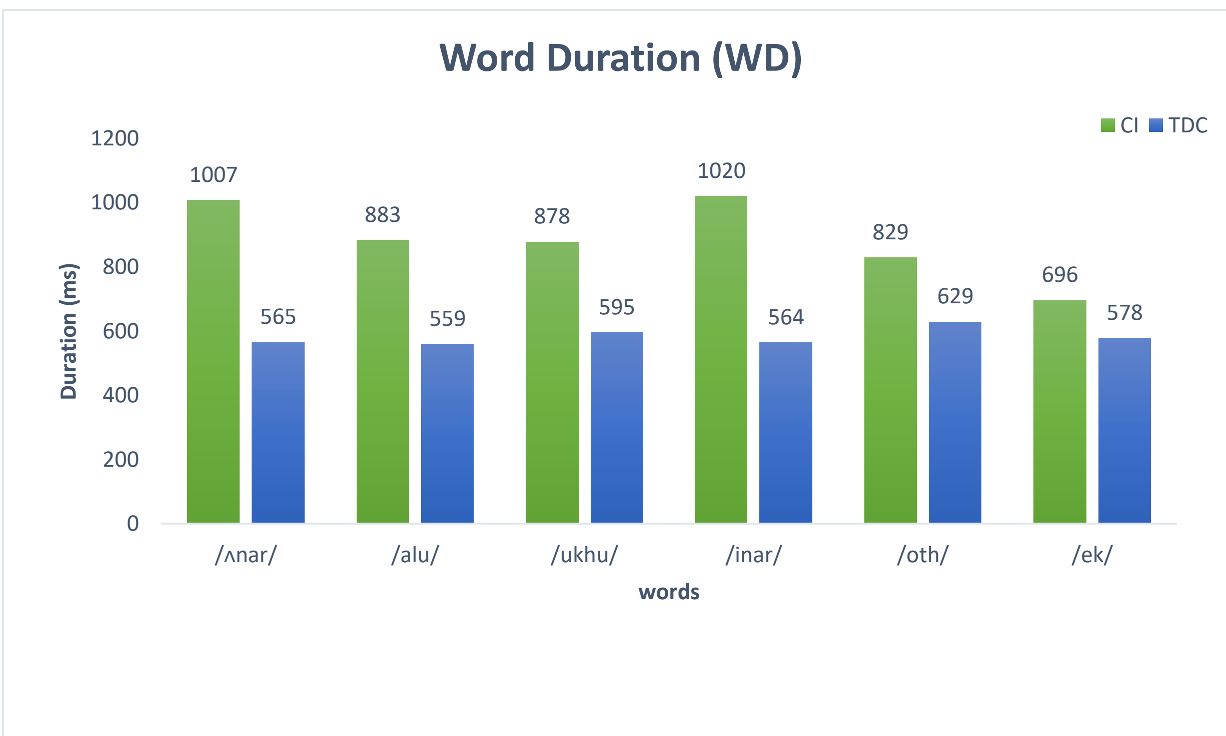
Note. SD = Standard Deviation, CI = Cochlear Implantees, TDC = Typically Developing Children, ** indicates $p < 0.01$, values are highly significant. * indicates $p < 0.05$, values are highly significant.

The mean and standard deviation were compared for word duration across children with cochlear implants and children with normal hearing. Mean word duration was found highest for word (/inar/) with vowel /i/ (CI *M* = 370 *SD* = 107, TDC *M* = 261

SD = 61) followed by words starting with vowels /ʌ/, /a/, /u/, /o/ and /e/ in cochlear implantees and for typically developing children the decreasing order was for words with /o/, /u/, /e/, /i/, /ʌ/, /a/ . In participants with a cochlear implant, the word duration ranged from 686 ms for /e/ to 1020 ms for /i/. Whereas, for participants with normal hearing word duration ranged from 559 ms for /a/ to 629 ms for vowel /o/. Smallest word duration was found in vowel /e/ in the CI group and for vowel /a/ in the TDC group. Cochlear implantees had mean scores more than typically developing children for all six vowels. Standard deviation was highest for the word /alu/ in CI (*SD* 250) and /oth/ in TDC (*SD* 173). This means that children with cochlear implants produce words with longer duration and higher variability.

Figure 4.7

Comparison of Word Duration in Cochlear Implantees and TDC.



MANOVA was used to analyze and compare the significance of word duration across groups (CI vs. TDC). Results indicated word duration was highly significant across TDC and CI (Table 4.4)

In a nutshell, the finding on word duration suggests that children with cochlear implants produced longer word duration. The statistical test showed a significant difference between the two groups ($p < 0.01$) for all six words tested. Hence, the null hypothesis stating there is no significant difference in word duration across CI and TDC is rejected.

Overall, children with cochlear implants had longer word durations than their peers with normal hearing abilities, consistent with previous reports in the literature on children with CI. Robb and Pang-Ching (1992), found similar results; word duration was longer among children with hearing-impaired compared to TDC. Also, Monsen (1978) and Uchanski and Geers (2003) found correspondence with the above finding and hypothesized a longer duration reflecting poorly developed speech skills in general.

However, significantly shorter word duration among participants with cochlear implants in contrast to the present finding was also noted in some studies (Lane et al., 1998; Leder et al., 1986; Oster, 1987; Perkell et al., 1992; Plant and Oster, 1986; Tartter et al., 1989).

In summary, it can be observed from the present study that the performance of children with cochlear implants on some acoustic parameters was comparable to typically developing children. Spectral parameters like fundamental frequency, F_1, and F_2 were closer to the TDC values indicating fewer deviations in them. However, temporal parameters such as word duration and vowel durations were significantly longer in cochlear implantees than in typical children.

CHAPTER V

Summary and Conclusions

Speech and language development of the children is altered because of significant hearing loss in pre-lingual or post-lingual conditions. With the advancement of technology to assist for overall improvement in hearing and enhancing the quality of life, the recommendation of cochlear implants to the hearing-impaired population is increasing. A cochlear implant is a surgical prosthetic device of significant budget and promising hopes among hearing-impaired participants and parents. There are many challenges and expectations following implantation in terms of better speech outcomes and age-appropriate language development. Despite the challenges, there is no consensus in terms of speech assessment to understand the types of errors and parameters focused on rehabilitation. There are no studies that have analyzed the acoustic parameters of vowels in participants' speech with a cochlear implant, specifically in the Nepali context. Hence, it necessitated a study to investigate these acoustic parameters (temporal and spectral) in native Nepali speaking children with pre-lingual hearing impairment using cochlear implants. The study's main aim was to investigate the acoustic characteristics of vowels in children using a cochlear implant and compare it with typically developing children.

The present study included 15 children using cochlear implants and age and gender matched 15 typically developing children. The participants of the age range four to eight years were included, and for children with a cochlear implant, the implant age of a minimum of two years was considered. The test stimuli consisted of six words containing six Nepali vowels (/ʌ/, /a/, /u/, /i/, /o/ and /i/) in word-initial position.

Participants were instructed to name the picture shown on the PowerPoint or were asked to repeat after the researcher. The performance was audio-recorded using the high-quality recorder (Olympus multi-track linear PCM recorder Model No: LS 100). The picture stimuli were randomly arranged to elicit the three productions of six stimuli considered in a comfortable manner.

The recorded speech samples were analyzed using PRAAT software version 6.1.0.1 (Boersma & Weenink, 2010). The temporal (vowel duration & word duration) and spectral parameters (fundamental frequency, first formant frequency, and second formant frequency) were measured from the waveform. All three productions of each stimulus were measured, and the average was considered. Fifteen percentage of randomly selected data from overall were subjected to inter-judge and intra-judge reliability: it showed good to excellent reliability.

Obtained data were subjected to descriptive statistics to obtain the mean and standard deviation of the variables considered. All the variables showed normal distribution, and thus, a parametric test was applied. All the five acoustic parameters considered in the study (two temporal and three spectral) were investigated and compared across groups (CI vs. TDC) using parametric test MANOVA. The result of the present study suggests that spectral parameters such as fundamental frequency, F_1, and F_2 were closer to the TDC values indicating fewer deviations. However, temporal parameters like word duration and vowel duration were found to be significantly longer in cochlear implantees compared to normal children.

Children with a cochlear implant showed significantly longer vowel duration and word duration compared to typically developing children. This may be due to immature articulatory movements, ineffective planning, and inadequate motor practice. The longer time duration may be because of stretched articulatory gestures for vowel production and also due to longer time taken to travel from one articulatory target to next in words. Because of reduced speech intelligibility and clarity due to hearing impairment and auditory deprivation, cochlear implantees compensate by elongating the duration of words and vowels. Also, the Lombard effect induced by average hearing listeners through binaural masking could be the reason for a longer duration.

Children with cochlear implants produce vowels with inconsistent frequencies. The fundamental frequency and formant frequencies (F_1 & F_2) were found to be variable compared to TDC. Mean F_1 produced by children with a cochlear implant is found to be higher than TDC, but not significant. Also, F_2 of back vowels were found to be higher in CI than TDC. This may be due to a lack of distinction between vowels and small sensory cues (auditory, kinesthetic, or proprioceptive). Children using a cochlear implant seem less consistent in the realization of front-back and high low dimensions and articulate with extra vocal efforts. Also inappropriate frequencies among cochlear implantees are the result of imitation of the exaggerated articulatory model of clinicians and caregivers.

To conclude, the present study's findings have provided information on some acoustic parameters of vowels in children using cochlear implants in comparison to TDC. It can be concluded from the present study that typically developing children and children with cochlear implants showed no significant difference in spectral parameters. Whereas, temporal parameters were found to be significantly longer in cochlear implantees. The findings suggest the benefit of a cochlear implant. An additional benefit, in the long run, can be expected with systematic and intensive auditory-verbal therapy and effective mapping by rehabilitation specialists.

5.1 Implications of the study

- The present study will shed light on understanding the acoustic characteristics of vowels in children with CI in Nepali.
- The study will provide an objective means of documenting the differences in the acoustic characteristics of vowels between cochlear implantees and typical hearing Nepali children.
- This will help understand the erroneous vowel production, which augments speech evaluation, intervention, cochlear implant mapping, and other rehabilitation procedures in CI.
- The information investigated from this study will serve as guidelines for improving speech intelligibility and improving the quality of life of children with CI.

5.2 Limitations

- In the present study, homogeneity across the cochlear implantees was not maintained concerning bimodal amplification devices.
- The current study included children in the age range of 4-8 years; thus, it cannot be generalized the same with younger and older children.
- The current study included only 15 participants, and this result cannot be generalized in the overall population.
- Only five acoustic parameters were taken. Hence, the overall benefit of surgery and therapy following cochlear implantation cannot be predicted.

5.3 Future recommendations

- A longitudinal study on CI can be carried out to see the effectiveness of long term cochlear implantation.
- Homogenous participants using the same type of speech processor with bimodal same power hearing aid or bilateral cochlear implant can be considered.
- The study can be considered with a larger sample size and different age groups.
- Further study, including other acoustic and perceptual measures, can be considered. This would give a more detailed picture to evaluate the effectiveness of CI.

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APPENDIX A

Stimuli Considered in the study

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APPENDIX B

Sample of consent form

All India Institute of Speech and Hearing, Manasagangothri,
Mysore, 570006

I Ms. Kranti Acharya, 2nd M.Sc. SLP fellow, am doing research as a part of dissertation on "Acoustic and articulatory characteristics of Vowels in Nepali Language in children with Cochlear Implantees and normal children's". During the course of research I have to collect only the speaking samples. There are no risks or discomforts involved during the study. Audio recording the sessions will be done and these recordings will be kept confidential. The participation in the study is voluntary and there is no compulsion.

Informed Consent

I have been informed about the study and understand its purpose and my child's participation in it. The possible benefits of my child's participation as human subject in the study are clearly understood by me. I understand that I have a right to refuse participation as subject or withdraw my consent at any time. I give my consent for my child's/student participation in this study.

I, ______________________________________, the undersigned, give my consent for my child's participation in this study.

(AGREE/DISAGREE)

Signature of Parent/Teacher | Signature of Investigator

(Name and Address) | (Name and Designation)

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