# SPEECH CHARACTERISTICS OF CHILDREN WITH HEARING IMPAIRMENT: AN ACOUSTIC ANALYSIS

**A thesis submitted to the University of Hyderabad for the Degree of**

**Doctor of Philosophy**

**In**

**Applied Linguistics**

**By**


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# CERTIFICATE

This is to certify that Mr.S.G.R.Prakash, worked under my supervision for the Ph.D. degree in Applied Linguistics at Centre for Applied Linguistics & Translation Studies, University of Hyderabad. His thesis entitled **"Speech Characteristics of Children with Hearing Impairment: An Acoustic Analysis",** represents his own independent research work which has not been submitted to any other institution for the award of any other degree.

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## DECLARATION

This is to hereby declare that I, S.G.R.Prakash, have carried out the research embodied in the present thesis entitled **"Speech Characteristics of Children with Hearing Impairment: An Acoustic Analysis"**, for the full period prescribed under Ph.D. ordinances of the university.

I declare to the best of my knowledge that no part of this thesis was earlier submitted for the award of any research degree to any other University.

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S.G.R.Prakash

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# CHAPTER – I

## 1.1. INTRODUCTION

Communication makes the humans different from animals. Speech is the most efficient medium of communication known to man. So much so that efforts are on to make speech as a medium of communication even between men and machines.

Speech is defined as audible manifestation of language by a complex and still rather mysterious process called as encoding. The speaker converts an idea he has in his mind into a stream of sounds, moving his lips, tongue and jaws in precise gestures.

According to Kent and Read (1992:1) speech is a complex, highly skilled motor act. The refinement and stabilization of speech motor patterns probably continues well into the teens. In the hearing impaired individuals, there is a difficulty in the same due to the loss of the auditory feedback.

The reception and expression of language takes place in the brain, but for this it requires several initial processes. Our ears pick up the sounds and reay them to the  cxbrain for interpretation of these arbitrary set of symbols. These sounds make up the words used in the particular language. During the whole process, the auditory system is used rather effortlessly for the development of speech and language. Expression of language can be spoken or written. Speech as a form of spoken language gives enormous opportunities at personal, academic, social, occupational levels which is otherwise not possible.

## 1.2. SYSTEMS INVOLVED IN SPEECH PRODUCTION

The movements of the speech organs such as the tongue, lips, velum, and vocals folds – result in sound patterns that are perceived by the listener. Scholars (Eguchi and Hirsch 1969) hold the view that speech is more than audible sounds; otherwise we would not bother to distinguish the speech sounds from those of other bodily movements, such as clapping or breathing. Speech gains unique importance as the primary means by which language expresses ideas and thought in all human cultures. The end-product of speech is an acoustic signal that represents the communicative message of the speaker.

Speech has three major arenas of study: the physiologic arena (articulatory phonetics), the acoustic arena (acoustic phonetics), and the perceptual arena (auditory phonetics). An understanding of speech requires the study of each of these arenas in relation to the others.

### 1.2.1. The physiological arena of speech / articulatory phonetics

The physiological arena is identified physically with the speech apparatus, consisting of three major anatomic subsystems: respiratory, phonatory and articulatory. These subsystems work closely together in speech and are often highly interactive (Kent and Read 1992:1-7).

### 1.2.2. The respiratory subsystem

The respiratory subsystem consists of the trachea, lungs, rib cage, and various muscles. Besides providing for ventilation to support life, this system produces most of the aerodynamic energy of speech. The aerodynamic parameters are air volume, flow, pressure and resistance. Volume is a measure of the amount of air and is measured with units such as litre (l) or millilitre (ml). Flow is the rate of change in volume and is expressed in units such as liters/minute or millilitres/millisecond (ml/ms). Pressure is force per unit area and is commonly expressed in Pascals. In speech studies, pressure often is recorded with a different unit, such as centimeters of water (cm $H_2O$). Resistance is a variable that relates flow and pressure, according to ***Ohms' law***. Ohm's law may be expressed in the following alternative form:

Pressure = flow*Resistance

Flow = Pressure / Resistance

Resistance = Pressure / Flow

Flow is directly proportional to pressure and indirectly proportional to resistance. If resistance is held constant, an increase in air pressure will result in an increase in airflow. If air pressure is held constant, an increase in resistance will cause a decrease in airflow.

Speech is produced with a relatively constant lung pressure of about 6-10 cm $H_2O$ or about one K Pa (Kilopascal or 1000 Pascal's). A simple demonstration of this would be as follows: Dip a straw to a depth of 6 cm in water, filled glass, and blow into the straw until bubbles begin to form at the end of the water-immersed straw. This corresponds to a pressure of 6-10cm H2O. There is only a little loss of air pressure from the tiny air sacs of the lungs up to the larynx, so that this air pressure (subglottal) is approximately equal to the air pressure in the lungs. If the larynx or the upper airways were not closed, air pressure developed by the respiratory system would be immediately released through the open tract into the atmosphere. Speech is generated by valving or regulating the air pressure and flow is generated by the respiratory subsystem. Therefore, the respiratory subsystem is an air pump, providing aerodynamic energy for the laryngeal and articulatory subsystems. The speaker inspires air by muscular adjustments that increase the volume of the respiratory system. Lungs then release air by combinations of passive recoil and muscular activity, depending on the aerodynamic requirements. In most languages, speech is produced by expiratory air. Therefore, speech has to be interrupted whenever the speaker breathes in. The typical respiratory pattern for speech is a quick inspiration followed by a much slower expiration on which speech is produced. During rest breathing, the inspiratory and expiratory phases of a breathing cycle are nearly equal in duration, but for speech the expiratory phase is prolonged relative to the inspiratory phase.

**1.2.3. The laryngeal subsystem**

The larynx is situated at the top of the trachea and opens above. It consists of 3 paired cartilages and 3 unpaired cartilages and a number of muscles. Of particular importance are the vocal folds that adduct to close the airways or abduct to open the airway. The vocal folds are a multilayered structure, which are capable of generating various frequencies. The rate of vibration of the vocal folds basically determines the frequency, which is perceived as pitch.

The length of the vocal folds varies from 8 mm to 16 mm. The frequency generated by the vocal folds depends on the mass, length and tension of the vocal folds. In general, adult males have low frequencies and adult females have comparatively high frequencies. Children have higher frequencies than adult males and females. The frequency of vocal folds also undergoes changes from childhood to senescence. In young children the frequency is high and at puberty it is lowered. In old age frequency decreases in females and increases in males.

The larynx is very important for speech not only because it is the first valve, which converts the expiratory air stream (noise) into puffs (voice), but also because it valves the air moving in or out of the lungs. When the vocal folds close tightly, no air movement will occur; when they open air moves to the upper airways. Finally, a partial abduction of the vocal fold is used to generate whispering. Larynx contributes little to the phonetic differentiation of speech sounds. Certainly it differentiates voiced from voiceless sounds. But laryngeal functioning is highly similar within voiced/voiceless groups of sounds. The sounds are made distinct by the shaping of the articulatory system.

### 1.2.4. The articulatory subsystem

The articulatory system extends from the larynx up through the lips or nose. This is termed as vocal tract and includes the oral and the nasal tracts. Energy can be transmitted through the oral cavity or the nasal cavity. The articulators are movable structures and include the tongue, lips, jaw, and velum.

The articulators shape the vocal tract, which determines the resonance frequencies. Energy from the vibrating vocal folds passes through the articulatory system and activates the resonance system of the vocal tract. Changing the articulatory position and height changes the resonance frequencies and thus the phonemes are made distinct. Speech articulation is described in terms of articulatory contacts and positions. Vowels are described in terms of tongue position, tongue height, and lip shape. Thus the speech production requires the coordination of all the above four sub systems.

## 1.3. IMPORTANCE OF HEARING IN SPEECH AND LANGUAGE DEVELOPMENT

The function of hearing became the foundation stone upon which our intricate human communication system was constructed. The structure of language is unique to homosapiens, although experimenters have demonstrated that signed symbols and other visual language forms can be taught to chimpanzees. Scholars believe that the beginnings of true language are evidenced in these primates (Premack and Premack 1972, Savage-Rumbaugh et al. 1980). Other investigators insist that the conceptual system learnt by these primates is not linguistic; i.e. they (the primates) do not "think in words"; instead they use a signalization system that is far removed from the higher symbolization and syntax of human language (Terrace et al. 1979).

The human baby appears to be born with "preexistent knowledge" of language–specialized neural structures in the brain that waits for auditory experience with language to trigger them into functioning. These structures are dependent on auditory stimulation for their emergence, providing of course that other developmental factors are normal (Northen & Downs 1991:1).

The auditory-linked acquisition of language is further unique to human beings because it is a time-locked function related to early maturational periods in the infant's life. The longer auditory language stimulation is delayed, the less efficient will be the language facility. The reason is that critical periods exist for the development of biologic functions, and language is one of the biologic functions of humans (Chomsky 1965:203). The normal hearing child is continuously exposed to sounds from birth or even before birth. It is through this continuous auditory stimulation that a normal child attains speech. The task is however very difficult for a child born deaf. Thus hearing controls speech, and without hearing speech fails to develop. Hearing impairment has a marked effect on the child's ability to acquire speech (Northen & Downs 1991:1).

Hearing is essential for the natural development of speech and language, and communication is interfered with by the presence of a hearing loss. The oral communication skills of the hearing impaired children have long been of concern to educators of the hearing impaired, speech pathologists and audiologists, because the adequacy of such skills can influence the social, educational and career opportunities available to these individuals.

## 1.4. EFFECTS OF HEARING LOSS

Hearing loss in the children is a silent, hidden handicap. It is hidden because children, especially infants and toddlers, cannot tell us that they are not hearing well. It is a handicap because, if undetected and untreated, hearing loss in children can lead to delayed speech and language development, social and emotional problems, and academic failure (Northen & Downs 1991:2).

Skinner (1978; cited in Northen & Downs 1991: 8-9) listed a number of liabilities to a child's language learning when a mild hearing loss exists:

- **Lack of Constancy of Auditory Clues when Acoustic Information Fluctuates**

When a child does not hear speech sounds in the same way from time to time, there is confusion in abstracting the meanings of words due to inconsistent categorization of speech sounds.

- **Confusion of Acoustic Parameters in Rapid Speech**

Even the normal hearing child suffers from variations of speech occurring between speakers and even in the same speaker. Frequency, duration and intensity vary as a result of differences between speakers of age, sex and personality. The child with a mild hearing loss will be confused in language acquisition as a result.

- **Confusion in Segmentation Prosody**

The child with a mild loss may miss linguistic boundaries such as plural markers, tenses, intonation, and stress patterns. These factors are a prerequisite to meaningful interpretation of speech.

- **Masking of Ambient Noise**

According to French and Steinberg (1947), the normal child requires a signal-to-noise ratio of +30 dB at 200-6000 Hz in order for speech learning to take place. It is rare in our modern culture for such a ratio to be present. Public school classes have no better signal-to-noise ratio than +12 dB. A child with even mild loss is handicapped in such situations.

- **Breakdown of Early Ability to Perceive Speech Sound**

Almost at birth infant begins to learn to discriminate speech sounds. Studies have shown that at 1-4 months the infant can discriminate between most of the English speech sound pairs. By 6 months the infant recognizes many of the speech sounds of language and is making ongoing cataloging of speech sounds as discussed. If these sounds are not perceived early, due to a hearing loss, learning can be impeded.

- **Breakdown in Early Perception of Meanings**

Often, during ordinary speech, the normal listener misses some unstressed or elided words or sounds that he or she is able to fill in by context. But when an infants hearing loss results in missing many of these soft or inaudible sounds, there is confusion in word naming, difficulty in developing classes of objects, and misunderstanding of multiple meanings.

- **Faulty Abstraction of Grammatical Rules**

When short words are soft or elided as they often are, it becomes more difficult for a slightly hearing impaired child to identify the relationships between words and to understand word order.

- **Subtle Stress Patterns Missing**

The mild conductive hearing loss is worse in the low frequencies than in the high frequencies. The emotional content of speech, its rhythm, and its intonation are communicated through the low frequencies. When these are lost, the emotional content of speech is confused – a condition that would impair learning of the speech milieu.

Developing an auditory feedback loop for self-monitoring of speech production underlies intelligible speech. Children with congenital or early reduced or defective hearing sensitivity do not cause one specific kind of communication problem. The effects of a hearing loss depend primarily on its degree, configuration, and stability and on the age of onset. In the hearing-impaired child the extent and type of early training; the type and timing of amplification; visual, emotional, and intellectual factors; and family attitude also influence language development. Age of onset of the hearing loss is an especially important factor in language development. A child who sustains significant hearing loss after he or she has acquired language will have a less severe linguistic deficit than the child whose hearing loss is present at birth or develops within the first few months of life. The major effect of a hearing impairment is the loss of audibility for some or all of the important acoustic speech cues. Elderly persons with hearing loss typically complain of their inability to understand speech. Conversation may be loud enough for them, but they cannot understand the words because they miss part of the acoustic information clues (Northern & Downs 1992:13).

Angelocci (1962) noted that hearing impaired speech is characterized by abnormal control over duration and fundamental frequency. In particular, duration of words or sentences often sees excessively long and pitch contour over individual words are excessively too high, too monotonous or simply ‘inappropriate’.

Onset of hearing impairment will have difficulty developing this auditory feedback mechanism, unless appropriate early amplification and training are implemented. Greater access to the speech signal results in increased opportunities to develop and use the auditory feedback loop. However, even children with minimal available hearing can learn to self monitor their speech and develop good articulation and voice quality.

Auditory feedback is important to realize self monitored speech perception, rather than perception of pure tone thresholds (Ross et al 1991:432-434).

Hearing loss of any degree or configuration will interfere with the development of speech perception categories. Reduced sensitivity of hearing at high frequency region negatively affects speech perception, making it more difficult for the child to learn to use acoustic cues of speech. A child with normal hearing is consistently exposed to an audible, clear speech signal despite interference from noise and distance, and so effortlessly acquires auditory perceptual skills. The hearing impaired child must try to cope with the distortion produced by the loss and the amplification while attempting the difficult, but not impossible, task of categorizing phonemes according to their acoustic features. Early identification of auditory management will enable the child to learn to use whatever multiple cues are available through amplification. This is especially true in the case of cochlear-implanted children who receive it earlier.

Developing an auditory loop for self-monitoring of speech production underlies intelligible speech. Children with congenital or early onset of hearing impairment will have difficulty developing this auditory feedback mechanism, unless appropriate early amplification and training are implemented. Greater access to the speech signal results in increased opportunities to develop and use the auditory feedback loop. However, even children with minimal available hearing can learn to self-monitor their speech and develop good articulation and voice quality. Auditory feedback is important to realize self-monitored speech perception, rather than perception of pure tone thresholds (Ross et al 1991:432-456)

Young cochlear implant or hearing aid users who speak relatively well typically have good speech recognition skills. However, some children who have good speech recognition skills do not necessarily acquire good speech production skills. Children who have profound hearing impairment also attend to visual speech information to acquire the sounds and words of their speech community. That is, children are more likely to produce "visible" phonemes and words correctly than "non-visible" "phonemes and words". Children who have profound hearing impairment and received cochlear implantation may become less reliant on visual information for acquiring speech and more reliant on auditory information. However irrespective of the type of device, the ultimate goal of the speech pathologist is to achieve speech intelligibility with in an acceptable range. Hence, there is need to assess the function of the newly emerged bioelectrical device.

## 1.5. AURAL REHABILITATION AND REHABILITATION TECHNOLOGY FOR THE HEARING IMPAIRED

Aural Rehabilitation refers to services and procedures for facilitating adequate receptive and expressive communication in individuals with hearing impairment. Selection of amplification device is a crucial component of aural rehabilitation process (Katz 1994: 638).

Rehabilitation Technology refers to systems that improve signal to noise ratio by transmitting amplified signal directly to the listener, transforms sound into visual or tactile signal. Rehabilitation technology devices are also called assistive listening devices.

**Categories of Assistive Listening Devices (ALDs)**

Assistive listening devices are broadly classified as:

a. Sound enhancement technology

b. Television enhancement technology

c. Telecommunication technology

d. Signal alerting technology

### 1.5.1. Sound Enhancement Technology

These devices transmit sound directly from the source to the hearing impaired listener. e.g individual hearing aids, group hearing aids (Induction loop system, hard wire system, Infrared system and FM system). These systems are used by hearing impaired in different listening situations like in Speech and language training, class rooms, theatres, family environment, television viewing, work place, conference halls, public places, etc.

**Examples for sound enhancement technology**


**Fig. 1.1. Body level and behind the ear hearing aid**

**Ref: http:\\images.google.com/images**

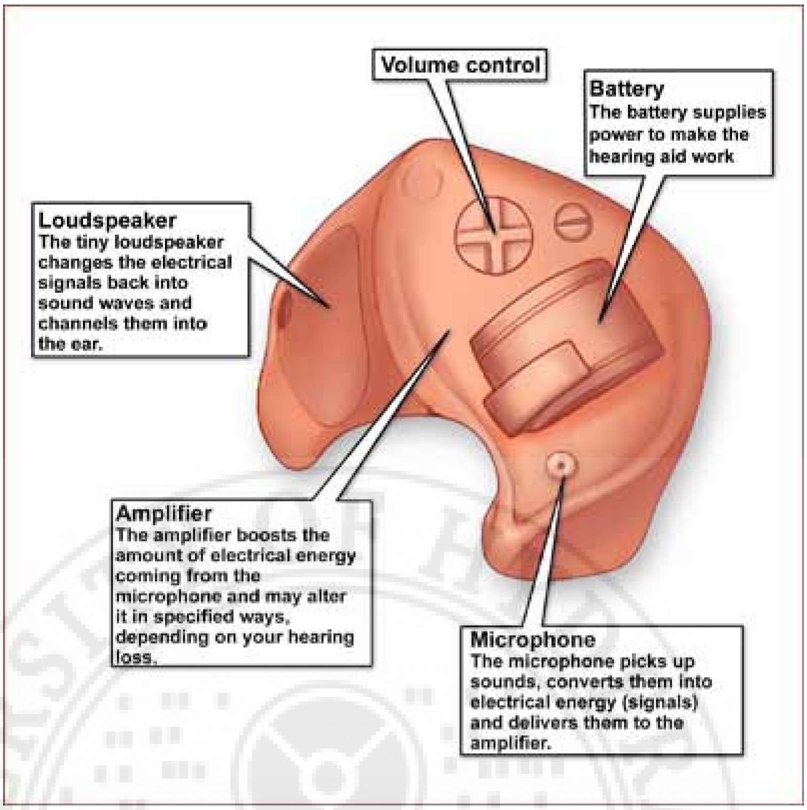



**Fig. 1.2. In the ear hearing aid**

**Ref: http://images.google.com/images.**

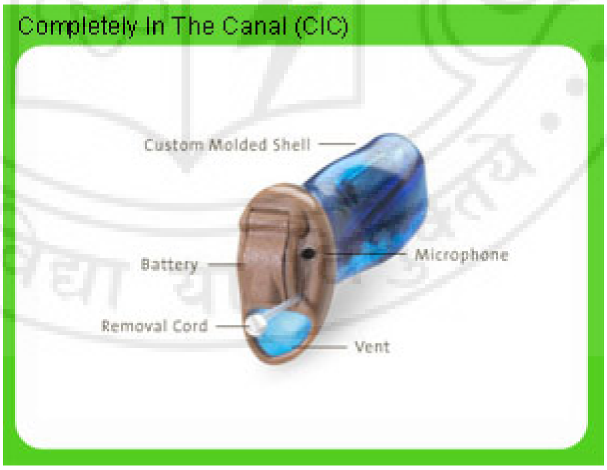
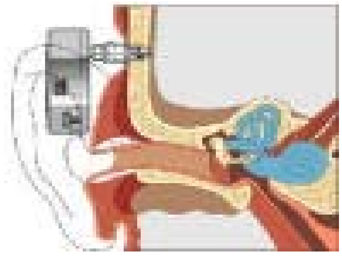



**Fig. 1.3. Completely in the canal**

**Ref: http://images.google.com/images.**

## Implants



Cochlear Implant

Bone anchored hearing aid

**Fig. 1.4. Cochlear Implant and Bone anchored hearing aid**

**Ref: http://images.google.com/images.**

### 1.5.2. Television Enhancement Technologies

These include devices used to improve perception of televised signal. Signal is transmitted to the listener via a, infrared or frequency modulation system. Closed captioning is also used for individuals with severe to profound hearing loss or for those with poor speech recognition ability.


Use of FM System

Tele captioning

**Fig. 1.5. Television enhancement technologiess**

**Ref: http://images.google.com/images.**

### 1.5.3. Telecommunication Technologies

Activation of T-switch on hearing aid is still used as an alternative way for hearing aid users to understand telephonic conversation. Telephone amplifiers, like amplified handsets, in-line amplifiers, and portable strap on amplifiers are also used for better telephonic signal for hearing impaired. Visual systems, like text telephone or teletypewriters are been used in other countries for hearing impaired with poor speech recognition ability.

TELEPHONE AMPLIFIER

TEXT TELEPHONE

**Telecommunication technology**

TELEPHONE ALD

**Fig. 1.6. Telephone amplifier and text telephone**

**Ref: http://images.google.com/images.**

### 1.5.4. Signal alerting technology

Auditory activities of daily living, like telephone ring, doorbell, baby crying, waking up alarm may not be heard by hearing impaired by using any amplification device, so certain signal alerting devices are available for these special needs, for example pillow vibrator for alarm, vibrotactile wristband for telephone ring and baby cry, visual (light) signal for door bell and vibro tactile wrist watches


**Fig. 1.7. Signal alerting devices**

**Ref: http://images.google.com/images.**

## 1.6. Hearing Aids

Hearing aids are electronic or battery-operated devices that can amplify and change sound. A microphone receives the sound and converts it into sound waves. The sound waves are then converted into electrical signals, which are amplified and converted back to sound waves.

### 1.6.1. Operation of hearing aid

A microphone receives the sound and converts it into sound waves. The sound waves are then converted into electrical signals, which are amplified by the amplifier and converted back to sound waves at the level of the receiver. Hearing loss affects people in different ways; so a hearing impaired person needs to get the right device for himself/herself.

### 1.6.2. Types of Hearing Aids

**Body level Hearing Aids**

The body of the instrument is worn on the body. It 'hooks' over dress. It is attached via wire with a receiver tubing to an earmould, which holds it in place in the ear.

**Fig. 1.8. Body worn hearing aid**

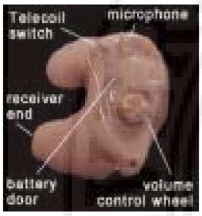
**Ref: http://images.google.com/images.**

**Behind the Ear (BTE)**

The body of the instrument is worn behind the ear. It ‘hooks’ over the pinna. It is attached via plastic tubing to a nearmould, which holds it in place in the ear.

**Fig. 1.9. Behind the ear hearing aid**

**Ref: http://images.google.com/images.**




**In the Ear (ITE)**

The complete hearing aid is in the ear or ear canal. The hearing aid is housed in a hard plastic shell which is often custom made by taking an ear impression.

**Fig. 1.10. In the ear hearing aid**

**Ref: http://images.google.com/images.**

**Completely in the canal (CIC) Hearing Aids**

These are "invisible" hearing aids, that is, hearing aids that fit completely within the ear canal, so they are not seen even when someone is looking directly into the ear.

**Fig. 1.11. Completely in the canal hearing aid**

**Ref: http://images.google.com/images.**

**Spectacles type**

**In the spectacle type** the hearing aid components are incorporated with in a spectacle frame. It is useful for persons who require glasses along with hearing aids.

**Fig. 1.12. Spectacle type of hearing aid**

**Ref: http://images.google.com/images**

Hearing aids are distinguished by their technology or circuitry. In early days hearing aid technology involved vacuum tubes and large heavy batteries. Today there are micro chips and digitized sound processing used in hearing aid design.

At present, two technologies are in vogue, the analog and digital technology. The simplified block diagrams of analog and digital hearing instruments are shown in figures 1 and 2 respectively. The conventional analog hearing instruments consist of a microphone, a pre-amplifier, a mean processor, an amplifier and a receiver. During analog processing, the microphone transduces the acoustic input signals into electrical input signal. The pre-amplifier amplifies the electrical input signals and the mean processor spectrally shapes the frequency response. After spectral shaping, the amplifier amplifies the electrical signals, which are then transduced by the receiver into acoustic output signals (Holube and Velde 2000:285-322).

In analog hearing instruments, both the acoustic and electrical signals are continuous in time and amplitude. Between any two moments in time, there are an infinite number of instants when the signal exists and there are an infinite number of possible amplitude values of the signal at that single moment. This technology is least expensive and can be appropriate for different types of hearing aids.

Analog hearing instruments may be digitally programmable; however signal amplification is still accomplished via analog means. Digitally programmable analog hearing instruments allow settings such as frequency response and gain to be manipulated digitally using a computer or hand-held programmer, however, digitally programmable analog hearing instruments do not provide true digital signal processing .

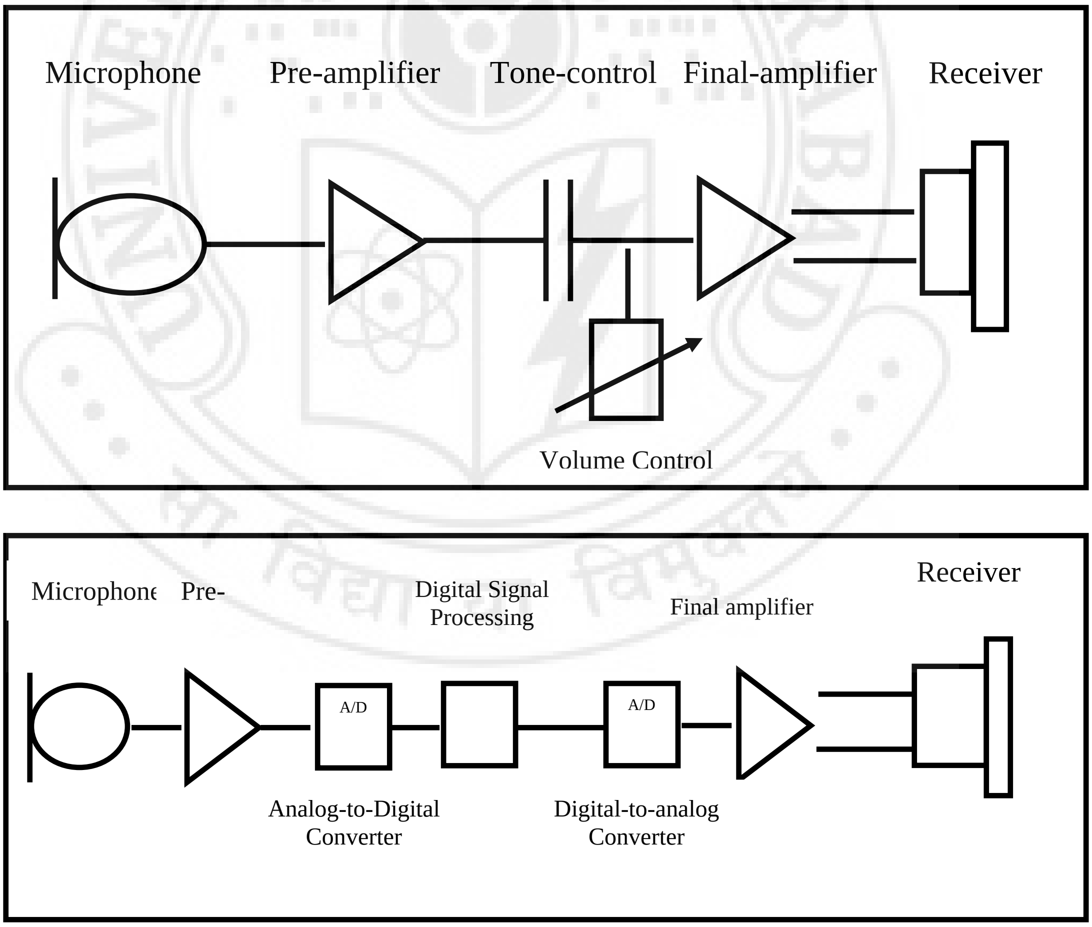



**Fig. 1.13. Simplified block diagram of digital hearing instrument.**

**Ref: http://images.google.com/images.s**

Research into digital processing began in the 1960s within Bell laboratories. Because of the slow speed of computer then, the necessary calculations could not be performed quickly enough. It was not until the late 1970s that the computers were fast enough for the output to be synchronized with the input and it was not until the 1980s that power consumption and size were decreased sufficiently to make wearable hearing aids. But it was not a commercial success. Later almost after 10 years in 1996, the first entirely digital behind the ear (BTE) hearing aids, in which digital signal processing (DSP) was used, became commercially available (Dillion 2001:16-17).

Digital programmable hearing aids have all the features of analog programmable hearing aids but use digitized sound processing to convert sound waves into digital signals. Digital hearing instruments consist of a microphone, a pre-amplifier, an analog-to-digital converter, a digital signal processor, a digital-to-analog converter, an amplifier and a receiver. During digital signal processing, the microphone transduces the acoustic input signal into an electrical input signal. The electrical input signals are amplified by the pre-amplifier and are digitized by the analog-to-digital converter. The digital signals are spectrally shaped by the digital signal processor and are converted into analog electrical signals by the analog-to-digital converter. The electrical signals are amplified by the amplifier and transduced into an acoustic output signal by the receiver (Lybarger and Lybarger 2000:1-35).

In digital hearing instruments, neither the acoustic nor the electrical signals are continuous in time and amplitude. The input signal is sampled at discrete points in time and each sample is truncated or rounded to a specific quantity within a discrete set of values. The digital technology is very expensive, but it allows improvement in programmability, greater precision in fitting, management of loudness discomfort, control of acoustic feedback and noise reduction.

### 1.6.3. Advantages of hearing aids

The client will have greater control on the device as he can try different hearing aids to see which one is qualitatively better, so that he can purchase a new device every couple of years. As the costs of accessories are minimal the client can afford to buy new device after a short gap. There will be greater flexibility and accessibility for repairs and client can adjust controls on these devices. These are easy to maintain and retain the residual hearing for later use of optimal hearing aid technology if any for those with severe hearing loss it may be great ease in discriminating low frequency sounds, e.g. /m/, /e/ and may better enjoy bass sounds of music.

### 1.6.4. Disadvantages of hearing aids

The hearing aids provide very less amplification in high frequency region. Ear-moulds and their acoustic feedback issues may be repetitive, time consuming and aggravating. Loud noises are bothering for those using linear amplification because as the level of input sound to the microphone of the hearing aid increases, output sound also increases in the same proportion. Hearing aids assist moderate to moderately severe and to some extent to severe hearing impaired persons but does not benefit profoundly hearing impaired persons due to poor aided responses. Hence hearing aids for those with severe to profound loss need to be fitted carefully, assertively and with proper monitoring.

## 1.7. Cochlear Implants

A cochlear implant is a technologically advanced medical device that helps adults and children who have bilateral severe to profound hearing loss and are not receiving satisfactory benefit from hearing aids or tactile devices to understand speech. An implant does not restore normal hearing. Instead, it can give a deaf person a useful representation of sounds in the environment and help him or her to understand speech.

### 1.7.1. Parts of the Cochlear Implant

The implant is surgically placed under the skin behind the ear. These are two basic parts of the device, i.e. external and internal.

**External device**

The components which are worn outside the body constitute the external device. It consists of a microphone which picks up sound from the environment, speech processor which selectively filters sound to prioritize audible speech and sends the electrical sound signals through a thin cable to the transmitter, a transmitter, which is a coil held in position by a magnet placed behind the external ear, and which transmits the processed sound signals to the internal device by electromagnetic induction.

**Internal device**

The components which are surgically implanted inside the ear constitute the internal device. A receiver and stimulator secured in bone beneath the skin, which converts the signals into electric impulses and sends them through an internal cable to electrodes, an array of up to 22 electrodes wound through the cochlea, which send the impulses to the nerves in the scala tympani and then directly to the brain through the auditory nervous system.

### 1.7.2. How does a Cochlear Implant Work?

A cochlear implant is very different from a hearing aid. Hearing aids amplify sounds so they may be detected by damaged ears. Cochlear implants bypass the damaged portions of the ear and directly stimulate the auditory nerve. Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as sounds. Hearing through a cochlear implant is different from normal hearing and takes time to learn or relearn. However, it allows many people to recognize warning signals, understand other sounds in the environment, and enjoy a conversation in person or by telephone.

### 1.7.3. Candidacy for Cochlear Implant

There are a number of factors that determine the degree of success to expect from the operation and the device itself. Cochlear implant centers determine implant candidacy on an individual basis and take into account a person's hearing history, cause of hearing loss, amount of residual hearing, speech recognition ability, health status, and family commitment to aural habilitation/rehabilitation.

**A prime candidate for cochlear implant**

- having severe to profound sensorineural hearing impairment in both ears, having a functioning auditory nerve,
- having lived a short amount of time without hearing (approximately 70+ decibel loss, on average),
- having good speech, language, and communication skills, or in the case of infants and young children, having a family willing to work toward speech and language skills with therapy,
- not benefiting enough from other kinds of hearing aids,
- having no medical reason to avoid surgery,
- living in or desiring to live in the "hearing world"
- having realistic expectations about results,
- having the support of family and friends.

### 1.7.4. Types of Cochlear Implants

A channel is a pathway through which information is transmitted from the implant to the auditory nerve. There are two types of channel system in Cochlear implants.

**Single channel Cochlear Implant**

A single channel system generally implies the insertion of a single electrode to which the signal is delivered through one pathway. The early single channel implants provide electrical stimulation at a single site in the cochlea using a single electrode. These implants are of interest because of their simplicity in design and their low cost compared to multi channel implants e.g. House/3M single channel implant, Vienna/3M single channel implant.

**Multi-channel Cochlear Implant**

In these implants, the signals are transmitted through several independent channels. They provide electrical stimulation at multiple sites in the cochlea using an array of electrodes, thereby exploiting the place mechanism for coding frequencies. The principal of these implants is, larger the number of electrodes, finer is the place resolution for coding frequencies. However frequency coding is also dependant on the number of surviving neurons e.g. Nucleus multi channel cochlear implant system, Med-El cochlear implant, Clarion multi channel implant, All Hear cochlear implants.

### 1.7.5. Contra-indication for Cochlear Implant

Meningitis, labyrinthitis ossificans, advanced otosclerosis and neuro fibromatosis II are contradications for cochlear implant. Apart from these hearing impaired individuals associated with mental retardation, psychosis and organic brain dysfunctions, are not good candidates for Cochlear Implant.

Lack of speech production data as a function of devices and degree of hearing loss is one of the difficulties faced by the clinician while evaluating the speech production skills of the hearing impaired. Acoustic research on the speech production of the cochlear implant and hearing aid users speech is one of the most direct ways to determine the benefit from audtory prosthesis. In the recent years there has been rapid increase in the fitting of the cochlear implant for both prelingual and postlingual hearing impaired individuals, irrespective of age. Neverthless, hearing aids for the hearing impaired is still preferred in developing country like India.

In order to develop more effective speech training procedure for children with hearing impairments, it is necessary to know their speech deviation from that of the normally hearing children and the effect of various errors and abnormal speech patterns on the intelligibility.

An acoustic analysis of speech is a method to check the speech production ability, and it is an objective description of the finer aspects of the speech. This will give information regarding the physical and temporal aspects of speech. This, in turn, helps in categorizing the patterns of speech of an individual as correct or incorrect production.

The review of literature shows that the acoustic analysis is an important measure in terms of diagnostic and intervention point of view, but there are very view studies on the hearing impaired speech with reference to the Telugu language.

The information obtained from the acoustic analysis will help in making use of the advances in technology with maximal effectiveness in facilitating the oral production skills of the persons with hearing impairment

The present study aims at finding the temporal, physical analysis of speech of Telugu speaking individuals who use hearing aids and cochlear implants with that of normal hearing peers.

**1.8. Need for the Study**

- Research on acoustic analysis of speech of the children with hearing-impairment will help to determine which acoustic correlates are impaired and to what extent. It also acts as a precursor to plan the therapy accordingly. This is, in turn, improves speech intelligibility.
- Acoustic research on the speech of the children with hearing-impairment using hearing aids and cochlear implants helps to determine how the affected acoustic characteristics correlate with intelligibility.
- No study so far has investigated all these acoustic aspects systemically in the children with hearing-impairment using hearing aids and cochlear implants in Telugu language.

## 1.9. AIM OF THE STUDY

This study analyzes the speech characteristics of Telugu speaking children with normal hearing, children with hearing impairment using hearing aids and cochlear implants, spectrographically in terms of average fundamental frequency (F0), formant frequencies (F1, F2 and F3), bandwidth characteristics (B1, B2 and B3), vowel duration and word duration of both long and short vowels in VCV syllable production.

- **The following are the objectives of this study:**

a) To evaluate and compare acoustically, the speech of children with normal hearing and children with hearing impairment who are using hearing aids.

b) To evaluate and compare acoustically, the speech of children with normal hearing and children with hearing impairment who are using cochlear implants.

c) To evaluate and compare acoustically, the speech of children with Hearing Impairment who are using cochlear implants and hearing aids.

### 1.10. HYPOTHESES

There is no significant difference in terms of fundamental frequency (F0), formant frequencies F1, F2, F3, bandwidth (B1, B2, B3) vowel duration and word duration of VCV syllable productions between

a) Children with normal hearing versus children with hearing impairment using hearing aids.

b) Children with normal hearing versus children with hearing impairment using cochlear implants.

c) Children with hearing impairment using hearing aids versus children with hearing impairment using cochlear implants.

# CHAPTER –II

# REVIEW OF LITERATURE

## 2.1. INTRODUCTION

Normal speech production requires auditory reception for monitoring of speech (Monsen 1974). Auditory feedback is particularly important in the early stages, in that, it allows the child to develop the same speech characteristics as those around him. Normally, attempts to produce speech follow with the development of the phonemic system and are the result of social pressures upon the child. Naturally, he wants to take advantage of the power of speech, and he can do this only by speaking to himself. His first word is amply rewarded by the approval and attention of his mother and other adults and it is not long before his speech productions are reinforced by getting what he wants or at least evoking a verbal response. This is the period during which the mother acts as interpreter between the baby and the world, and there is continuous pressure on the child to shape his articulation so as to bring it more and more in line with that of adults. If he is able to do so, it is just one more result of his use of acoustic cues. During the learning period, the child is trying to reproduce the sound patterns that he receives from adult speakers, primarily his mother. "It takes considerable practice and hence time for this process of auditory stimulation, to cause an adaptation to adult like speech to take place in a normal child" (Ross and Giolas 1978: 1-14). The task is however very difficult for a child who is born deaf.

Thus hearing controls speech, and without hearing, speech fails to develop. Hearing impairment has a marked effect on the child's ability to acquire speech (Whetnall and Fry 1964: 24).

Hearing impairment has a marked effect on a child's ability to acquire speech. This effect is related to the extent and type of hearing loss; thus the child who is profoundly hearing impaired, is most likely to have difficulty in both understanding speech and producing speech that is intelligible (Stark 1979: 229). One of the most devastating effects of congenital hearing loss is that normal development of speech is often disrupted. As a consequence, most hearing impaired children must be taught the speech skills that normal hearing children readily acquire during the first few years of life. Although some hearing impaired children develop intelligible speech, many do not (Osberger and McGarr 1982).

The 2002 sample survey conducted by the NSSO has estimated that about 1.8 percent of the population of the country suffered from physical and mental disabilities that include visual, speech, hearing, locomotor and mental disabilities. There are approximately 18.49 million disabled persons in the country. Estimated number of disabled persons by type of disability and sex separately for rural and urban India is given below (in lakhs): -

**Hearing Disability**

| Rural | | | Urban | | |
|---|---|---|---|---|---|
| Male | Female | Persons | Male | Female | Persons |
| 12.5 | 11.17 | 23.69 | 3. 62 | 3.31 | 6.93 |

The report brings out that there has been a significant decline in the prevalence and incidence of disability over the last decade. Prevalence and incidence rates of disability for the years as per the NSSO's surveys carried out during these years 1981, 1991 and 2002 are given below: -

**Hearing Disability**

| 1981 | | 1991 | | 2002 | |
|---|---|---|---|---|---|
| Prevalence | incidence | Prevalence | incidence | Prevalence | incidence |
| 573(rural) | 19 | 467 | 15 | 342 | 8 |
| 390(urban) | 15 | 339 | 12 | 254 | 7 |

Hearing loss of various degrees, such as mild to profound; have a significant effect on speech and language development (Nicolosi et al. 2004). The effect of degrees of hearing loss/severity on speech and language has been provided is as follows:

| Category | Handicap |
|---|---|
| 15 – 25dB | No significant delay in speech and /or language; may adversely affect auditory perceptual abilities. |
| 26 – 40 dB | Fair or distant speech may be difficult |
| 41 – 55 dB | Conversational speech can be understood at a distance of 3 to 5 feet; as much as 50% of class discussions may be missed if voices are faint or not in line of vision; vocabulary may be limited and Misarticulations may be present; language skills are mildly affected; reading and writing skills may be delayed. |
| 56 – 70 dB | Group discussion will be difficult to follow; language usage and comprehension may be deficit and confused; speech can be understood only if it is loud; speech and language are delayed; early speech is unintelligible. |
| 71 – 90 dB | voices are heard only from a distance of about one foot from the ear; environmental sounds and vowel sounds may be discriminated, but many consonants will be distorted and may not develop spontaneously if the loss is present. |
| >90dB | may hear some loud sounds, but is more aware of vibrations than tonal patterns; speech and language are defective and will not develop spontaneously if loss is present one year of age. |

The Success of Aural Rehabilitation depends on early identification, early intervention and appropriate selection of amplification devices. In India, currently there are two types of amplification devices available. They are hearing aids and cochlear implants.

Cochlear implantation is a rapidly emerging rehabilitation procedure in recent years. The provision of cochlear implantation has enormous potential rewards for profoundly hearing impaired children. Conceivably, the exposure to sound via electric stimulation to auditory nerve endings in the cochlear could change the entire life of the hearing impaired youth. Enhanced speech perception through this bioelectrical device could dramatically influence the speech and language development of hearing impaired children.

Lack of speech production data as a function of device and degree of hearing loss is one of the first difficulties faced by clinicians while evaluating the speech production skills of the hearing impaired. It is difficult to predict the acquisition of speech features in the absence of normative data. In order to fill this gap, several attempts have been made to document the changes in speech production. Investigators, researchers and examiners have been using some common approaches to estimate the speech production skills in hearing impaired children. Amongst those, the most commonly used are as follows (Ravindar 2006).

1. Test battery approaches, which composed of instruments, were typically constructed to measure the progress in speech production skills of hearing impaired and normal hearing children.

Instruments included for the assessment

- Fundamental Speech Skill test
- Phonetic task evaluation
- The Central Institute of Deaf (CID) inventory
- The phonetic level speech evaluation

2. Phonetic transcription system, which was developed to categorize the speech samples uttered by hearing impaired children (Carney et al. 1990 and Tobey 1991). Investigators have explored the use of metaphonological transcription used to code the pre-speech vocalization and speech utterance.

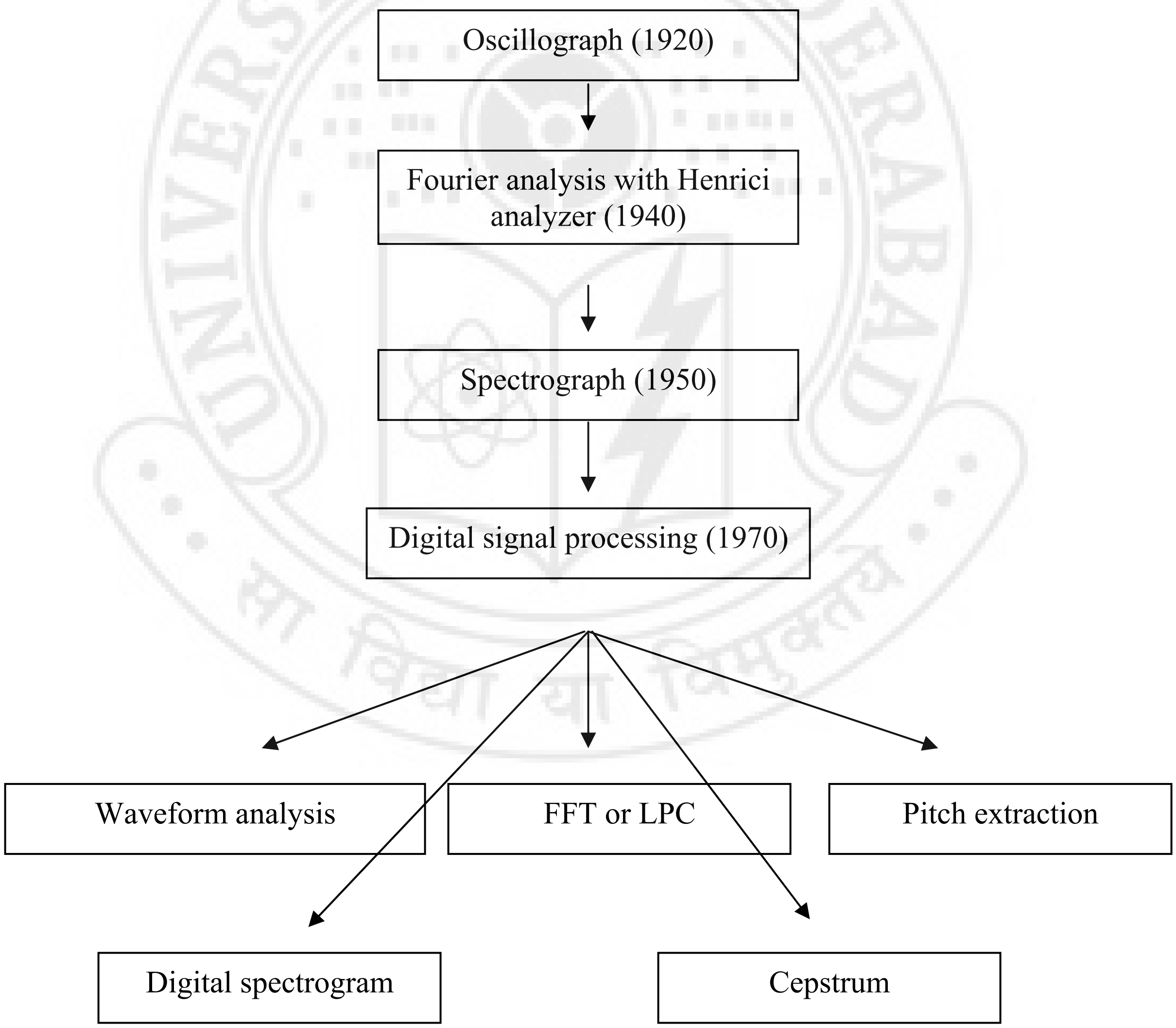
3. Spoken communication rules systems, which are used to estimate the speech production development by analyzing the speech and; language parameters in one's speech such as pragmatics, semantics, syntax, morphology and phonology.

4. Acoustic analysis of speech production of both children and adults in normal and as well as in disordered population. This approach uses the present day objective technology to assess the acoustic characteristics of obtained speech samples in order to determine the spectral and temporal features of consonants and vowels.

As the present study aims at understanding the speech characteristics of hearing impaired children who uses hearing aids and cochlear implants with that of normal hearing peers, the literature on the speech production is reviewed in terms of various approaches to acoustic analysis of speech, segmental errors, acoustic features and intelligibility of speech.

## 2.2. DIFFERENT APPROACHES FOR SPEECH ANALYSIS

The flow chart shows the historic development in the acoustic analysis of speech. It shows the basic techniques for the acoustic analysis of speech, starting with older non-digital or analog methods and modern computerized methods in analyzing speech signal (Sairam 2005: 8).




**The flow chart shows the historic developments in the acoustic analysis of speech.**

### 2.2.1. The Oscillogram

The acoustic analysis of speech began with oscillograms (waveforms, or graphs of amplitude over time) of speech sounds. Vowels were selected more often for analysis, as it is relatively easier to analyze them compared to most of the consonants. The sounds to be analyzed were represented oscillographically as pressure variation over time.

Representing speech sounds in a permanent manner was a technical challenge as these acoustic events were of very short duration. The development of oscillograph made it possible to derive fairly accurate waveforms of sustained vowels. However the waveforms were not sufficient enough to describe some of the important differences among vowels. This led to the generation of spectral representations plots of signal energy versus frequency.

Spectral analysis of speech is similar to the spectral analysis of light. In the acoustic analysis of speech, sound is broken into components of different frequencies; i.e., breaking the complex sound pattern into simpler constituents (Sairam 2005: 8-9).

### 2.2.2. The Henrici Analyzer

Henrici Analyzer is one of the earliest tools for spectral analysis. It is a mechanical device consisting of the five rolling integrating units (glass spheres) and the procedure of analysis is as follows:

a. Obtain the oscillogram of the waveform.

b. Select a representative portion, typically in the middle of the wave, and enlarge it with a projector.

c. Trace the enlargement on a plain white surface.

d. Trace the enlarged waveform with the Henrici Analyzer.

e. Calculate the values of the amplitude and phase relationships from dial readings associated with the glass spheres.

f. Plot the pressure (in dB) against frequency to obtain spectral (harmonic) analysis.

The procedure performs a harmonic analysis and assumes that the sound to be analyzed is essentially periodic. But since speech is quasiperiodic in nature, Henrici Analyzer gives an inaccurate picture of the energy distribution in speech sounds and further the analysis procedure was tedious (Sairam 2005: 9).

### 2.2.3. Filter Bank Analysis

Filtering is yet another approach to speech analysis. A filter is a frequency selective transmission system, i.e. like an acoustic window that allows some energy to pass while blocking other energy. Figure 2.1 shows the application of a bank of filters to the analysis of speech. The energy of the signal is effectively divided into frequency bank by the filter bank. Each filter passes only the energy in its frequency band. Indicating devices at the output of each filter can be used to display the energy in specific frequency regions. A filtering analysis of speech determines the amount of energy in specific frequency regions. The detail of the analysis depends on the number of filters used and their bandwidths. The bandwidth of a filter is the frequency range in which it passes energy. Usually, larger bandwidths would be used to analyze the entire frequency range of interest (e.g. 0-5kHz) with less than 25 filters input:

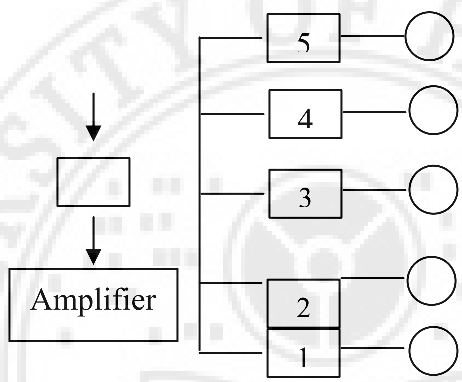



**Figure 2.1: Schematic diagram of filter bank analysis.**

A variable band pass filter is another analysis technique, which makes use of an idea of an adjustable filter that can act like any of the filters shown in figure 2.1. The signal to be analyzed is fed repetitively through the variable band-pass filters as its settings are adjusted to different frequency regions (Sairam 2005: 9-10).

### 2.2.4. The Spectrograph

Sound spectrograph, developed in the 1940s incorporating variable band-pass filter, provided major advantages to the study of speech. A relatively faster analysis using spectrograph made it possible for the scientists to collect more extensive data. It also provided a better delineation of the energy concentrations in speech. Further, the display of the running short-term spectrum called spectrogram enabled scientist to visualize change of energy concentrations in time. In a spectrograph, the signal to be analyzed is recorded on a magnetic drum that allows a continuously repeating playback of the signal. The magnetic drum can be linked to a tape loop. The signal then modulates a variable carrier frequency in a process called heterodyning because it is more practical to sweep the signal to be analyzed past a fixed filter than to analyze the original signal with a variable filter. In conventional spectrography, two filters bandwidths are used. The wide-band filter has an analyzing bandwidth of 300Hz, and the narrow-band filter has an analyzing bandwidth of 45 Hz. Some spectrographs have other bandwidth selection, such as 90 Hz and 600 Hz.

The complete process of recording through analysis involves the following steps:

a. The speech sample is transduced by a microphone so that air pressure variations of the acoustic signal are put into the form of voltage variations.

b. The electrical signal is then converted to an electromagnetic signal for storage on the magnetic drum of the spectrograph.

c. The stored magnetic pattern is converted back into an electrical signal for analysis as a spectrogram.

d. The signal is filtered so that the energy in various frequency regions can be determined.

e. The current of the electrical signal is amplified and fed to a marking stylus.

f. As the current flows from the stylus through the specially treated paper, a localized burning of the paper occurs. The burning produces a blackening of the paper in proportion to the current flowing through the stylus.

The conventional spectrogram is a three-dimensional display of time, frequency and intensity. Time appears on the horizontal axis running from left to right. Frequency is plotted on the vertical axis, increasing from bottom to top. Intensity is represented by the blackness of the pattern (Sairam 2005: 10-11).

### 2.2.5. Digital signal processing of speech

Introduction of digital computer challenged the dominance of the spectrograph. Further, continuous refinement of computers (hardware) and analysis programs (software) increased its dominance over traditional spectrograph.

The basic process in digitization is to convert a continuous (analog) signal to a digital (discrete) representation. The digital representation is a series of numbers. When an analog signal such as an acoustic waveform is digitized, two operations are performed simultaneously. The first is the discretization in time, i.e. analog waveform is sampled at certain time points, usually periodically spaced. The periodic spacing is reflected in the sampling rate, which specifies the regularity of the sampling process. A sampling rate of 10 kHz means that the original analog signal is sampled 10,000 times per second. The second operation is a discretization of signal amplitude. This operation called quantization represents the continuous amplitude variations of the signal as a discretization is therefore one of quantization. Sampling and quantization are the essence of digitization (Sairam 2005: 12).

**Filtering**

Pre-emphasis filtering is the first step in digital processing. Pre-emphasis refers to boosting of amplitude of high frequency components of the signal relative to the low frequency components. Pre-emphasis is often necessary, because most of the energy in speech is in the low frequency region. There are two ways in which pre-emphasis is accomplished. One is the use of a filter that provides a 6dB/ octave increase to the speech signal above some break point frequency, fb, where fb usually is chosen to be above 100 Hz but less than 1000 Hz. The specification of 6dB/octave means that for every doubling of frequency above the breakpoint, the energy increases by 6 dB. The second way to achieve pre-emphasis is by differentiating the input. This operation can be performed by the computer and is expressed by the following formula:

Y (n) =x (n)-ax (n-1)

Where x (n) is a sample of the signal at time n,

Y (n) is the first- differenced signal, and

A is a constant of multiplication

The pre-emphasized signal is fed to pre-sampling filter which is a low pass filter designed to reject energy above the highest frequency of interest. This filtering procedure is based on Nyquist's sampling theorem which states that the samples needed to represent a signal is twice the highest frequency of interest in the signal. For example, if you are interested in analyzing the speech signal up to 10 KHz, this frequency is the upper limit of analysis and the low-pass filter would be selected to reject energy above this frequency. Filters have various characteristics that define their operation and two of the characteristics are the pass-band ripple and the stop-band attenuation. The pass-band is the band of frequencies in which energy is passed with minimal loss. The stop band attenuation is a measure of the energy that remains in the region of the filter where energy transmission is most reduced, or filtered out. For general applications in speech analysis, it is desirable to have a stop-band attenuation of at least – 68 dB, i.e. the energy that remains in the stop band after filtering will be at least 68dB below the energy peak in the pass-band. Figure 2.2 shows the frequency response of a low pass filter.

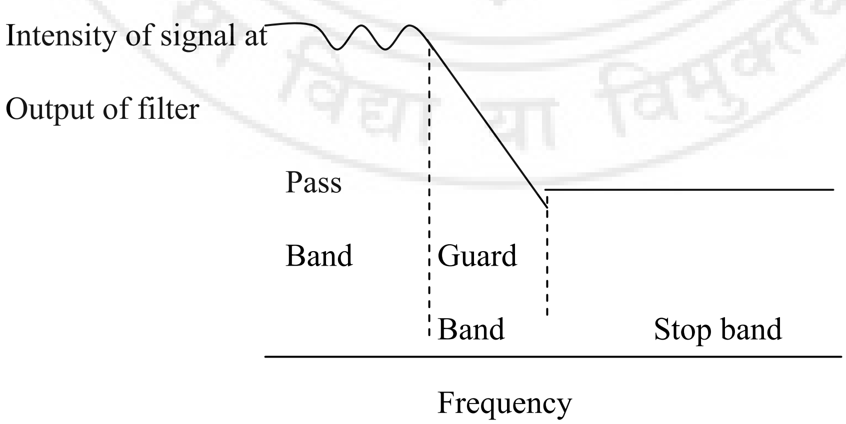



**Figure 2.2: Frequency response of a low-pass filter.**

**Sampling**

The signal after pre-emphasis and low-pass filtering will be ready for digitization. Digitization comprises of two process, sampling and quantization. Sampling is the operation by which the analog signal is converted to a series of samples that can be stored in a digital computer.

The sampling rate should be at least twice the highest frequency of interest. For example if the highest frequency is 10 kHz sampling should be done at a rate of 20 kHz. The sampling can also be done at higher rate but not at lower rate because serious errors can develop in the analysis called aliasing. As a result, the sampling operation yields a false, or aliasing signal.

**Quantization**

The next operation in digitization is called quantization. Quantization describes what has been done. A quantum is an increment of energy. When an analog signal is quantized, the continuous amplitude variations are converted to discrete values, or increments. The higher the number of quantization levels, the more accurately the quantized signal represents the analog signal. As a general rule, speech should be quantized with at least a 12-bit conversion, which provides 4,096 quantization levels. More lower the quantization levels, more distorted will be signal. With each additional bit of amplitude conversion, there is a doubling of levels of quantization. For example

| | |
|---|---|
| 8 bits | 256 levels |
| 10 bits | 1,024 levels |
| 12 bits | 4,096 levels |

Following operations of sampling and quantization, the signal is digitized as a series of quantized samples that can be encoded for storage in the computer. The original time-varying waveform of speech takes the form of a series of quantized samples, converting analog-to-digital signal (Sairam 2005: 14).

### 2.2.6. Modern Analytic Techniques

#### Waveform display

Displaying a sound pressure waveform is one basic function of most devices for speech analysis. From such a display, one can determine duration and relative amplitude, can judge periodicity from which fundamental frequency can be estimated. One can also select parts of the waveform for closer inspection and for editing. By moving the cursors and playing back the sound between them, the user could judge the duration of the vowel /a/. One can select any part of the signal, cut it and splice it. The speech waveform provides information about relative amplitude. In the same figure one can observe that the amplitude of the vowel is relatively higher than that of the word-medial consonant. To obtain a smooth amplitude curve, the signal should be averaged over time. Such smoothing can be done arithmetically, one way is known as root-mean-square (rms) averaging. The name identifies three of the steps, in reverse order. To calculate the amplitude the following should be done.

- Select a window length, the number of samples of speech to be averaged,
- Square the value of each simple in the first window,
- Calculate the arithmetic mean, or average, of the squared values in the window, and
- Take the square root of the resulting mean.

**Filters**

Filter is a system that passes (or enhances) some frequencies but attenuates others. Because a filter offers a frequency – selective transmission of energy, it has a response curve that varies across the frequency spectrum. The filter may be a low-pass or high-pass or band-pass. The frequency at which the filter's response starts to change is called the corner frequency.

In speech science, filters have two common applications: pre-emphasis and anti-aliasing. A pre-emphasis filter for speech is a high-pass filter, usually with a response that increases at 6 dB per octave above a corner frequency of few hundred Hertz. Such a filter enhances higher frequencies, which are lower amplitude in speech, on average. In fact, as speech radiates from the lips, it is attenuated by 6 dB per octave, so pre-emphasis at that rate simply restores the signal actually generated in the vocal tract. An anti-aliasing filter is a low-pass filter which sharply attenuates frequencies above half the sampling rate.

Filters can be analog or digital. An analog is an electronic circuit, tuned to respond to a certain range of frequencies. It is made up of resistors, capacitors, and inductors. By adjusting the value of these components, we can modify the response curve of the filter. A digital filter is a rule, an equation, applied to a sequence of samples of speech.

Filters share a crucial property with all other resonators, namely, a tradeoff between frequency resolution and time resolution. A wide band filters will smear a range of frequencies by responding to any frequency within its bandwidth. Conversely, a narrow band filter respond efficiently to frequencies within the band filter responds more slowly. The different types of filters are as follows:

- Butterworth filter: Maximally flat, that is, minimal ripple in either pass-band or stop-band.
- Chebychev filter: Sharper transition than butterworth, but ripple in pass-band.
- Chebychev II filter: Ripple in stop band but flat pass-band.
- Elliptic filter: Ripple in both the pass and the stop bands, but sharpest transitions between the bands (Sairam 2005: 26-27).

## Spectral analysis

For a spectral analysis, it is necessary to select a part of the waveform. The selected interval is called a frame. The duration of the interval selected for analysis is called frame length and is typically in the order of 20-30 msec.

Analysis of a speech sample of any length requires the use of several successive frames large, unnecessary computation is performed. If the overlap is too small, then the analysis might miss rapid changes in the signal. The energy in a frame is weighted according to a window.

**Four types of short-term analyses are as follows:**

- Fourier analysis
- Linear prediction
- Cepstrum analysis
- Autocorrelation

**Fourier analyses**

By Fourier analysis periodic waveforms, no matter how complex, could be analyzed as a sum of an infinite series of sinusoidal components, varying in amplitude and phase. Each component is an integer multiple of the fundamental. Essentially, it transforms periodic amplitude by time waveform into frequency by amplitude waveform, known as a spectrum. A spectrum is a graph of the amplitude of various frequencies. However, there are a few catches. First, Fourier's theorem applies to periodic waves; whereas speech sounds are only quasi-periodic (Any sound which dies out is not truly periodic). Second Fourier talked about continue signals whereas in digital analysis we deal with discrete samples. Third, computation is difficult. However, we can adapt Fourier analysis to a quasi-periodic waveform by windowing (gradually decreasing or increasing the amplitude of the signal, rather than turning it on and off abruptly). There are Discrete Fourier Transforms (DFT) that apply to sampled data, and one type of DFT is a Fast Fourier Transform (FFT).

**Linear prediction**

Linear prediction or linear predictive coding (LPC) build upon the fact that any sample in digitized speech is partly predictable from its immediate predecessors; speech does not vary widely from sample to sample. Linear prediction is just the hypothesis that any sample is a linear function of those that precede it. Linear predictive analysis, like a Fourier transform, relates a representation in time to one in frequency. A key difference is that a Fourier spectrum represents harmonics of the fundamental, while a linear predictictive coding spectrum represents formant frequencies and amplitudes.

**Cepstral analysis**

In this technique, Fourier transform is applied to a speech signal. That is a signal in time axis (sound pressure waveform) is transformed to a frequency axis (spectra). Again this signal is transformed back to time axis (cepstrum). In a cepstral analysis the first syllable of the spectrum is reversed to indicate cepstrum. Frequency is termed quefrency and harmonics are termed rahmonics (Sairam 2005).

## Autocorrelation

Two series of numbers are said to be highly correlated if they increase and decrease together. Such a series of numbers might be the hourly temperatures of yesterday and today, For example, if the temperature followed the same pattern of increase and decrease from hour to hour, the two lists of numbers would be highly correlated, even if yesterday was, say, much colder than today. When we sample a speech signal digitally, we get a series of numbers, each one representing the amplitude of the sound pressure waveform at a particular moment. To say that this waveform is periodic is to say that there is a repeated pattern of increase and decrease. If we were to compute the correlation between this waveform and an exact copy of the waveform (thus autocorrelation), the two copies would, of course, be perfectly correlated. But what if we computed the correlation of this signal with a slightly delayed copy of itself as between the top and middle channels? The correlation would be highest when the delay, known as the lag, was close to one pitch period. If we compute the correlation at lags which range over probable pitch periods, we would see peaks in the correlation at the actual pitch period. This is the essential idea of autocorrelation pitch analysis. It works because in voiced speech, formant structure does not change drastically within a few milliseconds, so that successive periods resemble each other. Unfortunately, autocorrelation in this sample form applied to a raw speech signal does not work particularly well. The formants also effect that location of correlation peaks, so that a common error is to find, not the glottal period, but the glottal periods plus the periods plus the period of the first or the second formant.

A simple method is low-pass filtering to effectively eliminate formants at high frequencies. More sophisticated techniques are also used. Despite these difficulties, autocorrelation is one of more reliable methods of determining fundamental frequency (Sairam 2005: 27-30).

### 2.2.7. Acoustic Theory of Speech Production

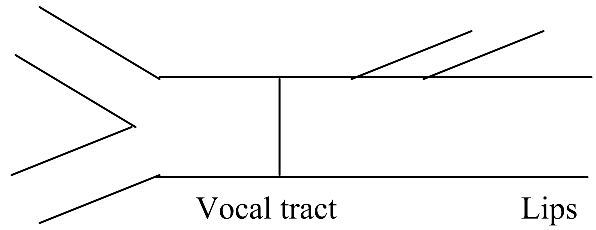
The acoustic theory of speech production or the source filter theory or the linear time-invariant source-filter theory was put forth by Fant (1960). The thesis of the acoustic theory in that P, the end product speech, is a product of the source energy (S) and the transfer function of the filter (T).

$$P = S*T$$

Sound pressures are represented as a function of frequency. If lip radiation (R) is added, then

$$P (f) = S (f) * T (f) 8 R (f)$$

Assume the vocal tract to be stretched. It will be a tube closed at one end (vocal fold) and open at the other end (lips). The vocal tract consists of oral tract and nasal tract. The length of the human oral tract in an adult male is around 17.5cm. There is a side shunt tube, the nasal tract, which is around 12 cm long. The resistance of the nasal tract is higher than that of the oral tract as it is mucous filled. Hence, expiratory air will pass through the oral tract unless it is closed. Figure 2.3 shows a schematic representation of the vocal tract. The expiratory air from the lungs passes through the vocal tract. At the point of vocal folds, air is converted to puffs of air, or noise is converted to voice which has a harmonic structure.




Stream of air/Noise (Inharmonic) Puffs of air/Voice (Harmonic)

**Figure 2.3: Schematic representation of vocal tract**

**Source**

Air is the main source of voice. At the level of glottis the source is termed glottal source. Fant (1960) considers different kinds of sources as follows:

a. Voiced source for all voiced sounds.

b. Noise source for all unvoiced sounds (figure 2.3). In case of noise source, the vocal folds are apart and hence the expiratory air is not modified at the vocal fold level.

c. Noise + voice source for /h/ and /h/ of murmured sounds (figure 2.4)

d. No source or silence.

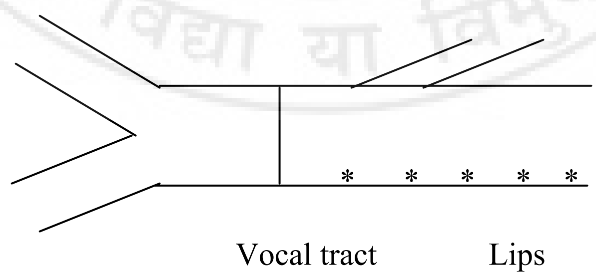



**Figure 2.4: Noise + Voice source**

At this point, we will consider the analogy of vibrating sting and compare it to the vocal folds. In the study of sound, a string or a wire usually denotes a thin, uniform and flexible thread or metallic wire whose length is large compared to its diameter. The production of musical sound in several instruments such as violin, veena, sitar, piano etc, is based on the transverse vibrations of stretched strings. When a stretched string is plucked, bowed or struck at any point at the right angle to its length, the string is set in to transverse vibrations: transverse waves travel along the string in both the directions and get reflected from the fixed ends. The direct and the reflected waves superimpose over each other giving rise to transverse stationary waves. The ends of the string being fixed must necessarily be nodes. The string vibrates such that it is divided in to an integral number of equal segments or loops. When the string vibrates as a single segment or loop (figure 2.5), it emits a note of lowest frequency called fundamental frequency (F10). When the string is vibrating in two equal loops (figure 2.6), the frequency of vibration is twice that of the fundamental frequency and when the string is vibrating in three equal loops, the frequency of vibration is thrice that of fundamental frequency and so on. Therefore, the overtones are harmonics of the fundamental.

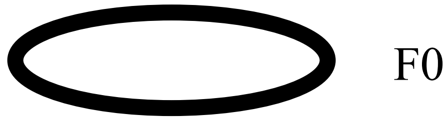



**Figure 2.5: String Vibrating as a single segment or loop.**

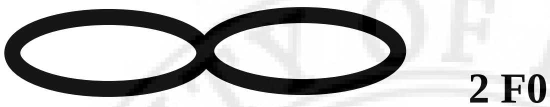



**Figure 2.6: String vibrating in two equal loops.**

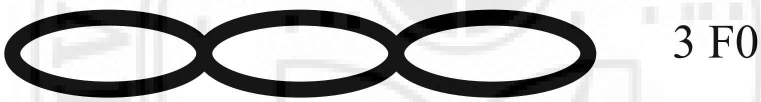



**Figure 2.7: String vibrating in three equal loops.**

The vocal folds can be compared to a string. The quasi-periodic vibration of the vocal folds (it is called quasi-periodic, as the periodicity of each wave differs owing to the mucous filled nature of the vocal folds) generates the energy source known as voicing. It is also termed glottal wave/glottal spectrum (representation of frequency and amplitude). The glottal waveform is a simple triangular wave (figure 2.8). The glottal spectrum is characterized by a fundamental frequency and its overtones. As an example, glottal spectra (figure 2.9) with a fundamental frequency of 100 cps consist of the following harmonics or overtones: 100 cps, 200 cps, 300cps, and so on.

The characteristics of the glottal spectra are as follows:

1. The fundamental frequency has the maximum amplitude.
2. The intensity decreases as the frequency increases.
3. The intensity decreases at the rate of – 12 dB/octave for vowels and -8 dB/octave for consonants.

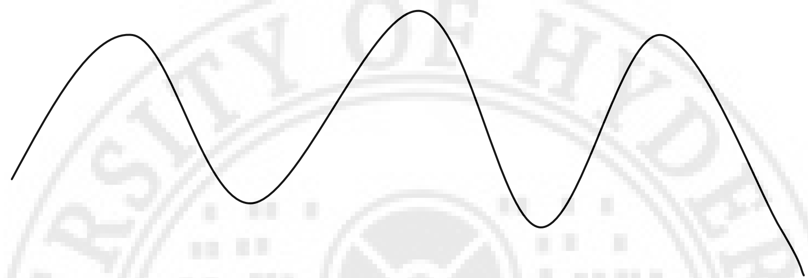


**Figure 2.8: Glottal waveform**

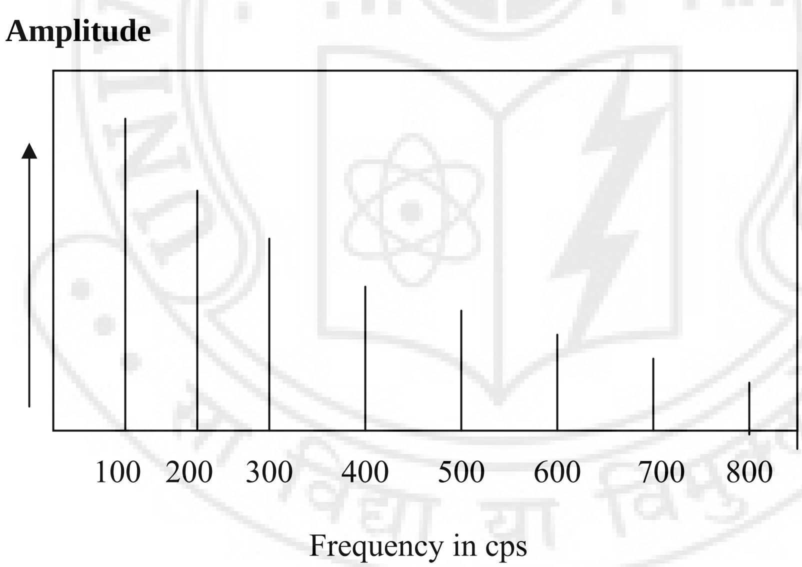



**Figure 2.9: Glottal spectra**

The glottal spectra for almost all voiced sounds are the same. This glottal spectrum enters the vocal tract where the spectra are transferred (Sairam 2005: 16-19).

**Filter / Transfer function**

To introduce the concept of resonance, let us begin with a tube that resembles human vocal tract. The tube consists of a vibrator (V) and a length of straight pipe (l). The vibrator is stretched to fit one end of the pipe and the other end is left open (figure 2.10). This pipe is open at one end and closed at another. Such a pipe has infinite number of resonance, located at a frequency given by odd-quarter wavelength relationship.

$$Fn = (2n- 1) C / 4 1,$$

Where, n is an integer, C is the speed of sound (about 35,000 cm/sec) and l is length of the pipe.

Resonance is a process of transmission by which energy of frequencies in tune with the resonator is passed through and energy of frequencies not in tune is absorbed. The selectivity of a resonator is dependent upon its size, mass and texture. Resonance frequency is indirectly proportioned to the volume of the cavity or R x 1/V.

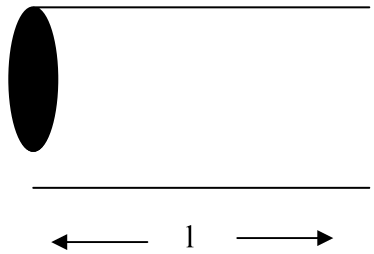
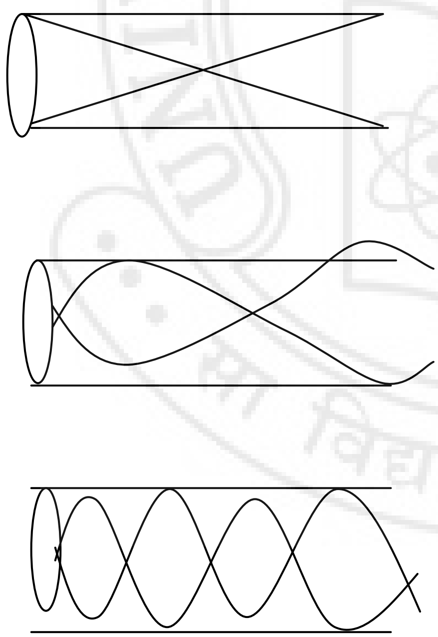


**Figure 2.10: Tube with a vibrator**

The pipe resonates with maximal amplitude of a sound whose wavelength is 4 times the length of the tube. Resonance (formants) occurs at C/41, 3C/41, 5C/41 and so on (figure 2.11). If one assumes 1=17.5 cm, then the first three formants of the tube will be as in figure 2.8.



$$F1 = \frac{35000}{41} = \frac{35000}{70} = 500 \text{ Hz}$$

$$F2 = \frac{3 \times 35000}{4 \times 17.5} = 1500 \text{ Hz}$$

$$F3 = \frac{5 \times 35000}{4 \times 17.5} = 2500 \text{ Hz}$$

**Fig. 2.11: Resonance of a tube with 1=17.5 cm (closed at one end).**

The vocal tract acts a resonator. The glottal spectra with a fundamental frequency and its harmonics enter the vocal tract, which is an air filled cavity and is around 17.5 cm long. At rest, i.e. without any articulatory movement, the vocal tract will resonate at 500 Hz, 1500 Hz, and 2500 Hz, etc. If the vocal tract length is doubled, for example 35 cm, then the resonance frequencies will be 250 Hz, 750 Hz, and 1200 Hz, etc. On the other hand if the vocal tract length is halved, i.e. 8.75 cm, then the resonance frequencies will be 1000 Hz, 3000 Hz 5000 Hz, etc. Calculations are illustrated in table 2.1.

| | L = 35 cm | L = 8.75 cm |
|---|---|---|
| F 1 = C /41 | 35000 = 250 Hz<br>4 x 35 | 35000 = 1000 Hz<br>4 x 8.75 |
| F 2 = 3 C/41 | 3 x 35000 = 750 Hz<br>4 x 35 | 3 x 35000 = 3000 Hz<br>4 x 8.75 |
| F 3 = 5 C/41 | 5 x 35000 = 1250 Hz<br>4 x 35 | 5 x 35000 = 5000 Hz<br>4 x 8.75 |

**Table 2.1: Resonance frequencies of vocal tracts with different length.**

When the tube is open at both ends the resonance frequencies are calculated by the formula R1 = C/21, R2 = 2 C / 21, R3 = 3C/31, etc.

When the articulator moves, the air particles in the vocal tract are disturbed and realigned. For example in the production of vowel /a/ the vocal tract would look like as in figure 2.12.

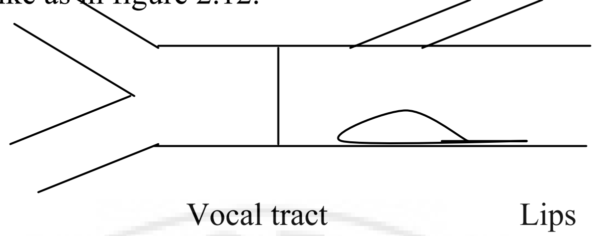



**Figure 2.12: Vocal tract configuration in the production of /a/**

The oral tract is roughly divided into two cavities. The point where the articulator approximates the place of articulation is termed constriction (C). The cavity behind the effective constriction is termed back cavity (BC) and that in front of the effective constriction is termed front cavity (FC). The first resonance frequency (F1) depends upon the volume of back cavity (V1) and the second resonance frequency (F2) depends upon the volume of front cavity (V2), though erroneously. F1 and F2 are indirectly proportional to V1 and V2, respectively. The transfer function of such a tube is depicted in figure 2.13. The glottal spectra that pass through such a tube will be modified by the filter transfer function.

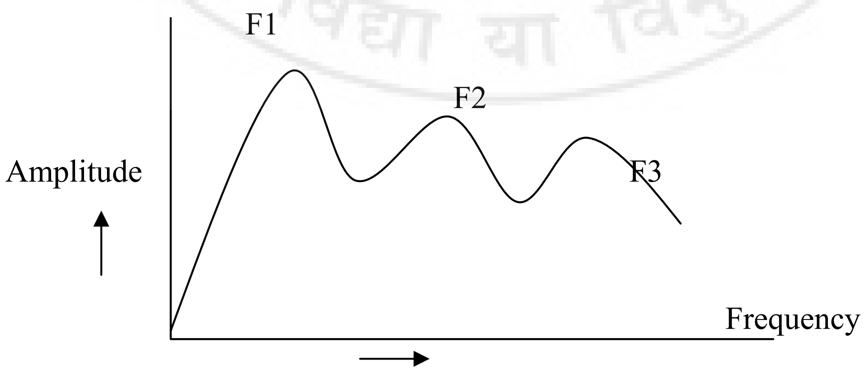



**Fig.2.13: Transfer function of vowel /a/**

Energy of frequencies near the vicinity of the resonance frequency will be passed through the tube and the vocal tract will absorb energy of frequencies far away from the resonance frequencies. Thus the end product will have peaks at rounds 750 Hz and 1200 Hz. A simple glottal spectrum is transformed to a complex speech spectrum. Figure 2.14 shows the end product of vowel /a/

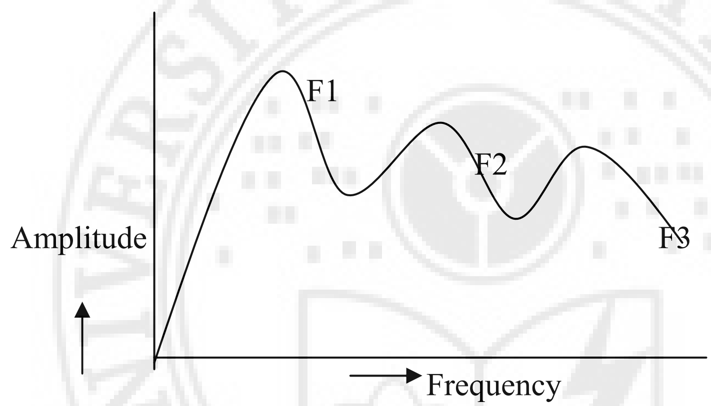



**Figure 2.14 End product of vowel /a/**

Let us consider the example of vowel /i/, a high front vowel. This vowel is characterized by larger back cavity volume and shorter front cavity volume compared to vowel /a/ (figure 2.15).

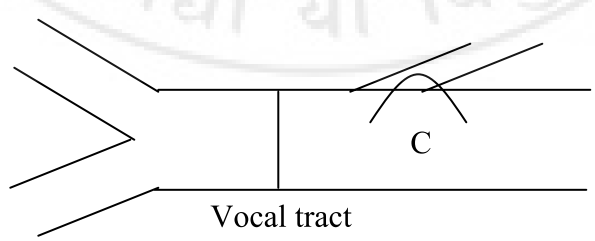



**Figure 2.15: Vocal tract configuration in the production of vowel /i/.**

As V1 is larger (compared to vowel) /a/, F1 will decrease and as V2 is smaller (compared to vowel) F2 will increase. The same glottal spectra passing through a vocal tract for the production of /i/ will have different transfer functions with F1 at 300 Hz and F2 at 2100 Hz. The energy in frequencies around 300 Hz and 2100 Hz is passed through the oral tract and energy in the remaining frequencies is absorbed. Thus, the end product with peaks at 300 Hz and 2100 Hz sounds as /i/. The same glottal spectrum (of /a/) is transformed into complex speech spectra which is different than the speech spectra of /a/.

In the production of /u/, a high back vowel, there are two constrictions in the oral tract. One is in the back part of the oral tract and another at the lip. However, the effective constriction is at the lip end, as it happens to be tube end. Therefore, back cavity will involve the whole of the vocal tract and front cavity will include air cavity in front of the lips (figure 2.16).

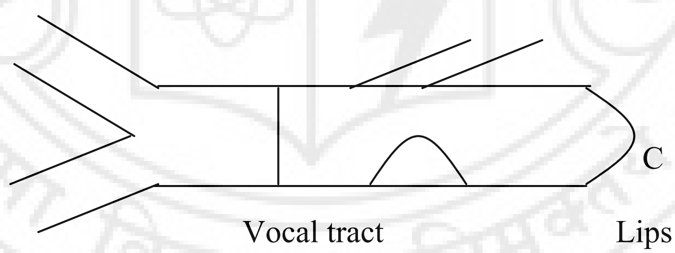



**Figure 2.16: Vocal tract configuration for the vowel /u/.**

As the volumes of both the cavities are large, F1 and F2 are markedly reduced and occur at around 300 Hz and 900 Hz. Thus, the same glottal spectra is transformed into different speech spectra by virtue of different filter function or transfer function of the vocal tract which is brought about by different shapes of vocal tract generated by the articulatory configurations. Thus, if one do not have articulators it is difficult to produce different speech sounds. Because the articulators bring about different cavity configurations that lead to different resonance patterns it is possible to produce different speech sounds. If not for articulators, it would be only an undifferentiated glottal sound.

**Other modifications of the source**

Apart from the source (air) modified at the level of vocal folds, there are several sources generated in the oral tract. When the oral tract is completely closed and released as in the production of plosives a transient source is generated. Also, when the air passes through a small constriction as in the production of fricatives a turbulent source is generated. A turbulent source will have air jetting at high frequencies and thus produce a high frequency sound. Figure 2.17 shows the transient (Tr) and turbulent (Tu) sources.

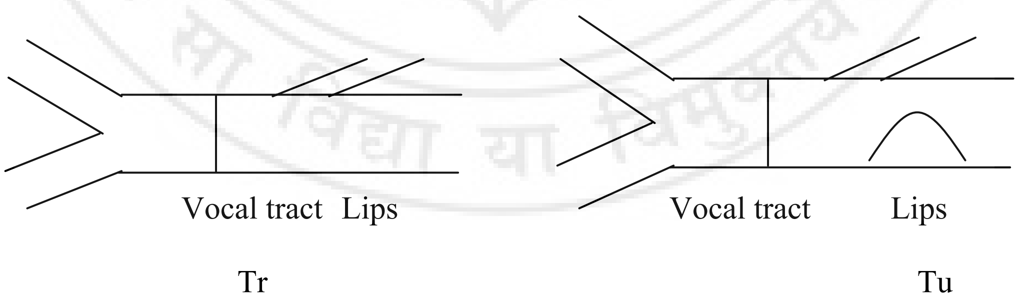



**Figure 2.17: Transient and turbulent sources.**

**Effects of losses in the Vocal Tract**

Internal loss such as viscous friction between air and walls of the vocal tract, thermal conduction through the walls of the vocal tract, and vibration of the walls of the vocal tract can affect the speech output. Viscous friction and thermal conduction have their greatest effect in the high frequency resonance (above 3-4 kHz). The variations of air pressure inside the tract will cause the walls to experience a varying force. Thus, if the walls are elastic, the cross-sectional area of the tube will change depending upon the pressure in the tube. Since the pressure variations are very small, the resulting variation in cross-sectional area can be treated as a small perturbation of the nominal area.

External loss includes effect of lip radiation. The intensity of the speech signal is directly proportional to the area of lip opening. The radiation characteristic is a term that accounts for the way in which the vocal tract terminates into the atmosphere. It can be approximated as a 6dB increase in spectral energy. Radiation losses are most significant at higher frequencies (Sairam 2005: 16-24).

### 2.2.8. Description of Telugu Vowels

Vowels are produced by allowing the vocal folds to vibrate as the air flow moves through the mouth which is held in an open and fixed position. The shape of the organs- tongue and lips alter the shape of oral cavity and give different vowels of their characteristic sound quality. To describe vowels, the position of tongue, duration/extent of phonation and lip shape are important. The common terms used to describe the tongue positions are front, central, back, high, mid and low; the lip shape is described as either rounded or unrounded and extent of phonation is described long and short (Subba Rao 1992: 5).

In the Telugu language there are eleven vowel phonemes. They are /i/, /e/, /a/, /o/, /u/, which may be long or short, and the phoneme /æ/ is phonetically always long. However for this study only 10 vowel phonemes, that is /i/, /e/, /a/,m/o/, /u/, are used which are long & short. The distinction between long and short vowels is illustrated by such pairs as pa:du 'to sing', padu 'to fall', we:llu 'fingers', wellu 'go', do:ra 'half-ripe', dora 'master', cu:ruku 'to the sloping roof' curuku 'smart', wi:du 'this man', widu 'to leave'. Long and short vowels contrast in initial, medial and final syllables. It may, however be noted that in single morphemes, the occurrence of long vowels in medial and final syllables is common only in loanwords from Hindi-Urdu, e.g.pako:di: 'a savoury' (Kostic et al. 1997: 7).

**The Tongue positions and lip shapes during Vowel production:**

The tongue positions are described below

**Front:** These vowels are produced when tongue tip moves either up or down.

**Central:** These vowels are produced when the middle part of the tongue is used to produce vowels either by moving up or down.

**Back:** These vowels are produced when back of the tongue rises or lowers compared to the resting position of tongue.

**High:** These vowels are produced when tongue moves and stays at higher place than the resting position of the tongue.

**Mid:** These vowels are produced when tongue makes no change in its height.

**Low:** These vowels are produced when the tongue position is lower than the resting position of the tongue.

The lip shapes and duration of phonation are described below:

**Rounded:** These vowels are produced when the lips are in a rounded position.

**Unrounded:** These vowels are produced when the lips are not in a rounded position.

**Long vowel:** These vowels are produced with long duration of phonation.

**Short vowel:** These vowels are produced with short duration of phonation

**Table 2.2. The Tongue positions and lip shapes during Vowel production**

| Sound | Description | Examples |
|---|---|---|
| /i:/ | Front, high, unrounded long | i:ga (fly), i:du (swim) |
| /i/ | Front, high, unrounded short | idi (this), illu (house) |
| /e:/ | Front, mid, unrounded long | e:nugu (elephant), e:du (seven) |
| /e/ | Front, mid unrounded short | ettu (lift), ekku (climb) |
| /a:/ | Central mid unrounded long | a:ta (play); a:ru (six) |
| /a/ | Central mid unrounded short | amma (mother); akka (sister) |
| /o:/ | Back mid rounded long | no:ru (mouth); ko:ti (monkey) |
| /o/ | Back mid rounded short | okati (one); ollu (body) |
| /u:/ | Back high rounded long | u:ru (village); u:gu (swing) |
| /u/ | Back high rounded short | uppu (salt); uduku (wash) |

(Subba Rao 1992: 63)

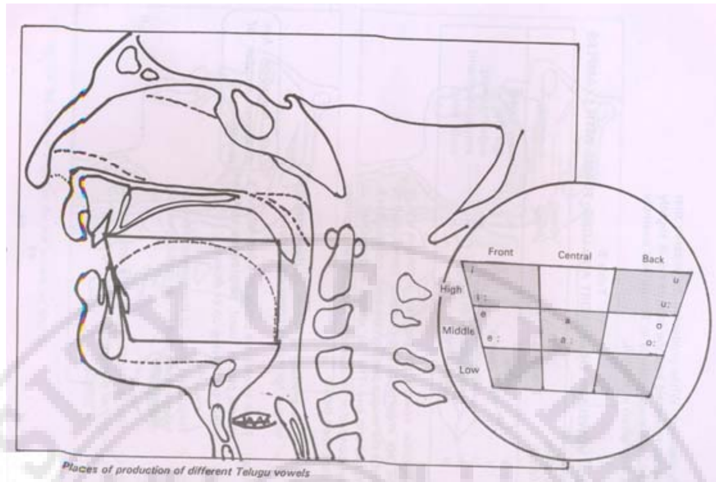



**Figure 2.18: The positions of various vowels in the oral cavity [From Subba Rao (1992)]**

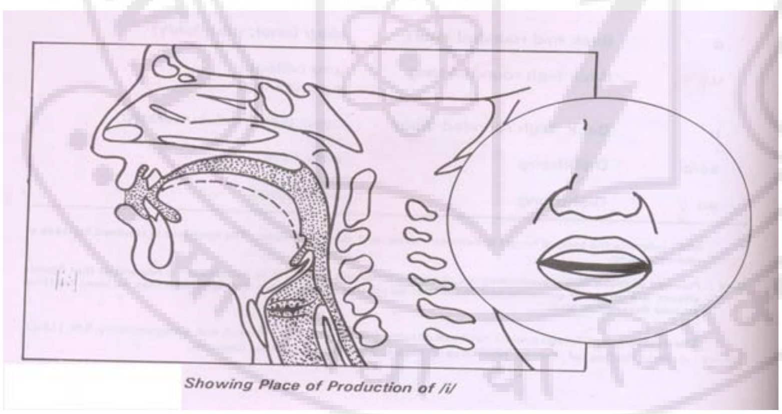



**Figure 2.19: Place of production of /i/ [from Subba Rao (1992)].**

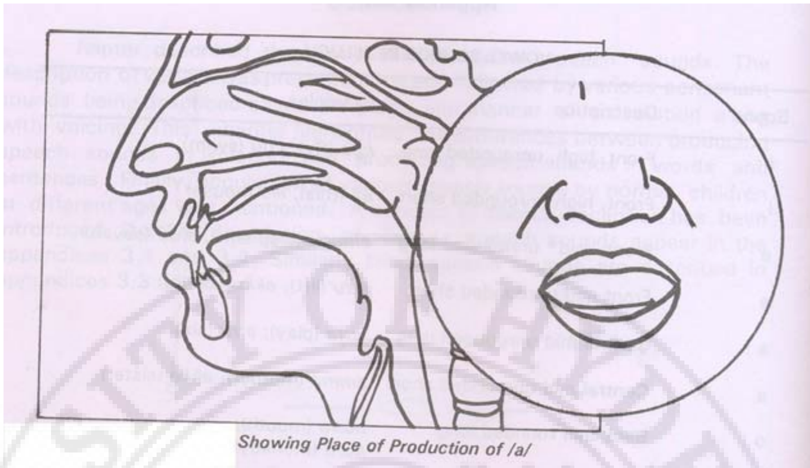



**Figure 2.20: Place of production of /a/ [From Subba Rao (1992)]**

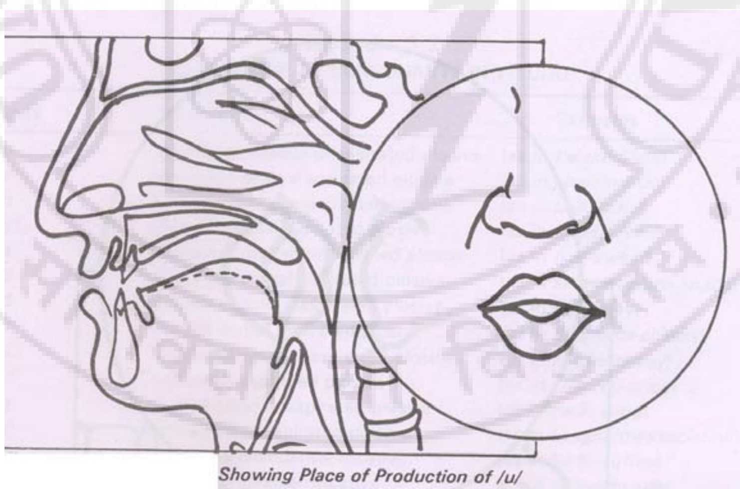



**Figure 2.21: Place of production of /u/ [From Subba Rao (1992)]**

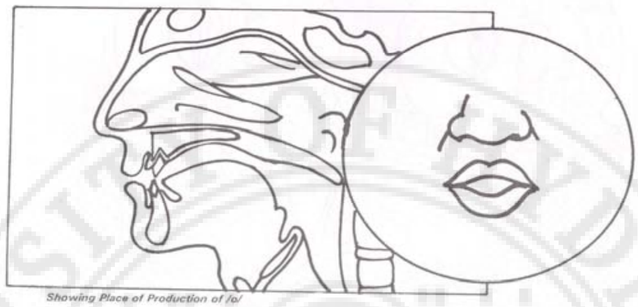



**Figure 2.22: Place of production of /o/ [From Subba Rao (1992)]**

**/ i: /**

Telugu long vowel /i: / is a phoneme which can stand at the beginning of a word, or in medial or final positions. The vowel is front, unrounded and high. The lips are neutral during the pronunciation of this vowel and are partly adjusted to the position of the following consonant. The jaw angle is that for normal breathing through the mouth. When followed by the vowel /a/ in the next syllable the lip position and the jaw angle are more open, due to the law of vowel harmony. The vowel is fully voiced. The soft palate blocks the passage to the nasal cavities and the air stream is directed completely through the mouth. The vowel is not nasalized except in the part of its transition adjacent to a nasal consonant. The tip of the tongue is placed behind the lower front teeth. The front and mid part of the tongue are raised towards the alveolo-palatal area. The back of the tongue is lowered. The first formant is placed in the area between 250 Hz to 300 Hz. The second formant can be found between 2,200 Hz to 2,600 Hz. The third formant, which is very weak, is placed between 2,700 Hz up to 3,000 Hz. The fourth formant is placed between 3,500 Hz to 3,700 Hz. There is a remarkable acoustic energy between 800 Hz and 1,200 Hz (Kostic et al. 1997:11-12).

**/i/**

Telugu short vowel /i/ is a phoneme which occurs in initial, medial and final position in words. During the pronunciation of the Telugu short vowel /i/ the lips are in neutral position or slightly adjusted towards the position of the following consonant. The jaw angle is in the position for breathing through the mouth. The soft palate is raised and the air stream is prevented from going through the nose cavities. The vowel is oral, although when adjacent to a nasal consonant it may be slightly nasalized. It is fully voiced. The tip of the tongue touches the edges of the lower teeth and the front part of it is raised towards the alveolo-palatal region. The first formant of Telugu short vowel /i/ is located at 250 Hz, but in its different varieties, it may rise up to 350 Hz and even to 400 Hz. In this case the quality of the vowel tends to resemble the quality of the vowel /e/. The second formant is located around 2,500 Hz to 2,600 Hz, but it may drop down even to 2,250 Hz and in this event the first formant is located between 350 Hz to 400 Hz. The third formant is very weak and is located between 2,750 Hz to

3,000 Hz. The vowel is accompanied by a concentration of acoustic energy around 1,000 Hz (Kostic et al. 1997:16-18).

**/e: /**

Telugu long vowel /e: / is a phoneme which occurs in the initial, medial and final positions in words. The position of the lips for Telugu long vowel /e:/, depending on the vowel harmony law in the Telugu language, is neutral or slightly spread. The jaw angle is more open than for breathing through the mouth. The vocal cords are set in action and the vowel is fully voiced. The soft palate is raised, preventing the air stream from going through the nasal cavities, so that the vowel is not nasalized except when adjacent to a nasal consonant.

The tip of the tongue leans behind the gum of the lower teeth, forming a very shallow valley in the front part of the tongue which is raised, curving towards the alveolo-palatal area. The back part and the root of the tongue are in neutral positions. When the vowel has a more open variety, the position of the tongue tends to approach the position for front vowel /a/. The vowel is not centralized as is the case with long and short vowels /i:/ and /i./ Telugu long vowel /e:/ has a larger field of variety of articulation than the long vowel /i:/ It may have a very close variety, approaching the cardinal vowel /e/ and an open variety characteristic of the cardinal vowel /æ/.

The acoustic structure of this vowel shows considerable variety of f1 ranging from 370 Hz upto 750 Hz. This dynamism of the second formant of the vowel also shows a considerable field of variation as well, so that f2 may be found from 1,500Hz to 2,500Hz. The variation of the second formant is closely related to the dynamism of the first formant showing that the vowel quality varies from a close to very open variety. The third formant is found at 2,750 Hz (Kostic et al. 1997:20-22)

**/e/**

Telugu short vowel /e/ is a phoneme which appears in initial, medial and final positions in words. The lips are in neutral position, as for breathing through the mouth, and it largely depends on the jaw angle which, on the other hand, varies according to the vowel quality. The jaw angle may be that for closed /e/, similar to the cardinal vowel /e/ and open front cardinal vowel /a/.

The vocal cords are in action and the vowel is fully voiced. The position of the tongue is similar to that for long vowel /e/. As we noticed in the previous section, long vowel /e:/ is not neutralized to such an extent that neutralization may be regarded as one of its characteristics. This is not applicable to short vowel /e/. In order to acquire this neutral quality of short vowel /e/, the back part of the tongue has to be placed in a position to form the laryngo-pharyngeal cavity similar to that for the neutral vowel /Ə/. The tip of the tongue is placed in the gum if the lower front teeth and the front part of it is raised mid–way towards the alveolopalatal area. When it tends towards centralization it has more prominent intensity of speech organs than otherwise. The short vowel /e/ has the largest field of variety of all Telugu vowels and it is the most unstable.

The acoustic structure of Telugu short vowel /e/ shows this large field of variety of its quality. The first formant may vary from 250 Hz to 600 Hz, which shows that the vowel may have a range from very close to very open quality. The second formant varies from 1,500 Hz upto 2,700 Hz. If the second formant has a high position the first formant drops to 300 Hz and the quality of this vowel may be confused with that of the vowel /i/, the third formant of the vowel is very weak and may be found between 2700 Hz and 3000 Hz (Kostic et al. 1997:24-26)

**/a: /**

Telugu long vowel /a: / is a phoneme, which may be found at the beginning, in the middle and at the end of the words.

During its pronunciation the lips are neutral and the jaw angle is more open than for breathing through the mouth. The soft palate is raised, preventing the air stream from passing through the nasal cavities. The vowel is oral although it may be slightly nasalized when adjacent to nasal consonants. The tip of the tongue is pulled back, resting flatly on the gum of the lower front teeth. The back part of the tongue is slightly raised from a horizontal position and retracted towards the laryngo-pharyngeal cavity. The laryngo-pharyngeal cavity and the position of the larynx play a remarkable role in the formation of the vowel quality. The back part of the tongue and the muscles of the laryngopharyngeal cavity walls have higher tension than the mid and front part of the tongue or the lips during the articulation of the vowel. The articulatory action is located in the back part of the buccal cavity and in the laryngo-pharyngeal area as well. The guttural quality of the vowel is due to the position of the larynx and its connection with the root of the tongue.

Its acoustic structure shows remarkable dynamics in the position of the first formant which may drop down to 500 Hz in the lower limit and reach 800 Hz for the upper limit. It is very often placed between 600 Hz and 700 Hz. If the long vowel /a:/ has a low first formant at about 500 Hz the second formant is located around 1000 Hz and the vowel resembles the vowel /Ə/. If the first formant has a relatively high position, about 800 Hz, the second formant will be located around 1200 Hz regardless of the position of the second formant (Kostic et al. 1997:28-30).

**/a/**

Telugu short vowel /a/ is a phoneme which occurs in the initial, medial and final positions in words. The lips are in neutral position, depending on the jaw angle which is that for breathing through the mouth, or slightly adjusted under the influence of the articulation of the following consonant. The soft palate is raised and the air stream prevented from passing through the nasal cavities goes through the mouth cavity. The vocal cords are set in action and the vowel is fully voiced. The position of the tongue varies between that of the long vowel /a:/ and the neutral vowel / ə/. The tip of the tongue leans behind the gum of the lower teeth and the mid part of the tongue is in a horizontal position. The back part is slightly raised and pulled towards the laryngo-pharyngeal cavity.

The laryngeal system is in a tense position and on a higher level than for the vowel /a:/. The tensity of the back part and the root of the tongue as well as the tensities of the muscles of the laryngo-pharyngeal walls are noticeable. The main articulatory action is located in the back part and root of the tongue as well as the larynx itself.

The dynamics of the first formant for Telugu short vowel /a/ is lower than for the long vowel /a:/. The first formant is located around 600 Hz to 750 Hz and the second formant is placed between 1200 Hz to 1400 Hz. We have found the second formant located at around 1300 Hz in the majority of cases. The third formant may vary from 1500 Hz to 3300 Hz (Kostic et al. 1997:33-34)

**/o: /**

Telugu long vowel /o:/ is a phoneme occurring in the initial and medial positions in words but not in the final position. The lips are rounded and very slightly protruded. Sometimes they are quite neutral and their opening depends on the jaw angle. Compared with their position for the Telugu long vowel /a: /, the lip shows a forward movement from /a: / to / ə: /. The jaw angle is more open than for breathing through the mouth. The soft palate is raised, and the air stream, prevented from passing through the nasal cavities, goes through the mouth cavity. The vowel is not nasalized, and has a pure oral quality.

The tip of the tongue is placed behind the gums of the lower front teeth and the front and mid part are gradually raised towards the soft palate. The back part of the tongue is in the position for cardinal vowel /o/ at the beginning of its pronunciation and moves towards the position for the central vowel during its pronunciation.

The first formant for Telugu long vowel /o:/ is located between 400 Hz to 500 Hz, the second formant is located between 900 Hz and 1100 Hz and the third formant, being very weak and in many cases absent, may be found between 2700 Hz and 3000 Hz (Kostic et al. 1997:37-39).

**/o/**

Telugu long vowel /o/ is a phoneme which may be found in the initial and medial positions in words. The lips are slightly rounded and protruded for the pronunciation of Telugu short vowel /o/ as in the case of the long vowel /o: /. The soft palate is lifted, closing the passageway for the air stream through the nose cavities, and causing it to be directed through the mouth passage. The vowel is not nasalized and it is fully voiced. The position of the tongue is very similar to that of the long vowel /o: /.

The first formant for Telugu short vowel /o/ is located between 400 Hz and 600 Hz, the second formant is placed between 1000 Hz and 1250 HZ and the third formant is very weak and in the majority of cases it is missing (Kostic et al. 1997:41-43).

**/u: /**

Telugu long vowel /u: / is a phoneme which may stand at the beginning of a word, within it, but not normally at the end of it. The lips are rounded and protruded for its pronunciation so that they affect the lip position of the following speech sounds and influence these sounds more than vice versa. Therefore the role of lip position is very important for the quality of the long vowel /u: /, and certainly more so than for the front vowels. The soft palate is raised and the air stream is directed towards the mouth, so that the vowel is not nasalized. The tip of the tongue lies flat behind the gum of the lower front teeth and the back of the tongue is raised towards the palato-velar area. The passage for the air stream, consisting of the area between the surface of the back of the tongue and the back part of the buccal cavity, is narrow, but wide enough to allow the air stream to pass without friction. The laryngo-pharyngeal cavity is larger for this vowel than for the vowel /o/. The first formant is located around 400 Hz with a very field of variety, the second formant is located between 900 Hz to 1000 Hz and the third formant is missing in the majority of cases. According to the acoustic structure of this vowel it shows high stability of its quality, and it may be said that this vowel is more stable than others (Kostic et al. 1997:45-46).

**/u/**

Telugu short vowel /u / is a phoneme which occurs in the initial, medial and final positions in words. The position of the lips is the same as that for the /u:/. The soft palate is raised, preventing phonatory air from escaping through the nose cavities. The vocal cords are set in vibration and the vowel is fully voiced. As in the case of long vowel /u: /, the back of the tongue is raised towards the back part of the roof of the mouth. Due to its very short duration, transition movements are very quick and the dynamics of the articulator is greater for /u/ than for the long vowel /u: /.

The first formant is located around 300 Hz to 350 Hz and it is slightly lower than that for the long vowel /u:/. The second formant is located in the majority of our examples at 900 Hz with its maximum limit at 1000 Hz. The third formant is very weak and is missing in the majority of our examples. The stability of the quality of the short vowel /u/ is very high and is similar to that of the long one (Kostic et al. 1997:49-51).

## 2.3. STUDIES RELATED TO SPEECH CHARACTERISTICS OF PERSONS WITH HEARING IMPAIRMENT

### VOWELS

Vowels are produced by allowing the vocal folds to vibrate as the airflow moves through the mouth which is held in an open and fixed position. The shape of the organs – tongue and lips alters the shape of oral cavity and give different vowels their characteristic sound quality (Subba Rao 1992: 47)

Based on the Phonetic inventory from the spontaneous speech samples of hearing impaired children, the most commonly used vowels by young hearing-impaired children includes the central vowels and the low front vowels

/a/, /ϵ /. The extreme high vowels /i/, /u/ occurred relatively infrequently in the speech of children and the vowel usage of these children was similar to that of the hearing infants of 11 to 12 months (Carr 1953; cited in Rathna Kumar1998: 2.7).

Geffner and Freeman (1980) analyzed the spontaneous speech of 65 deaf children aged 6 years and found that low vowels were correctly produced than those with mid or high tongue positions. Sykes (1940; cited in Rathna Kumar 1998: 2.8) reported that four to seven year old hearing-impaired children produced almost half to the number of vowel sounds in isolation but not in combination with consonants. Hudgins and Numbers (1942; cited in Rathna Kumar 1998: 2.8), one of the first investigators, who studied the production of vowels and diphthongs in the speech of the hearing impaired, classified the errors according to five major types:

1. Substitution of one vowel for another
2. Neutralization of vowels
3. Diphthongization of vowels
4. Nasalization of vowels
5. Errors involving diphthongs

**CONSONANTS**

Consonants are produced by narrowing (Constricting) one or more parts of the mouth to complete or near closure thus causing disturbance to the flow of air or redirection of airflow. Some of these consonants are voiced and some are unvoiced. During production of some consonants nasal cavity is open (Subba Rao 1992: 51).

Nober (1967; cited in Rathna Kumar 1998: 2.18) analyzed correctly articulated consonants according to place of articulation and found that bilabials had highest score (59%) followed by labio-dentals (48%), glottals (34%), lingua dentals (32%), lingua –alveolars (23%), lingua-palatals (18%) and lingua-velars (12%). Gold (1978; cited in Rathna Kumar 1998: 2.18) examined the segmental errors in mainstreamed hard of hearing and profoundly hearing impaired children. He reported that, the sounds produced in the front of the mouth are most often correct, followed by the back consonants. Sounds produced in the middle of the mouth were prone to errors than the sounds produced in the back of the mouth.

Hudgins and Numbers (1942; cited in Rathna Kumar 1998: 2.21) who studied the articulatory errors of 192 subjects between the ages of 8 and 20 years with moderate to profound hearing loss used a material which included reading simple sentences. The articulatory errors were divided into substitutions, omissions, distortions and addition of phonemes. The common type of consonantal errors included confusion of the voiced –voiceless distinction , substitution of one consonant for another, added nasality, misarticulation of consonants, blends, misarticulation of aborting consonants and omission initial or final consonants of word.

**Studies related to voicing errors**

Smith (1975) has reported that voicing errors were common in children with hearing impairment and most often involved substitutions of the voiced for voiceless pair. Markides (1970; cited in Rathna Kumar 1998: 2.22) studied the speech characteristics of 110 British hard of hearing and deaf children and reported the substitution of the voiceless consonants for the voiced consonant. Nober (1967; cited in Rathna Kumar 1998: 2.22) used Templin Darley test of articulation and analyzed the production of phonemes by 46 severe to profound hearing loss subjects and reported that voiceless phonemes were produced more correctly than voiced phonemes.

**Studies related to substitution errors and omission errors**

Smith (1975) has reported that the hearing-impaired children had erroneous production of palatal plosives, fricatives, affricates and nasals. Glottals were frequently substituted for stops whereas the bilabial plosives, glides and fricatives /f/ and /v/ were produced correctly.

Hudgins and Numbers (1942; cited in Rathna Kumar 1998: 2.24) reported that the omission of consonants might occur in the initial and /or final position of the words, and also reported that as the nonfunctioning of releasing or arresting of consonants respectively. The consonants which were frequently omitted from the initial position of words included / h/, /l/, /r/, / y/, / ɵ/, / s/.

Markids (1970; cited in Rathna Kumar 1998: 2.24) reported that the deaf children misarticulated nearly 72% of all consonants attempted, while the partially hearing children misarticulated a little over 26%. This study showed that, in the deaf individuals omissions were more than substitutions and distortions. Among partially hearing impaired children substitutions were found to be more than omissions and distortions.

The stops are unique among the sounds of speech in that they include a variable period of total blockage of airflow during which sound output may cease. During this interval, air pressure rises behind the point of closure to be released as a burst of acoustic energy. Plosives are stops in which the pressure is built up pulmonically. It has been reported that it is difficult to extract the acoustic characteristic of consonants produced by the hearing impaired either because of the mismatch between spectrograph filters and fundamental frequency or due to source function abnormalities (Monsen et al. 1979; cited in Rathna Kumar 1998: 2.25)

Perkell et al. (1992) have found that there were trends towards improvement of vowel production. They also expressed an opinion that along with cochlear implant, the prior experience of language governed the gains.

However a study by Tye-Murray et al. (1996) found no difference between speech with and without cochlear implants on vowel height, vowel place, initial consonant place, initial consonant voicing and final consonant voicing.

Tye-Murray and Kirk (1993) have used phonetic vowel evaluation to find how children with implants produced vowels and diphthongs. They concluded that the production of vowels and diphthongs diversified and became more accurate over the period of usage of cochlear implant.

The review of literature has shown that the children using cochlear implants have benefited in the perception of speech sounds. The benefit is also evident in their speech production.

**Formant frequency characteristics of vowels**

Vowel production in an individual is influenced by vocal tract configurations. The vocal tract configuration modifies spectrum of the vowels. The length of pharyngeal tract, the location of constriction in the tract and the degree of narrowness of the constriction affect the formant frequency locations for vowels.

(1) Length: The frequencies of all formants become low as the length of the vocal tract increases.

(2) Lip rounding: Increased constriction of the labial port also lowers all formant frequencies.

(3) Anterior oral constriction: Elevation of the front of the tongue lowers the first formant and raises the second formant.

(4) Posterior oral constriction: Raising the posterior part of the tongue tends to lower the second formant.

(5) Pharyngeal constriction: Narrowing the pharynx raises the frequency of the first formant.

(6) Nasalization: The effects of coupling the nasal resonant space to the vocal tract are very complex. Not only are the resonant frequencies altered, but also anti-resonance is introduced.

Peterson & Barney (1952; cited in Rathna Kumar 1998: 2.10) studied the formant frequencies of vowels in children. The formant frequencies studied were the first (F1) and second (F2). Formants are traditionally used to provide an acoustic description of vowels. The higher formants other than F1 and F2 are less important to determine the phonetic quality of vowels sounds. For speech intelligibility second formant is more important as it lies within the most sensitive range of human hearing. F1 represents the tongue height. F1 increases and then decreases as the vowel changes from /i: / to /u/. F2 which represents the constriction of the tongue in the front back plane which decreases from /i:/ to /u/ and it represents the constriction of the tongue in the front –back plane.

Eguchi and Hirsh (1969 cited in Rathna Kumar 1998: 2.11) studied formant frequencies of vowels in children of both the sexes and ages 3 to 13 years. They reported the mean formant frequencies of vowels produced by children of age range 5 to 10 years are as follows.

| | /i/ | | /i:/ | | /a/ | | /a:/ | | /u/ | |
|---|---|---|---|---|---|---|---|---|---|---|
| Age | F1 | F2 | F1 | F2 | F1 | F2 | F1 | F2 | F1 | F2 |
| 5 | 408 | 3235 | 645 | 2418 | 643 | 2423 | 901 | 1530 | 452 | 1477 |
| 6 | 397 | 3108 | 512 | 2281 | 611 | 2238 | 689 | 1308 | 431 | 1385 |
| 7 | 411 | 3204 | 664 | 2280 | 736 | 2299 | 870 | 1398 | 481 | 1525 |
| 8 | 397 | 3104 | 585 | 2195 | 685 | 2222 | 743 | 1359 | 450 | 1437 |
| 9 | 403 | 3106 | 308 | 2296 | 647 | 2295 | 836 | 1352 | 469 | 1392 |
| 10 | 403 | 3028 | 645 | 2193 | 734 | 2255 | 814 | 1336 | 469 | 1351 |

Sheela (1988) studied four children with congenital deafness of 8 to 10 years. She found that the hearing impaired children had higher F1, F2 and lower F3 than those of normal group. She concluded that hearing impaired speakers tend to keep the tongue at higher position in the oral cavity and this might be because of pharyngeal constriction. She further added that speech intelligibility was poor due to the lowered second formant. However, the hearing impaired group showed higher variability than normal. Levitt (1976 (cited in Rathna Kumar 1998: 2.11-12)) studied the acoustic and perceptual characteristics of speech of the children with deafness and reported that the formant frequency values were typical of the schwa vowel.

Ryalls et al. (2003) studied CV syllable productions of French speaking children aged 8 to 10 years, in each of the three groups, i.e children with normal hearing, children with moderate to severe hearing loss, children with profound hearing loss. Each group consists of 10 subjects. The speech samples were obtained through imitation and they were recorded. The recorded samples were subjected to spectrograph analysis by using Bliss speech analyzing software. He found that F1, F2 and F3 for children with profound hearing impairment were significantly different from that of both children with moderate to severe hearing impairment and normal hearing children. The formant frequencies of children with profound hearing losses exhibited more centralized formant frequencies. He further stated that the F2 second formant showed typically higher frequencies in the children with greater degree of hearing loss. He concluded that the F2 of /i: / would change according to the degree of hearing loss than for F2 values of /u/ and /a/.

Geers et al. (2003) analyzed the speech of 181 cochlear implant users and 24 normal hearing age mates (age range between 8 to 9 years). They obtained the sentences from spontaneous speech samples and analyzed the target words in these. They found that second formant frequency (F2) values were within the range of values of normal hearing children. The F2 values are depicted below:

**Table 2.3: The mean and standard deviation of second formant frequency (F2) for vowel /i: / and /i/ in 24 normal hearing children and 181 cochlear implanted children.**

| | Total Communication | | | Oral | | | Normal Hearing | | |
|---|---|---|---|---|---|---|---|---|---|
| Measure | Mean (SD) | Min | Max | Mean (SD) | Min | Max | Mean (SD) | Min | Max |
| F2 /i:/ (HZ) | 2838 (360) | 1437 | 3557 | 3003 (237) | 2437 | 3451 | 2978 (181) | 2511 | 3379 |
| F2 /i/ (HZ) | 1430 (152) | 1144 | 2052 | 1408 (143) | 1096 | 1789 | 1422 (145) | 1211 | 1678 |

Zwicker and Terhardt (1980) proposed bark (critical band) scale as a means of converting acoustic frequency measures to a scale that more closely reflects the processing capacities of the peripheral auditory systems. It has been determined from a wide variety of psychoacoustical experiments, including loudness summation, narrow-band masking, and two-tone masking, threshold of complex sounds, phase sensitivity, musical consonance, and discrimination of partials in a complex tone. A current functional view of the auditory system is that it is composed of a series of internal bandpass filters whose bandwidths overlap. The bandwidth of each one of these internal filters corresponds to a critical band. Acoustic energy falling within the critical bandwidth of an internal filter is integrated. One Bark equal to the width of one critical band which represents a relatively constant length of about 1.3mm along the basilar membrane and about 1300 cochlear neurons physiologically. The Bark scale increases with frequency linearly up to about 500Hz and approximately logarithmically thereafter.

Syrdal and Gopal (1986) employed acoustic analyses of the distance between formants and vowel features in American English production. The results revealed a critical distance of 3 bark between F1 and F0 and between F3 and F2 to predict vowel height and place respectively. F1-F0 distances less than 3 Bark were obtained in high vowels whereas low vowels exhibited F1-F0 distances greater than 3 Bark. Similarly, front vowels presented F3-F2 greater than 3 bark. The vowel contrasts of height and place in the American English inventory met the criteria of sufficient discriminability by taking advantage of the critical distance constraints imposed by the perceptual spectral center of gravity effect.

Rathna Kumar (1998: 4.26-27) in his study on temporal and acoustic aspects of speech in Telugu speaking children and reported that:

(a) For vowels, the bandwidth B1 in the case of male hearing impaired group was lower for vowels /i/, /u:/, /e/ and significant differences were found only for vowels /u/ and /e:/ when compared to the normal male group.

(b) B1 in the case of female hearing impaired group was found to be lower for vowel /a/, /a:/, and /e/ and significant differences were found for vowels /u:/ and /o:/ as compared to normal group.

(c) B2 for male hearing impaired group was found to be lower for all the vowels except /i/ and /u/ and significant difference was found for vowel /o/ when compared to the normal group.

(d) B3 in the vowels uttered by male hearing impaired group were found to be lower for all the vowels except /a/, /o:/ and significant difference was found only for /o:/ and /e:/ when compared to normal male groups. Thus, over all it was found that the bandwidth of vowels shown by both male and female hearing impaired groups were found to be lower than normal groups.

Crystal Chan Waiman (1997) investigated how perceptual constraints affected the contrastiveness and intelligibility of spoken vowels from speakers with severe and profound hearing loss. 10 speakers with normal hearing, 10 with severe hearing loss and 10 with profound hearing loss produced the vowels /a/, /i/, each in a CVC context. Acoustic analyses included measurement of the fundamental frequencies and the first three-formant frequencies of each vowel. The frequencies obtained were transformed to Bark auditory scale, which is a scale more closely reflecting the processing capacities of the peripheral auditory systems, to establish auditory formant distances. The Bark scale increase with frequency linearly up to about 500 Hz. The result obtained from the analysis of the mean Bark distances of high versus low (F1-F0) and front versus back vowels (F3-F2), it was suggested that the 3-Bark critical distance differentiating vowel placement was violated by both severe and profound hearing-impaired speakers whereas the 3-Bark critical distance for height differentiation was only violated by profound hearing-impaired speakers.

**Fundamental frequency characteristics**

It is well known that the fundamental frequency lowers as one progress from childhood through adolescence and then to adulthood. In order to achieve these changes in fundamental frequency, normal auditory feedback plays an important role (Boone 1966). He also stated that the voice of hearing impaired children of 7-8 years is not higher than the normal hearing group. But, as the deaf children grow older, they do not necessarily develop the lower voices of the normal hearing preadolescent children. He concluded that the deaf child or adult, who lacks auditory feedback, appears not to be getting enough pitch perception through the amplification device. Several investigators have reported higher fundamental frequency in their deaf subjects.

A study by Angelocci et al. (1964) on speech of the deaf children through the spectrogram and found higher fundamental frequency in them and he concluded that deaf children tend to have higher fundamental frequency due to lack of auditory monitoring of their own speech and as well as sometimes faulty time integration between the articulators.

Rajanikanth (1986), Manjula (1987) and Aparna (1996) investigated the fundamental frequency in the speech of children with profoundly hearing impairment studying in Kannada medium. The samples obtained from these children were the production of /a/, /i/, /u/ vowels in isolation and repeated sentences and were analyzed acoustically. The results indicated that the hearing impaired children had higher average fundamental frequency. However, individual variations in the speech of hearing impaired children were apparent.

Willeman and Lee (1971) hypothesized that the hearing impaired speakers used extra vocal effort to give them an awareness of the onset and progress of voicing and this become the cause for the high pitch observed in their-speech. The auditory feed back system is the main channel for appropriate establishment and production of pitch (F0).

Rahul (1997) studied the speech pattern of kannada speaking hearing impaired children in the age range of 5 – 8 years, he reported the following:

1. The fundamental frequency is great in the speech of the hearing impaired as compare to the normal hearing speakers for vowel /a/, /a:/, /e/, /e:/, /i/, /i:/, /o/, /o:/, /u/ and /u:/ in the word initial and word medial position.
2. The vowel formant frequencies, in the speech of the hearing impaired vary from that of the normal hearing speakers, such that,

(a) F1 may be higher, lower, or similar to the normal hearing speakers.

(b) The F2 is lower than normal for the front vowels, and higher than normal for the back vowel.

(c) The F3 tends to be higher than the normal hearing speakers.

Schenk et al. (2003) aimed at investigating the features of vowels, which reflect improvements in speech production. Speech of ten postlingually deafened subjects (5 male / 5 female) was recorded when reading a German text before 3 and 12 months after implantation respectively. The vowels were analyzed for fundamental frequency (FO), the formant frequencies (F (1), F (2), F (3)) as well as for the vowel space (difference between F(1) and F(2) in Hertz)

The results revealed that

- F (0) decreased descriptively only after 3 and 12 months respectively.
- F(1) of the vowel /e/ was significantly lower after 12 months and for /o/ after 3 months for the male patients, also their vowel space expanded significantly for the vowel /o/ after 12 months.

The authors concluded that regained auditory feedback after implantation had an effect on the improvement of the production of vowels.

Campisi (2005) studied the acoustic abnormalities of the deaf pediatric voice and the effect of artificially restoring auditory feedback with cochlear implantation in 30 children (15 prelingually, 15 postlingually deaf) with severe to profound hearing loss. Objective voice analysis was done prior to implantation at the time of implant activation and 2 and 6 months post activation. Fundamental frequency, long – term control of Fundamental frequency (vF0) and long term control of amplitude (vAM) were derived. The dynamic frequency range and formant frequencies (F1, F2, and F3) were also determined. The authors concluded that the mean F0 was 267.8 Hz and consistent with established normative data. The mean measurement of jitter and shimmer were also within normal limits. The notable feature of the acoustic analysis was a statistically significant elevation in vFO. The auditory deprivation resulted in a poor long term control of frequency and amplitude during sustained phonation. The inability to maintain a sustained phonation may represent the partial collapse of an internal model of voice and speech.

Poissant (2006) examined the relationship between objective and subjective measurable changes in speech production following a direction in auditory feedback provided from an implant in six children with profound sensorineural hearing loss. Speech samples were collected in two conditions with and without auditory feedback from their implants. Objective measures included duration, fundamental frequency as well as the first and second formats of vowels. Subjectively the samples were analyzed by familiar and unfamiliar listeners. The results indicated that all the children, demonstrated variable acoustic voice and speech changes in following deactivation of their CI devices. On the whole, it can be concluded that following the implantation deaf children relay to some extent on auditory feedback from the implant to control and modify F0, duration and vowel formant production.

Cerci et al. (2006) investigated the effect of cochlear implant on voice development in prelingually deaf children. They studied 60 prelingually deaf children with cochlear implantation. The voice analyses were made between 6 to 21 months after the first fitting and six months after base line. They evaluated F0, F1, F2 values of vowel /a/. The subjects were divided into 2 groups – (1) according to age: below 48 months (2) according to the duration of CI usage. The results revealed that F0 and F2 values significantly differed between the first and second voice analysis where as the change in F1 value was insignificant. They also found that there was no significant difference found in terms of F0, F1, F2 values between experimental & age matched control group.

Kunisue et al. (2006) investigated the correlation between vocal and hearing development by longitudinal analysis of sound spectrograms as a basic system for evaluating progress in vocal development. They evaluated 2 school aged children with prelingual deafness and assessed speech perception & speech intelligibility after cochlear implantation. One child had non–syndromic hearing impairment without any known neurological deficit, while the other child had hearing impairment, mental retardation and attention deficit disorder. The authors recorded their voices for monthly follow up after cochlear implantation and used it for formant analysis and then compared it with their mother's voice and monosyllable production. The results in the study reveal that there is a high concordance between monosyllable speech perception and speech intelligibility F1–F2 forms for these points resembled that of their mothers after 1 year follow-up. Thus, the authors conclude that there appears a fair improvement of articulation after cochlear implantation demonstrated by F1-F2 analysis.

Perkell et al. (2007) investigated the timing of changes in parameters of speech production in six cochlear implant users by switching their implant microphones off and in a number of times in a single experimental session. The subjects were asked to repeat for short, two word utterances in quasi–random order. Postural measure were made of vowel sound pressure level (SPL) duration

F0, contrast measure were made of vowel separation. The results reveal that there were some changes in duration, SPL and F0 during the vowel in which hearing state was changed, V1 as well V2 and subsequent utterance repetition.

Evans and Deliyski (2006) also used acoustic analysis to explore changes in noise and speech of three prelingually deaf male subjects pre and post implantation over 6 months. They obtained F0, jitter, shimmers, noise–to–harmonic ratio, voice imbalance index, soft phonation index, amplitude, F0 variation, F0 range, speech rate, nasalance and vowel production. The results showed patterns of change for some of the parameter while there was considerable variation across the subjects. All the subjects demonstrated a decrease in F0 in at least one content and also a change in nasalance towards the norm as compared to their normal hearing control group.

## 2.4. TEMPORAL CHARACTERISTICS OF VOWELS

### Vowel duration

Rathna Kumar (1998: 2.12) states that in his analysis of vowel duration, the duration of a phoneme bears important information in the perception of a speech message. Each vowel has an intrinsic duration which is influenced by the physical properties of the speaker's production mechanism. This need not be learnt. Even prior to the age of three, children can recognize important temporal parameters of the language.

Duration is an important aspect of the message comprehended. Several studies on the durational aspects of speech sounds have been conducted which reveal marked variations as well as small variations in the segmental duration (Carlson and Granstrom 1975). Variation in segmental duration is important cause of acoustic variability in the realization of linguistically identical units (Nooteboom 1973). Among segmental duration vowel duration is an important parameter which provides information on the prosodic as well as linguistic aspects of speech.

Vowel duration may have different linguistic functions in different languages. In certain languages, meaningful difference may be associated with the change in the duration of a consonant or vowel. In some languages, however, changes in the duration of sound may be determined by the linguistic environment and may be associated with preceding or following segmental sounds, initial or final position of an utterance, or type and degree of stress. Such durational changes in turn may become cues for the identification of the associated phoneme (Peterson and Lehiste 1967).) The durational rules are a reflection of the performance of the speaker's control of temporal factors in speech (Umeda 1975).

Hillenbrand et al. (1995) carried out a study on vowel acoustics. The subjects included in the study were 45 men, 48 women and 46 ten to twelve year old children. The stimulus material included 12 vowels in /CVC/ context. In which they reported significant differences in vowel duration across the three talker groups. They also reported longer durations for children than adults; the values are shown in the table 2.4 below.

**Table 2.4 Average Vowel duration measured in msec for men, women and children (Hillenbrand et al. 1995):**

| Vowel | /i: / | /i/ | /e: / | /e/ | /a: / | /a/ | /o: / | /o/ | /u: / | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|
| Male | 243 | 192 | 267 | 189 | 278 | 267 | 283 | 265 | 192 | 237 |
| Female | 306 | 237 | 320 | 254 | 332 | 323 | 353 | 356 | 249 | 303 |
| Children | 297 | 248 | 314 | 235 | 322 | 311 | 319 | 310 | 247 | 278 |

Nataraja and Jagadish (1984) conducted a study to measure the durations of /i/ and /u/ in a VCV syllable /idu/ in 10 male and 10 female adults. The subjects were asked to read three sentences at normal pitch and also at two other pitches (higher and lower than normal pitch) maintaining the loudness constant. The results indicated that all the male subjects of the study showed distinct increase in the duration of vowel /i/ and /u/ when the fundamental frequency was either increased or decreased. Similarly in females, the duration of vowels /i/ and /u/ had increased at high and low fundamental frequencies when compared to the duration of vowels at normal fundamental frequency.

Savithri (1986) analyzed the duration of Kannada vowels. The subjects included for the study were 3 males and 3 females in the age range of 22-40 years. The vowels studied in the study were /a/, /i/, and /u/ and 10 stop consonant which covered all the places and manner of articulation. The results obtained indicated that the average duration of vowels in females was longer when compared to males.

Sasidharan (1995) investigated vowel duration in Malayalam. The subjects included were 10 normal adults (5 males and 5 females) in the age range of 18-30 years. Fifty words with ten vowels /a, a:, i, i:, u, u:, e, e:, o, o:/ in the word initial, medial and final positions were selected. The results indicated that vowel duration was also affected by gender differences; he reported that vowels were longer in females compared to males.

Sreedevi (2007) studied vowel duration in Kannada for ten long and short vowels /a/, /i/, /e/, /o/, /u/ and /a:/, /i:/, /e:/, /o:/, /u:/. The total number of 30 subjects participated in the study. The subjects were divided in three age groups 7-8 (children) years, 14-15 (adolescents) years and 20-30 years (adults). Each group consisted of 5 males and 5 females. The results indicated that the short vowels in females were longer by 16% and 17% to their male counter parts in adolescents and adults, females also showed 10%, 17% and 19% long vowel duration when compared to their male counterparts in children, adolescents and adults.

Prabhavathi Devi (1990) studied the length of vowels in Telugu with the help of instruments and compared it with that of English. The following aspects were taken into consideration while describing the vowel in both the languages: 1) phonemic contrast, 2) intrinsic duration, 3) influence of adjacent sound 4) positional variation, 5) syllable structure, 6) stress. The important findings of the study were 1) In both English and Telugu the contrast between the short and long vowels is phonetic as well as phonological (though in English a few short vowels do not have corresponding long vowels). The ratio of the long and short vowel in English as well as in Telugu is more or less the same. It is approximately 1:2 for Telugu as reported by Girija and Sridevi (2003). 2) In both the languages under study, the duration or length of a vowel is related to the degree of openness or the height of the tongue. A low or open vowel is longer than high or closed one (Girija and Sridevi 2003). This brings out another interesting fact that the duration of a vowel in Telugu is affected by the adjacent sounds as in English. 4) The length of the vowel, in the word final position is greater than it is either in the medial or initial position in Telugu as well as in English.

**Table 2.5.Duration of short vowels in initial position reported by Prabhavati Devi (1990)**

| Vowel | /a/ | /i/ | /e/ | /o/ | /u/ | /a:/ | /i:/ | /e:/ | /o:/ | /u:/ |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration | 107 | 93 | 103 | 143 | 90 | 253 | 223 | 207 | 243 | 187 |

**Table 2.6.Duration of short vowels in initial position reported by Girija and Sridevi (1990).**

| Vowel | /i/ | /i: / | /e/ | /e: / | /a/ | /a: / | /o/ | /o: / | /u/ | /u: / |
|---|---|---|---|---|---|---|---|---|---|---|
| Duration of vowel | 86 | 178 | 87 | 176 | 80 | 217 | 129 | 200 | 77 | 183 |

Konefal et al. (1982) reported that the prepausal lengthening effect identified for adults were also found in young children's spontaneous utterance. Durational changes in vowels serve to differentiate not only between vowels themselves but also between similar consonants adjacent to those vowels. Lengthening or shortening of a vowel or any speech segment can be done by altering the particular context.

Rashmi (1985) measured the vowel duration of /i/ in /idu/ in Kannada speaking children's speech and found that both males and females showed a consistent decrease in the vowel duration as a function of age. The vowel duration reported by Rashmi is shown in the table 2.7.

**Table 2.7. Vowel duration of /i/ in /idu/ in Kannada speaking children in different age groups.**

| **Age** | **Vowel duration (msec)** |
|---|---|
| 5-6 | 158.07 |
| 6-7 | 121.79 |
| 7-8 | 111.32 |
| 8-9 | 88.31 |
| 9-10 | 87.28 |

Savithri (1984) found that a low vowel had longer duration than a high vowel in Kannada. The duration of the speech segment is altered in hearing impaired speakers. There is a general tendency towards lengthening of vowels and consonants. The prolongation of speech segment such as phonemes, syllables and words are often, present in the speech of the hearing –impaired (Osberger and McGarr 1982:221). Calvert (1961; cited in Rathna Kumar: 2.15) was among the first to do objective measurement of phonemic duration in speech of the hearing impaired by spectrographic analysis of bisyllabic words. The result of this study showed that hearing impaired speakers extended the duration of vowels.

Studies done by Rajanikanth (1986), Shukla (1985), Sheela (1988) and Jagadish (1989) on Indian hearing-impaired population speaking kannada showed longer vowel duration. Rajanikanth (1986) who used and compared male and female hearing impaired (n = 53) found significant difference. Sheela (1988) and Jagadish (1989) studied speech of the hearing impaired children and found that the hearing impaired showed greater variation in their vowel production. Osberger and Levitt (1979) observed that syllable prolongation in the speech of the hearing impaired was due to prolongation of vowels.

Roman (2004) studied voice onset time encoding in patients with left and right cochlear implants by investigating stop-consonant discrimination in normal hearing listeners and cochlear implantees by recording auditory evoked potentials (AEPs) to /bepsilon/ and /pepsilon / syllables. The results demonstrated that:

1. The time- locked components of AEPs mimic the temporal structure of the

stimuli, indicating that both patients and control subjects encode those syllables according to the temporal cue.

2. The side of implantation does not affect the general structure of AEPs and /b epsilon / - /p epsilon/ discrimination thresholds.
3. Poor time- locking to the syllable's temporal structure is associated with poor discrimination.

These findings reveal that EEG investigation of temporal processing provides an objective index of speech perception that could be used with children with cochlear implant.

Chinchilla and Nogaki (2005) in their study explored the relative contributions of spectral and temporal information to voice gender identification by cochlear implant users and normal hearing subjects. Voice gender identification was tested for two talker sets.

In talker set 1. The mean fundamental frequency values of the male & female talkers were different by 100Hz while by 10Hz in Talker set 2. CI listeners achieved higher levels of performance with talker set 1, while reduced performance for talker set 2.

For normal hearing listeners, performance was significantly affected by spectral resolution for both sets. Also the performance of CI listeners was similar to normal subjects listening to 4-8 spectral channels. The results suggest that CI patients may attend strongly to periodicity cues for voice gender identification due to reduced spectral isolation.

**Duration Characteristics of Vowels**

The duration of a phoneme bears important information in the perception of speech. Each vowel has an intrinsic duration that is influenced by the physical properties of the speaker's production mechanism. Even vowel duration is an important aspect in one's language system. It changes the meaning and understanding of a word by a listener when it is mispronounced. This need not be learned. Even prior to the age of three, normal children can recognize important temporal parameters of language.

Konetal (1982) reported that the pre-pausal lengthening effect identified for adults were also found in young children's spontaneous utterances. Durational changes in vowels serve to differentiate not only between vowels themselves but also between similar consonants adjacent to those vowels.

Calvert (1961; cited in Rathna Kumar 1998: 2.15) based on the objective measurement of phonemic duration speech of the hearing impaired using spectrographic analysis of bisyllabic words and reported that the hearing impaired speakers extended the duration of vowels. Further, he added that hearing impaired children have the tendency towards lengthening of vowels and consonants.

Disimoni (1974) based on the oscillographic measurements of vowel and consonant duration in CVC and VCV utterances of 3, 6 and 9 years old children. He reported the following.

(1) Variability of the duration tended to decrease with age.
(2) The vowel duration in the voiceless consonant environments remained relatively constant for all age groups, while in voiced consonant environments, it was found to increase with age.
(3) When compared vowel durational values compared for voiced and voiceless consonant environments were found to be significantly different in 6 and 9 year old subjects, but not in 3 year old subjects.

Studies conducted by Rajanikanth (1986), Shukla (1985), Sheela (1988) and Jagadish (1989) on Indian hearing impaired population showed longer vowel durations in all the hearing impaired subjects. Rajanikanth (1986) reported significant increase in vowel duration in VCV syllables of 53 Kannada speaking profoundly hearing impaired children. Sheela (1988) and Jagadish (1989) studied VCV syllable utterances of hearing impaired children and reported that hearing impaired showed a greater variation in vowel production in both the initial and medial positions.

Somya (1992) reported that in the speech of severely and profoundly hearing impaired children, the mean vowel duration obtained were higher than normal subjects. Sheela (1988) investigated vowel duration of bisyllabic Kannada VCV words in children with profound hearing impairment in the age range of 8-10 years and the results indicated that the hearing impairment group had significantly higher vowel and word duration. Stomberg et al (1979) observed syllable prolongations in the spontaneous speech productions of hearing impaired children. They concluded that this was due to prolongation of vowels.

Leeper (1987; cited in Rathna Kumar 1998; page no 2:15) studied the total syllable duration for VCV syllables, initial and final vowel duration in five hearing impaired and nine age and sex matched normal hearing children who served as controls. The speech stimuli employed were bisyllabic (VCV) utterances with a symmetrical vowel /a/ - obstruent /p/ - vowel /a/ format. The stimuli were in 3 – utterance contexts of increasing length, i.e. /apa/, /saw apa/ or /saw appa/. The results showed that hearing impaired children took significantly longer time than their controls to produce the syllables. In addition, there was a numerical trend for the word like utterances in the phrase to be shorter than the next word for the hearing impaired children than normals. Analysis of the temporal characteristics of initial and final vowels in the /appa/ utterance showed that the hearing impaired children had significantly larger duration on both positions of the syllable than did their controls.

Ryalls (2003) studied 18 basic stop syllables in moderate to severely hearing impaired and profoundly hearing impaired children. He found that increased syllable duration was observed more commonly in profoundly hearing impaired children than in moderate to severely hearing impaired children. However, both groups demonstrated extended syllable duration than normal hearing children. These results are in agreement with that of Leeper (1987). Thus, the hearing impaired speakers had an overall tendency to prolong the segmental duration. This leads to altering of time control. Reduction in the rate of speech in turn results in poor speech intelligibility.

Geers and Rosalie (2003) studied the selective acoustic characteristics of cochlear implant user's speech and analyzed the vowel duration at initial and final positions. Results indicated that vowel duration of these children were significantly longer when compared with their normal hearing age mates. On the whole, cochlear implant users produced 59-79% accuracy at initial position and 58-86% accuracy at final position. The duration of the vowels are tabulated below:

**Table 2.8: Means and standard deviations of vowel duration found for initial and final vowels of target words**

| Measure | | Duration of Vowels in m sec | |
|---|---|---|---|
| | TC (n=89)<br>Mean(SD) | Oral (n=92)<br>Mean (SD) | NH(n=24)<br>Mean (SD) |
| Duration of initial vowel | 270 (103) | 210 (85) | 138 (19) |
| Duration of final vowel | 566 (132) | 546 (79) | 498 (44) |

Further, they concluded that the educational setup that the child is attending influences the language development of children and the acquisition of speech features.

Lane (1994) compared the VOT and syllable duration in four postlingually deafened recipients using multichannel cochlear implants for the English plosives, with speakers having normal hearing. For cochlear implant users, recordings were made before and at intervals following, the activation of implants. It has been found that in normal speakers, the VOT vary approximately linearly with syllable duration while in implant users, there was reduction in mean syllable duration following activation. The results also suggest that:

- In pre-implant all four speakers uttered voiced plosives with too short VOT when compared with normal subjects.
- Voiceless plosive mean VOT was abnormally short for two speakers and close to normal for the remaining two implantees.

These findings supported the hypothesis that speakers use their hearing to calibrate mechanisms of speech production by monitoring their articulations & acoustic output.

**Timing**

Physical measures of speaking rate have shown that profoundly hearing impaired speakers on an average take 1.5 to 2.0 times longer to produce the same utterances as do normal hearing speakers (Boone 1966; cited in Rathna Kumar 1998: 2.39). Hearing impaired speakers have been found to speak more slowly than even the slowest speakers with normal hearing. When hearing impaired speakers and normals have been studied under similar conditions, the measured rates of syllables or word production have often differed by a factor of two or more (Hood 1966; cited in Rathna Kumar 1998: 2.39).

Nikerson (1974) studied on rate of speech for reading among deaf and normal children revealed that reading rate was found large differences between the groups although the mean rate for the deaf was as high as 108 words/minute. The problem of reduced rate of speaking in the deaf speaker seems to be related to two separate problems:

a. Increased duration of phonemes and

b. Improper and often prolonged pause within utterances

**Increased duration of phonemes**

The duration of phonemes bears important information in the perception of a speech message. Duration changes in vowels serve to differentiate not only between vowels themselves but also between similar consonants adjacent to those vowels (Raphel 1972 and Gold 1980). There is a general tendency towards lengthening of vowels and consonants in the deaf (Angelocci 1962, Boone 1966, Levitt 1978 and Sheela 1988; cited in Rathna Kumar 1998: 2.39).

**Voice Onset Time (VOT)**

VOT is defined as the time equivalent of the space from the onset of stop release burst to the first verticals striation representing glottal pulsing. The release of the oral occlusion relative to the onset of glottal pulsing is termed the voice onset time of that consonant and it helps in achieving Voice –Voiceless distinction (Lisker and Abramson 1964; cited in Rathna Kumar 1998: 2.27).

VOT values either overlapped or VOT was found to be longer for voiceless stops than voiced stops. VOT measurements for / k /. /g / were found to be more complex than that of / p /, / b/, / t / and / d / implying that the subjects did not distinguish VOT among stops based on place of articulation. More segments were produced as voiced ones by the hearing impaired. Those who had clear demarcation of the voiced –voiceless categories tended to have high speech intelligibility (Rathna Kumar 1998: 2.28).

A study by Ravi Shankar (1981), Kushal Raj and Nataraja (1984) on VOT of normal hearing subjects in Kannada revealed that there was no significant difference in the VOT values with the increase in age (Table. 2.9).

**Table 2.9: Mean VOT for voiceless stop consonants (/p/, /t/, & /k/ ) from the studies of Ravi Shankar (1981), Kushal Raj and Nataraja (1984) for normal hearing children aged from 4-10 years.**

| Male Age | VOT values I milliseconds | | | | | |
|---|---|---|---|---|---|---|
| | /p/ | | /t/ | | /k/ | |
| | Ravi Shankar | Nataraja | Ravi Shankar | Nataraja | Ravi Shankar | Nataraja |
| 4 to 5 years | 18.4 | 18.9 | 22.4 | 35 | 41 | 28.07 |
| 5 to 6 years | 18 | 13.77 | 18.4 | 26.1 | 42.4 | 20.93 |
| 6 to 7 years | 18.4 | 15.66 | 17.4 | 23.21 | 38.6 | 19.43 |
| 7 to 8 years | 16.0 | 15.90 | 23.00 | 23.00 | 40.00 | 21.30 |

Monsen (1978) measured the VOT spectrographically in 36 children with profound hearing loss on word initial stops (/p/,/t/,/k/) and (/b/,/d/,/g/) and their results revealed the following: Some children distinguished the cognates in the normal manner. Voice onset time values were longer for the voiceless than voiced segments and voice onset time contrasts were longer for velars than for alveolars and bilabials. However, most of the hearing-impaired speakers did not observe the voiced-voiceless distinction and deviated from normal speakers in a similar way.

Leeper (1987) studied voice onset time among hearing impaired and normal children and reported that there was no significant difference in voice onset time for hearing impaired and normal hearing children. Shukla (1985) studied VOT in hearing impaired adults and reported that both the hearing and hearing impaired speakers had positive VOT values for voiceless stops. The VOT for the hearing impaired speakers showed negative values for voiced stops, while in a majority of hearing impaired speakers negative VOT were absent. The mean VOT values produced by both the groups increased as the place of articulation moved backward in the oral cavity.

Somya (1992) studied the speech of the Malayalam speaking children with severe to profound hearing loss and stated that there was no significant difference in the mean VOT values of both the groups though the hearing group showed longer voice onset time values for both voiceless and voiced stops.

Ryalls (2003) studied the acoustic properties of CV syllables and reported that children with profound hearing impairment demonstrated much less differentiated voice onset time between voiced and voiceless initial stops.

However, both Indian and Western studies show that voiced stops of hearing impaired tend to have longer voice onset time when compared with that of voiceless stops. This may result from a problem in temporal resolutions of speech sounds in profoundly hearing impaired children.

Geers (2003) studied voice onset time for /t/ and /d/ in normal and cochlear implanted school children in the age of 8 to 9 years. He found that children who attended oral settings produced voice onset times for /t/ and /d/ of 85% and 84%, respectively. In comparison children who were attending the total communication settings produced voice onset times of 62% and 63% respectively. The data is displayed in table 2.10.

**Table 2.10: Mean and standard deviation of alveolar stop consonants for 24 normal hearing children and 181 cochlear implant children**

| VOT | TC (n=89) | | Oral (n=92) | | NH(n=24) | |
|---|---|---|---|---|---|---|
| | Mean (Sd) | Min : Max | Mean (Sd) | Min : Max | Mean (Sd) | Min : Max |
| VOT /t/ (msec) | 65(32) | 32:149 | 80(21) | 18:142 | 72(15) | 40:101 |
| VOT /t/ (msec) | 17(11) | -46:37 | 1(9) | -43:36 | 17(5) | 1:25 |

Their results showed that children who studied in total communication system or oral system did not differ significantly in their ability to produce voice onset times for /d/.

## 2.5. TRANSITION CHARACTERISTICS

Formant frequencies of stops produced by the hearing impaired have been reported to be difficult to extract due to the acoustic characteristics of consonants either because of the mismatch between spectrograph filters and fundamental frequency. Moreover, for any sound due to the mis-articulation or modification either at the place of articulation or in the manner of articulation or both, the spectrographic pattern itself may be lost. There can be even additional spectral changes because of the insertion of the unwanted segment into the target sound. The extents of frequency range of the formant transitions reported are limited (Huggins 1980). Even it has been found that the slopes of transitions remained fairly flat when either a rising or falling pattern was indicated. Moreover, the F2 transitions in the speech of the hearing impaired have been found to be reduced in both time and frequency domain. Hearing impaired children have been reported to have a restricted range of movement or articulators in static position or with fronting or backing of the tongue or even with unwanted lowering of the velum affecting the spectral characteristics of the speech. It is to be noted that every production by the hearing impaired (whether correct or incorrectly produced) will have its own unique pattern. This may be on account of the inappropriate breath management for speech activities at the respiratory level; because of the increased level of amount of tacto-kinesthetic feedback; and because of the unique production patterns of the utterances by the hearing impaired, there will be a unique spectral change in the speech of hearing impaired (Calvert 1961; cited in Rathna Kumar 1998: 2.15).

Ravindar (2006) studied 45 Hindi speaking children in the age range of 6-12 years who were using hearing aids and cochlear implants. The acoustic analysis of CV syllable was compared with normal and reported that, there was a significant difference for fundamental frequency in normal hearing and hearing aid group as well as hearing aid group and cochlear implant group. Similarly he also reported a significant difference of F1, F2 and F3 between normal hearing and hearing aid groups along with the hearing aid group and cochlear implant group. A significant difference was found for vowel duration in CV syllable production of three vowels in all three groups.

## 2.6. INTELLIGIBILITY OF SPEECH OF THE HEARING IMPAIRED

Speech intelligibility refers to the degree to which the speech of an individual can be understood by listener. As the hearing impaired children have difficulty in co-ordination of the timing of targeting of the different articulatory movements and transition from one articulatory target to the other, they have poor speech intelligibility.

One of the most recognized but least understood concomitants of deafness is a deficit of oral communication skills. The speech produced by many deaf persons is frequently unintelligible to even experienced listeners like parents of the children with hearing loss and teachers of the deaf. It is frequently difficult to determine the exact nature of speech errors that reduce the speech intelligibility (Metz 1982; cited in Rathna Kumar 1998: 2.34).

Osberger and McGarr (1982; cited in Rathna Kumar 1998: 2.34) conducted a study on speech intelligibility of 192 subjects with hearing impairment ranging 8-19 years of age, a group of experienced listeners were asked to listen to the speech samples of the hearing impaired and write down whatever was understood by them. The mean score for the group was found to be only 29%.

Markids (1970 cited in Rathna Kumar 1998: 2.35) studied 58 hearing impaired children aged 7 to 9 years and reported that only 31% of their words were intelligible to their teachers whereas 19% intelligible to listeners and Gold

(1980; cited in Rathna Kumar 1998: 2.35) found that only about 20% of the speech of the deaf is understood by the person on the street. The lack of intelligibility may be attributed to several frequently occurring segmental and suprasegmental errors.

Ling (1976; cited in Rathna Kumar 1998: 2.36)) reported that, the intelligibility ratings can vary not only with the type of judge employed but also with materials used and with the methods of analysis applied. However, the results of various investigators suggest that the overall level of speech intelligibility is grossly inadequate for oral communication. Intelligibility rating have been reported to be 10 -15% higher when judged by teachers or experienced listeners than those by the naïve listeners.

Hudgins (1942; cited in Rathna Kumar 1998: 2.34) reported that, the words and sentences which are spoken directly to listener in a face to face situation are more intelligible than sentences that are tape recorded. This suggests that contextual cues also affect the intelligibility of speech. Poor speech intelligibility achievement in the hearing impaired has been correlated to several variables related to reception and production of speech.

Monsen (1978) found that all children he studied with hearing losses of 95 db HTL or less had intelligible speech but those with losses greater than 95 dB HL did not always have poor or unintelligible speech. Smith (1975) observed a systematic decrease in intelligibility with poor hearing level until a level of about 85 dB HL after which the intelligibility was poor.

Smith (1975) reported a high negative correlation between speech intelligibility and total number of consonants and vowel errors. Among consonant errors omission of initial consonants, voiced-voiceless confusion, and errors involving compound consonants had most detrimental effect on speech intelligibility. Substitution errors, nasality errors, omissions of final consonants and errors involving consonants had a lower correlation with intelligibility and contributed to a much lesser extent to the reduced intelligibility of hearing impaired children's speech.

Monsen (1978) examined the relationship between intelligibility and four acoustically measured variables of consonant production, three acoustic variables of vowel production and two measures of prosody. The three variables that were highly correlated with intelligibility were:

(1) the difference in VOT between /t/ and /d/

(2) the difference in F2 location between /i:/ and /I/

(3) acoustic characteristics of the nasal and liquid consonants.

Other segmental errors that have been observed to have a significant negative correlation with intelligibility are: Omission of phonemes in the word initial and medial position, consonant substitutions and unidentifiable or gross distortions of the intended phonemes (Levitt et al 1980).

In addition, Geers et al. (2003) studied the development of speech production skills in 181 children who were implanted by 15 years and had 4 to 6 years of experience to implantation. They examined speech intelligibility in relation with accuracy of consonant and vowel production. Their results revealed that speech intelligibility measured on an average at 63.5% and with the accuracy of phonemic production of higher for consonants (68%) than for vowels (61.6%) for the group. Among consonants more plosives were observed (91.6%) than fricatives (78.4%).

The results of various studies (Osberger and Levitt 1980 and Erber 1979) suggest that overall levels of speech intelligibility are utterly inadequate for oral communication because profoundly hearing impaired children who use conventional hearing aids mostly depend on the visual cues due to little auditory information (Ling 1976). However, the provision of cochlear implantation provides more auditory information in addition to visual cues. Thus they observed more access to speech information for cochlear implant users than the conventional hearing aid users.

Studies that have attempted to determine the cause and effect relationship between speech errors and intelligibility have dealt primarily with timing. Tye-Murray, Spencer and Woodworth (1995) showed that intelligibility of the speech of children with cochlear implant increased as a function of experience. This is supported by a study done by Osberger, Robins, Todd and Riley (1994), who has shown that speech intelligibility increased irrespective of whether the children with cochlear implants used total communication or oral communication.

Osberger, Maso and Heslie (1993) have measured the speech intelligibility of children with cochlear implants, tactile aids and hearing aids. They concluded that subjects with early onset of deafness who received their single–or multi channel cochlear implant before age of 10 years demonstrated the highest speech intelligibility, where as subjects who did not receive their devices until after age 10 had the poorest speech intelligibility.

## Conclusion

In the light of this review of literature it can be summarized that there are number of parameters that contribute to the development of speech and language characteristics of children with hearing impairment such as degree of hearing loss, age of onset of hearing loss, duration of speech therapy, type of schooling, type of amplification devices (hearing aids, cochlear implants, group amplification devices etc.), communication method used, parental motivation, intelligence, early identification and early intervention programmes and so on and the review shows that there are many studies done to explore these factors which contribute to the development of speech and language in children with hearing impairment.

Apart from these, review has also been done on the analysis of acoustic characteristics of speech of the children with hearing impairment in different languages which is very helpful in terms of diagnostic and intervention point of view. This also assists in making use of the advances in technology with maximal effectiveness in facilitating the oral production skills of persons with hearing impairment.

As there are very few studies which have explored the acoustic characteristic of hearing impaired speech with reference to Telugu language using hearing aids and cochlear implants, the present study has been taken up to analyze the acoustic data of Telugu speaking children with normal hearing, children with hearing impairment using hearing aids and cochlear implants, as it serves as one of the most direct ways to determine the benefit from auditory prosthesis, spectrographically in terms of average fundamental frequency (F0), formant frequencies (F1, F2 and F3), bandwidth characteristics (B1, B2 and B3), vowel duration and word duration of both long and short vowels in VCV syllable production.

# CHAPTER – III

# METHODOLOGY

## 3.1 Introduction

The current study is taken up with the aim to analyze the speech characteristics of Telugu speaking children with normal hearing, children with hearing impairment using hearing aids and cochlear implants, spectrographically in terms of average fundamental frequency (F0), formant frequencies (F1, F2 and F3), bandwidth characteristics (B1, B2 and B3), vowel duration and word duration of both long and short vowels in VCV syllable production.

## 3.2. Subjects

The following methodology was adopted for the study

A total number of 48 subjects (24 males and 24 females) participated in the study. The subjects for the study were divided into three groups with 8 males and 8 females in each group. Group I consists of 16 age matched children with normal hearing (males=8, females=8), Group II consists of 16 children (males=8 and females=8) with hearing impairment using hearing aids. Group III consists of 16 children (males =8, females =8) with hearing impairment using cochlear implants. All three groups consist of children with Telugu as native language. The subject selection criteria for each group would be as follows.

### 3.2.1. Group I Selection criteria

The subjects were selected by keeping the following criteria in mind:

1. No history of any hearing disorder.
2. In age range of 6-12 yrs (mean age-8.09).
3. No other history of neuromotor problems, mental retardation and other systemic disorders.
4. Ability to read simple VCV words in Telugu script.

### 3.2.2. Group II Selection criteria

The children with hearing impairment using hearing aids were selected based on the following criteria: (For details see appendix-I)

1. The children having bilateral severe to profound sensorineural hearing loss.
2. In the age range of 6-12 yrs (mean age-8.09).
3. Using hearing aids behind the ear (BTE) hearing aid, binaural fitting for at least 2 years.
4. Attending speech language therapy for at least 2 years.
5. Using at least simple sentences at the time of speech sample recording.
6. Ability to read simple VCV words in Telugu script.
7. No concomitant neuro-motor disorder, mental retardation and other systemic disorders.

### 3.2.3. Group III Selection criterion

The children with hearing impairment using cochlear implants were selected based on the following criteria (For details see appendix-II)

1. The children have bilateral severe to profound sensory neural hearing loss implanted with cochlear implant in one ear.
2. In the age range of 6-12 years (mean age-8.09)
3. Using cochlear implant in monaural fitting for at least 2 years.
4. Prior to use of implant children who had used a hearing aid and those who haven't used are also considered as subjects.
5. Attending speech language therapy for at least 2 years.
6. Using simple sentences at the time of speech sample recording.
7. Able to read simple VCV words in Telugu script.
8. No concomitant neuro-motor disorder, mental retardation and other systemic disorders.

## 3.3. Material

The test material consisted of ten bisyllabic Telugu words (VCV) having short vowels, /a/, /i/, /u/, /e/ and /o/ and long vowels /a:/, /i:/, /e:/ and /o:/. Simple words with VCV syllables were selected for the study so that both normal and children with hearing impairment using hearing aids and cochlear implants can read whichever is written on the flash cards) (size 6’’X 4’’). The first consonant will always be a plosive. This is to aid in appropriate temporal measures of the first vowel. The vowels analyzed are in the initial position. The full length of the variety can be found in the initial syllable and the shorter one in all initial syllables. The materials used for the study have been enclosed as appendix III.

### 3.4. Recording Procedure

The speech samples of all the children were recorded in a quiet room of the school building using a tape recorder. Subjects were comfortably seated and the microphone was kept at a distance of 10 cms from the mouth of the subjects. The recording microphone was covered by well foam to avoid capture of air turbulence and other noises. The subjects were instructed to read the word written on the flash card presented to them by the experimenter. The experimenter presented one card at a time to the child. Each child read the card at the comfortable loudness. Three readings of each word by each child have been recorded on a Digital recorder (D.35, Sony). A Sony C300 microphone was used to capture the response samples. But, out of three trails one which was considered to be most intelligible was selected for analysis purpose for each subject of the three groups. Subject was made to repeat after the experimenter whenever the subject had difficulty in reading the target word. A personal computer with CSL-4500/PRAAT, software program and processing unit was used to digitize the sample and analyze the acoustic properties.

### 3.5. Acoustical Analysis

The obtained data was subjected to the acoustical analysis to compare and analyze the speech characteristics of Telugu speaking children with normal hearing, children with hearing impairment using hearing aids and cochlear implants, spectrographically in terms of acoustic parameters such as average fundamental frequency (F0), formant frequencies (F1, F2 and F3), bandwidth characteristics (B1, B2 and B3), vowel duration and word duration of both long and short vowels in VCV syllable production.

#### 3.5.1. Parameters

The details of the parameters studied are as follows:

**Fundamental frequency (F0)**

Fundamental frequency is the first harmonic of the voice. It is the physical measure of lowest periodic component of the vocal fold vibration. In the present study Fundamental frequency is directly measured using the PRATT software. The recorded sample i.e. syllable, that was stored on computer using the software PRAAT, was displayed on the monitor of the computer and by visual inspection, the investigator, highlighted the vowel by moving the cursor from the beginning of the vowel i.e., the starting of the signal represented as waveform, to the end of the vowel i.e., end of the waveform and listened the same by playing the highlighted waveform back to confirm auditory that the vowel was highlighted then the highlighted portion was considered and "show pitch" was clicked to get average fundamental frequency of that vowel. When the highlighted waveform was considered auditory that it was not covering the vowel portion then the cursor was moved forwarded/backward depending on the position of the cursor and played back again. This procedure was carried out till the investigator was satisfied or confirmed auditorily that the highlighted portion of the waveform was covering the vowel portion and then highlighted portion was considered and show pitch was clicked to get average pitch of that vowel. This was done to obtain average fundamental frequency of the each vowel spoken by each subject of the three groups.

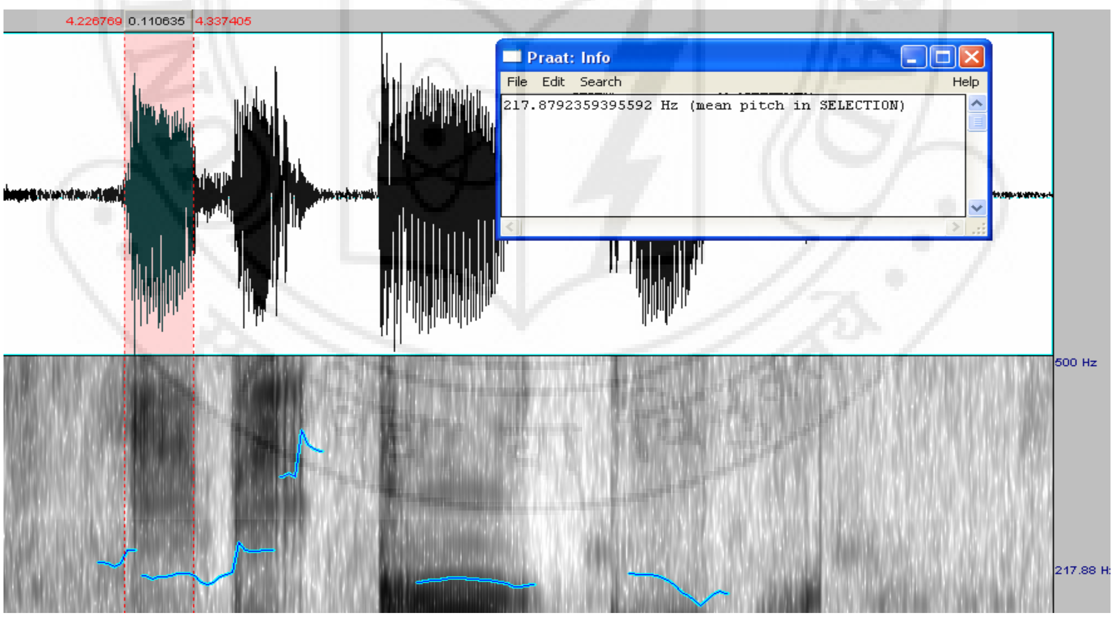



**Fig. 3.1. Fundamental frequency of a vowel in a VCV of subject with normal hearing.**

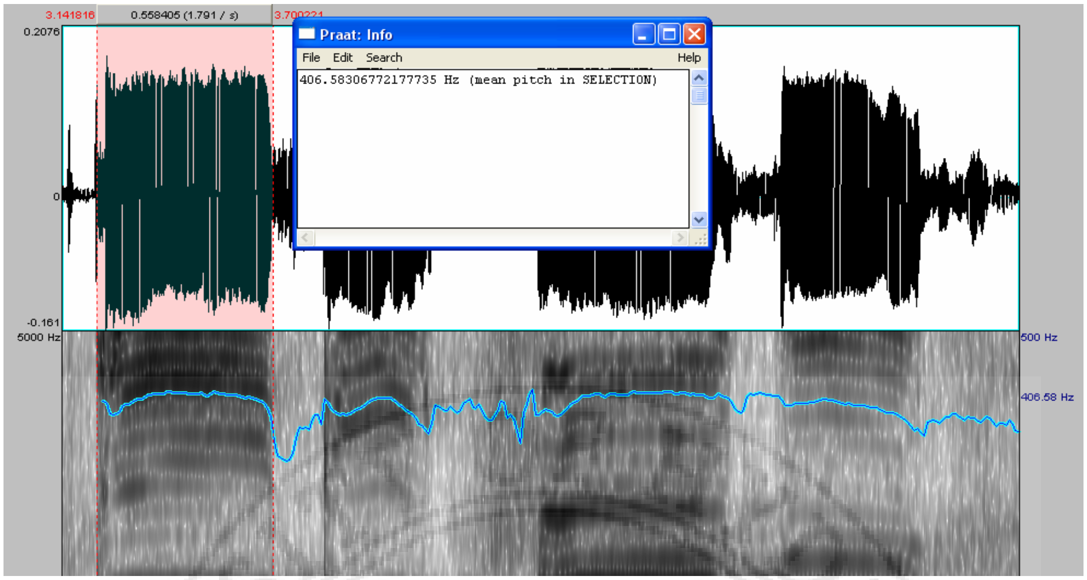



**Fig. 3.2. Fundamental frequency of a vowel in a VCV of subject with hearing impairment.**

**Formant Frequencies (F1, F2 and F3)**

Formant frequency is the center frequency of the formant. Formant frequencies F1, F2, F3 where noted at steady state for each of the first vowel in a VCV word. The unit used is Hertz. To extract the vowel formant frequencies ($F_1$, $F_2$, $F_3$) the spectrogram of each utterance using the formants programmer of the software "PRAAT" was used. The recoded sample i.e., each word that is stored on computer using the software PRAAT, was displayed on the monitor of the computer and by visual inspection, the investigator, highlighted the vowel by moving the cursor from the beginning of the vowel i.e. the starting of the signal represented as waveform, to the end of the vowel i.e. end of the waveform and listened the same by playing the highlighted waveform back to cinfirm auditorily that the vowel was highlighted then show formants was clicked to get formant frequency of that vowel, when the highlighted waveform was considered auditorily that it was not covering the vowel then the cursor was moved forward/backward depending on the position of the cursor and played back again. This procedure was carried out till the investigator was satisfied or confirmed auditorily that the highlighted portion of the waveform was covering the vowel and then show formants was clicked to get formant frequency value of that vowel. This was done to obtain each of the vowels spoken by each subject of the three groups.

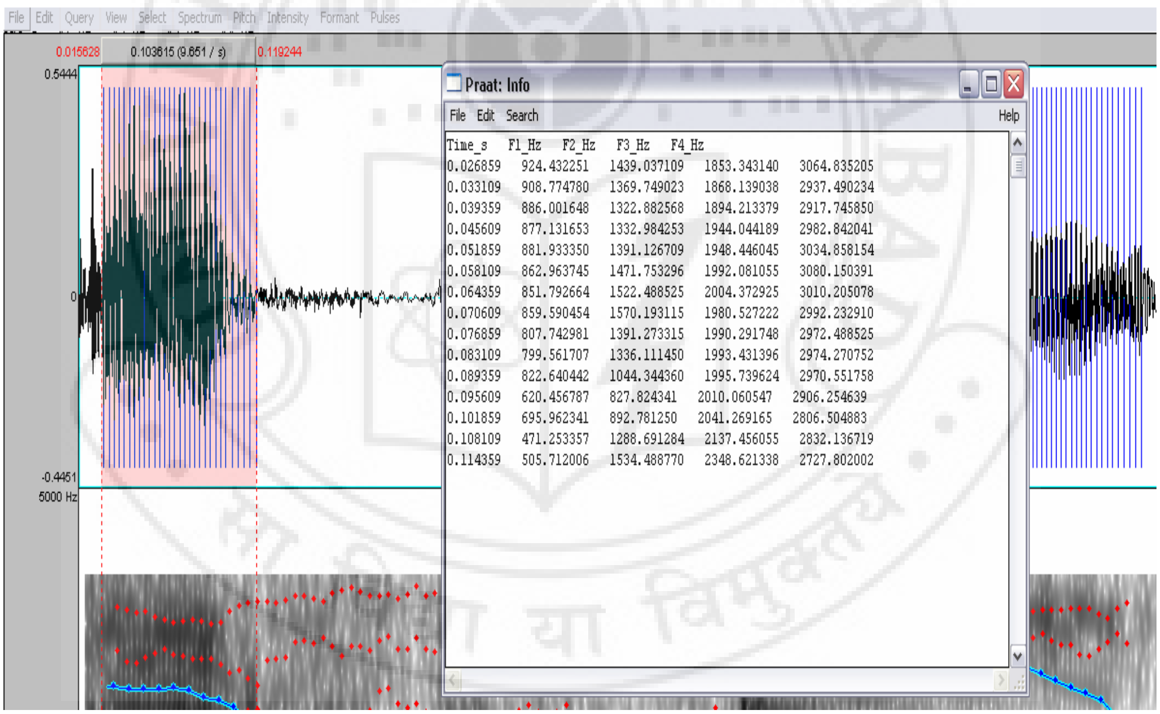



Fig. 3.3. Formant frequencies F1, F2, F3.

**Band width (B1, B2 and B3)**

Bandwidth is a measure of frequency band of a sound, especially a resonance. Bandwidth is determined at the half-power (3 dB down) points of the frequency response curve. That is both the lower and higher frequencies that define the bandwidth are 3 dB less intense than the peak energy in the band. The bandwidth, B1, B2, B3 of each of the formants F1, F2 and F3 respectively were noted for the first vowel in steady state. The unit used is Hertz.

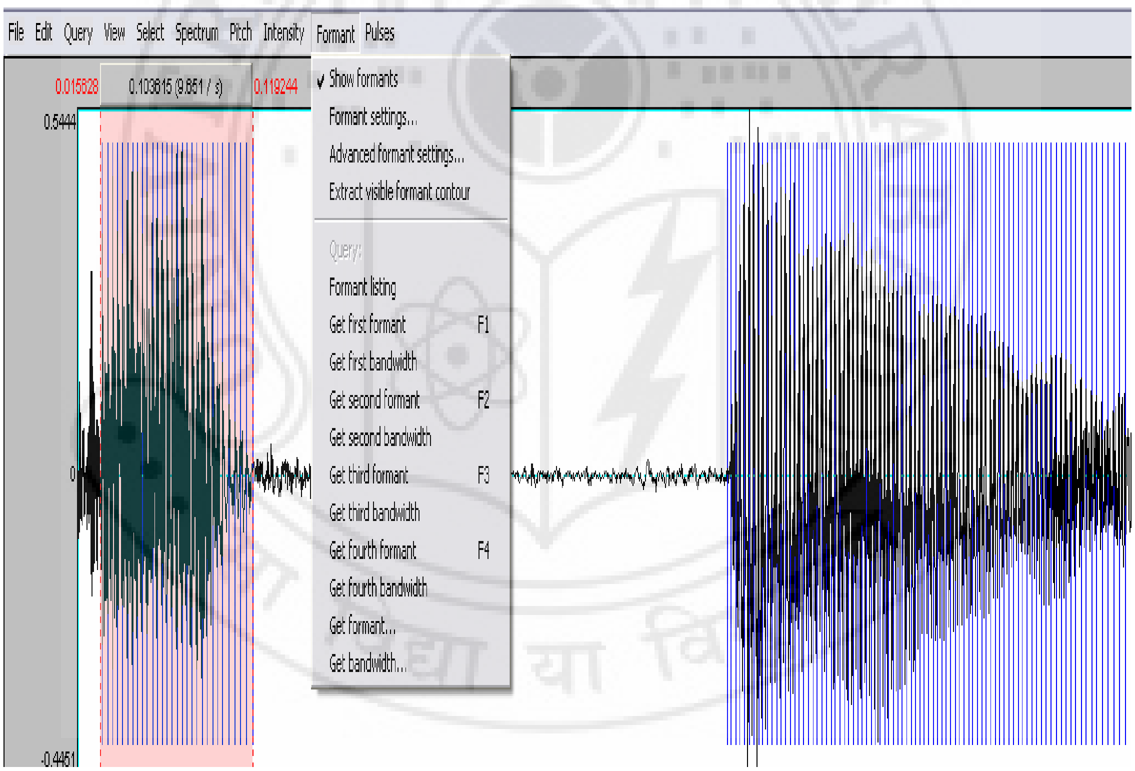



Fig. 3.4. Formant frequencies F1, F2, F3 and B1, B2, and B3.

**Vowel Duration**

Vowel duration is the duration of the first vowel in its steady state from onset to offset in the following consonant. The following consonant being a plosive, duration of vowel was measured till the closure duration onset. The unit used is msec.

The “PRAAT” software was used to measure vowel duration also. The vowel duration was considered to extend from the beginning of the periodic marking to the end of the periodicity. This duration was highlighted, through the use of cursors. The highlighted portion was played back through headphones, to confirm that the vowel under study has been marked correctly and thus the duration has been identified correctly. Once this was confirmed, the duration of the highlighted portion was read from the display on the monitor directly. When the highlighted waveform was considered auditorily that it was not covering the vowel duration then the cursor was moved forward/backward depending on the position of the cursor and played back again. This procedure was carried out till the investigator was satisfied or confirmed auditorily that the highlighted portion of the waveform was covering the vowel duration and then it was noted as vowel duration of that vowel. Once this was confirmed, the vowel duration of the highlighted portion was read from the display on the top of the frame directly. This was done to obtain each of the vowels spoken by each subject of the two groups.

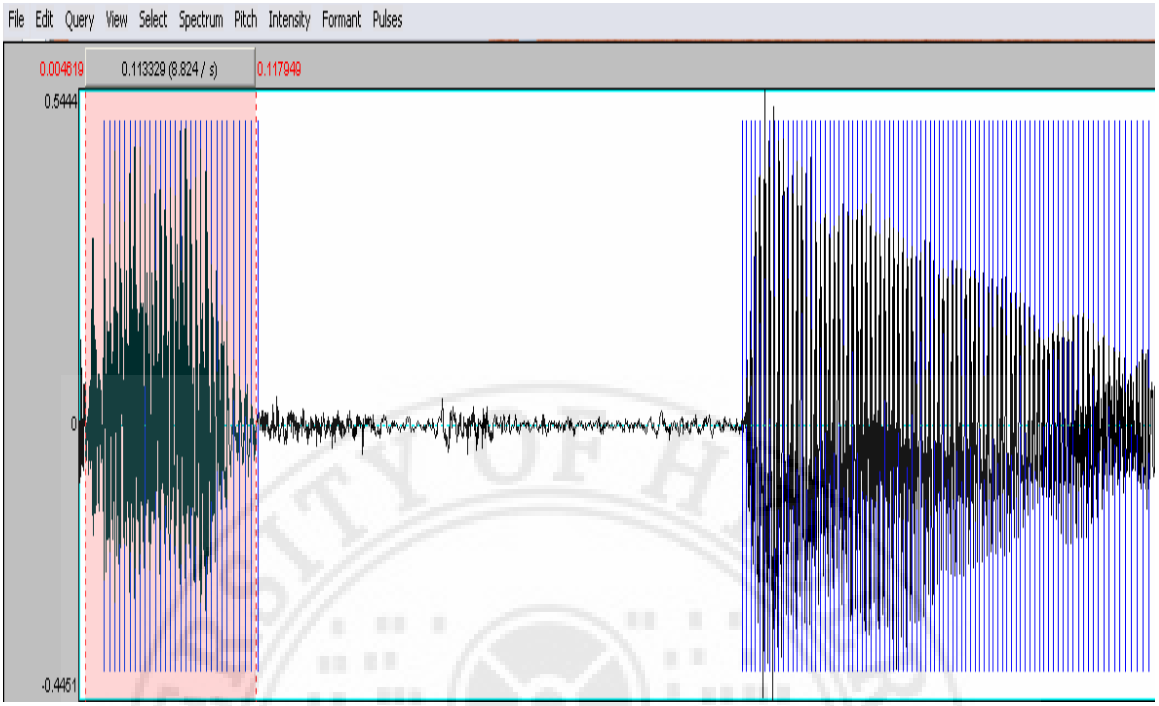



**Fig. 3.5. Vowel duration for word / atu /.**

**Word duration**

Word duration is the duration of whole VCV word. It is the sum of vowel duration, consonant duration and pause duration. The unit used is msec. The waveform and spectrogram of the word were displayed on the computer monitor using the PRAAT software. The whole word was identified based upon the continuity of the waveform by clinical inspection by the experimenter. The whole word was considered to extend from the beginning of the signal to the end of the signal for the word and it was highlighted through the use of cursors. The highlighted portion was played back through headphones, to confirm that the word under study has been highlighted and then the duration has been marked correctly. Once this was confirmed, the duration of the highlighted portion was read from the display on the monitor directly. When the highlighted waveform was considered auditorily that it was not covering the word duration then the cursor was moved forward/backward depending on the position of the cursor and played back again. This procedure was carried out till the investigator was satisfied or confirmed auditorily that the highlighted portion of the waveform was covering the word duration and then it was noted as the word duration of that word. Once this was confirmed, the duration of the highlighted portion was read from the display on the top of the frame directly. This was done to obtain each of the words spoken by each subject of the three groups.

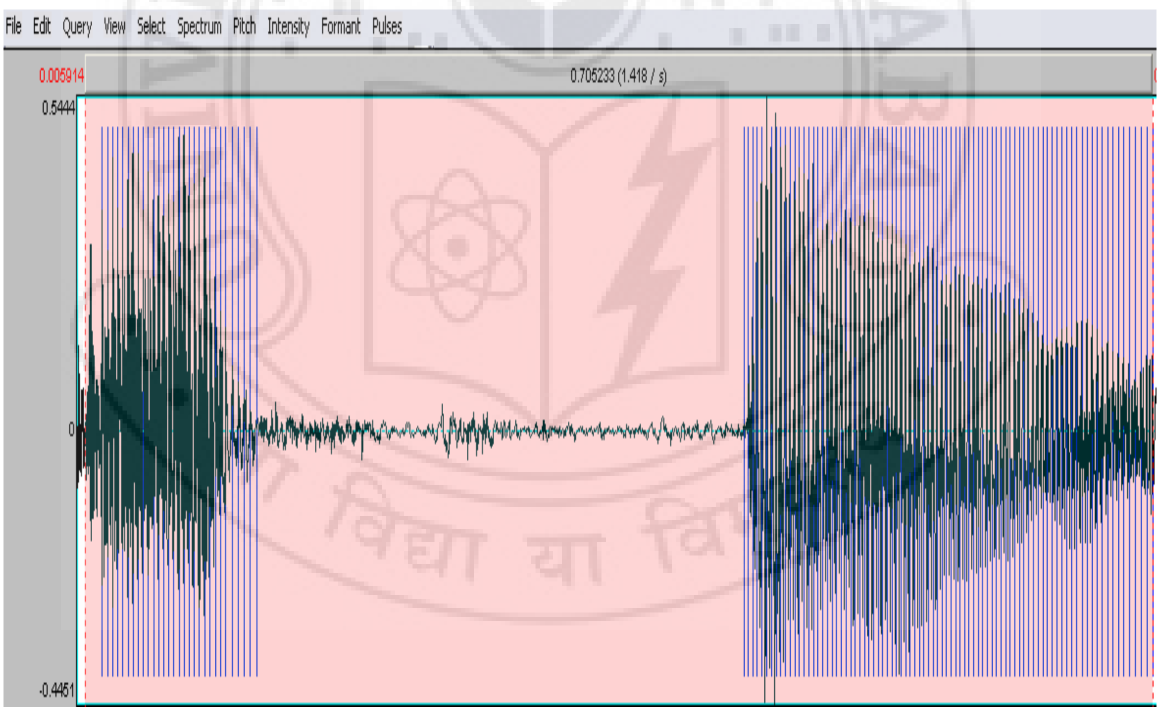



**Fig. 3.6. Word duration for word /atu/**

### 3.6. Statistical Analysis:

The obtained data was analyzed and compared by computing the mean scores and standard deviations for each of the group. Inter group comparisons were done with appropriate statistical tools. The results are discussed in the next chapter.

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## CHAPTER IV

## RESULTS AND DISCUSSION

### 4.1. Introduction

The present study was aimed at investigating the acoustic and temporal characteristics of Telugu speaking children with hearing impairment. A total number of 48 subjects (24 males & 24 females) participated in this study. The subjects for the study were divided in to three groups with 8 males and 8 females in each group. Group I (NH) consists of 16 age matched children with normal hearing (males=8, females=8), Group II (HA) consists of 16 children (males = 8, females = 8) with hearing impairment using hearing aids. Group III (CI) consists of 16 children (males=8, females = 8) with hearing impairment using cochlear implant. All three groups consist of children with Telugu as native language.

The test material consisted of 10 di-syllabic Telugu words (VCV) in total, five short vowels /a/, /i/, /u/, /e/, /o/ and remaining 5 long vowels /a:/, /i:/,/u:/,/e:/,/o:/. The subjects were instructed to read the words written on flash cards. The speech samples thus obtained were spectrographically analyzed to obtain the following acoustic parameters.

1. Fundamental frequency (F0)
2. Formant frequencies (F1,F2 and F3)
3. Band width characteristics (B1, B2 and B3)

4. Vowel duration
5. Word duration

## 4.2. Fundamental frequency

Fundamental frequency is the first harmonic of the voice. It is the physical measure of lowest periodic component of the vocal fold vibration. Fundamental frequency is an important acoustic aspect of any ones speech. The fundamental frequencies five short vowels /a/, /i/, /u/, /e/, /o/ and long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production for the three groups namely children with normal hearing (NH) group, children using hearing aid (HA) group and children using cochlear implant (CI) group.

**Table 4.2.1. Mean and standard deviation values of fundamental frequency (F0) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| Fundamental frequency (F0) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 277 | 259 | 292 | 266 | 239 | 240 | 259 | 281 | 282 | 280 |
| | SD | 142 | 11 | 15 | 33 | 16 | 18 | 17 | 11 | 13 | 11 |
| HA | Mean | 392 | 388 | 397 | 393 | 393 | 394 | 396 | 392 | 388 | 394 |
| | SD | 35 | 32 | 32 | 21 | 14 | 11 | 20 | 20 | 23 | 19 |
| CI | Mean | 345 | 345 | 346 | 348 | 347 | 349 | 346 | 346 | 343 | 343 |
| | SD | 12 | 14 | 15 | 14 | 15 | 13 | 14 | 12 | 12 | 13 |

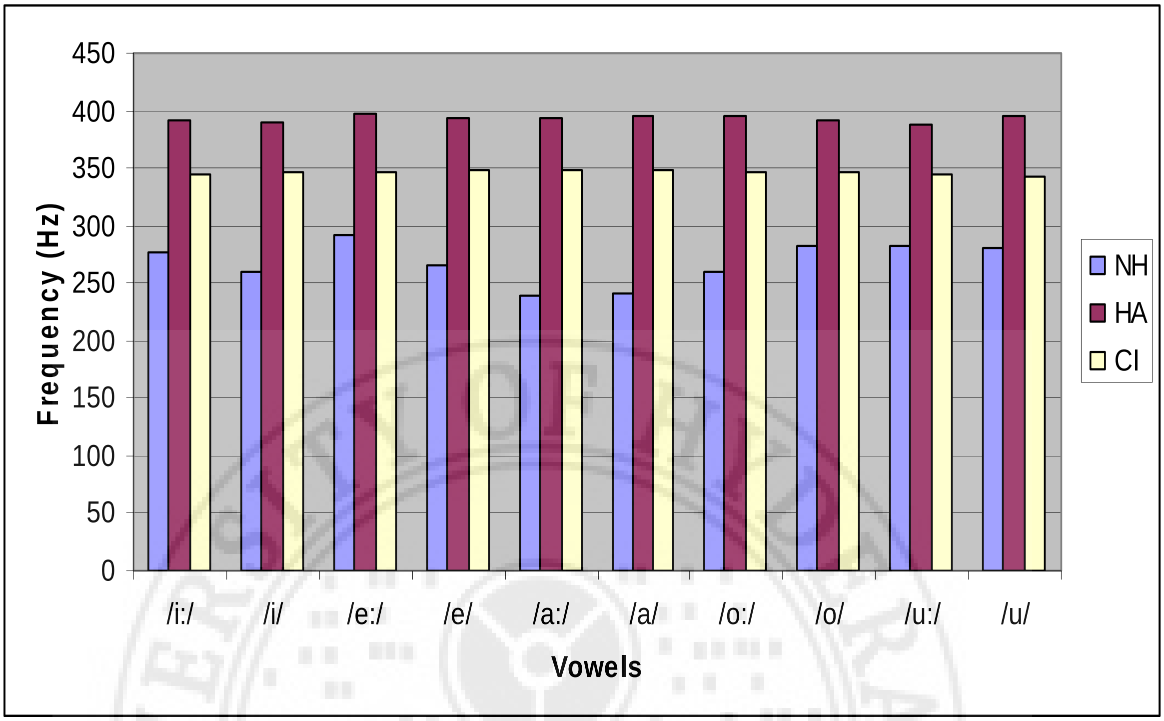


**Fig. 4.2.1. Mean values of fundamental frequency (F0) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.2.1 and Fig. 4.2.1 show the Mean values of the fundamental frequency for three different groups for the said ten vowels. With reference to the mean values of the fundamental frequency in the normal hearing children group (NH), the highest fundamental frequency was noticed for the vowel /e:/ (292Hz), followed by /u:/ (282Hz), /o/ (282Hz), /u/ (280Hz), /i:/ (277Hz), /e/ (266Hz), /o:/ (259Hz), /i/ (259Hz), /a/ (240Hz), /a:/ (239Hz).

In the hearing impaired group using hearing aid (HA), the highest fundamental frequency was noticed for the vowel /e:/ (397Hz), followed by /o:/ (396Hz), /u/ (394Hz), /a/ (394Hz), /a:/ (393Hz), /e/ (393Hz), /i:/ (392Hz), /o/ (392Hz), /i/ (388Hz), /u:/ (388Hz).

In the cochlear implant group (CI), the highest fundamental frequency was noticed for the vowel./a/ 349 Hz followed by /e/ 348Hz, /a:/ 347Hz, /o/ 346Hz, /e:/ 346 Hz , /i/ 345Hz , /u:/ 343Hz and /u/ 343Hz.

The mean fundamental frequency values of the hearing aid group (HA) are higher when compared with the cochlear implant group (CI) and normal hearing group (NH) for all the vowels. The mean fundamental frequency values of the cochlear implant group (CI) are higher than normal hearing group (NH) and lower than the hearing aid group (HA) for all the vowels.

To establish whether the Mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effect of group on fundamental frequency for all the vowels is significant ($P < 0.05$). (See appendix IV – Table 1. a-j).

To find the individual differences between the groups Least significant difference Post- Hoc paired group analysis was applied and it revealed that there was a significant difference ($P<0.05$) among all three groups for all ten vowels. This means that there is a significant difference in the fundamental frequency for all the vowels between normal hearing group (NH) and hearing aid group (HA), normal hearing group (NH) and cochlear implant group (CI), and hearing aid group (HA) and cochlear implant group (CI). (See appendix IV – Table 1. a-j).

The mean fundamental frequency values produced by the hearing impaired groups were found to be greater than that of the normal hearing subjects. These findings are in accordance with the findings of Angelocci et al. (1964), Rajanikanth (1986), Sheela (1988) and Ravindar (2006).

On the basis of the above findings, the following hypotheses are rejected:

1. There is no significant difference in terms of fundamental frequency of the normal hearing group and cochlear implant group.

2. There is no significant difference in terms of fundamental frequency of normal hearing group and the hearing aid groups.

3. There is no significant difference in terms of fundamental frequency of the hearing aid group and the cochlear implant group.

Picket (1968) has suggested that the increase in fundamental frequency in hearing impaired may be due to increased sub glottal pressure and tension of the vocal folds. His opinion has been that the increased vocal effort is directed at the laryngeal mechanism for kinesthetic feedback and thus leading to increase in fundamental frequency.

Willemain and Lee (1971) had hypothesized that the hearing impaired speakers used extra vocal effort to get an awareness of the onset and progress of voicing and this caused the high pitch which was observed in their speech.

In case of cochlear implant group, the fundamental frequency values obtained was lesser than that of hearing aid group, which may be because, they simultaneously perceive the voicing feature and are less dependent on the visual cues when compared to hearing aid group (Geers 2003). Poissant et al. (2006) concluded that following the implantation, hearing impaired children rely to some extent on auditory feedback from the implant to control durational aspects.

## 4.3. Formant frequency

Formant frequencies decide the quality and intelligibility of vowel in one's speech and it demonstrates the articulatory and acoustic relations. Among these, first and second formant frequencies play a major role and the rest do not affect quality and intelligibility. The height of the tongue in relation to the second formant frequency of a desired vowel will be decided by the third formant frequency. The findings of three formants are discussed under the following subheadings:

### (a) First formant frequency (F1)

The first formant frequency for each of five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.3.1. Mean and standard deviation values of first formant frequency(F1) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| First Formant frequency (F1) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 574 | 579 | 715 | 713 | 846 | 874 | 743 | 726 | 708 | 685 |
| | SD | 69 | 68 | 96 | 102 | 68 | 79 | 88 | 80 | 95 | 97 |
| HA | Mean | 726 | 730 | 865 | 866 | 856 | 884 | 845 | 842 | 872 | 835 |
| | SD | 75 | 75 | 76 | 85 | 96 | 114 | 86 | 82 | 87 | 65 |
| CI | Mean | 669 | 673 | 764 | 769 | 808 | 819 | 822 | 823 | 841 | 814 |
| | SD | 54 | 50 | 44 | 47 | 68 | 67 | 82 | 76 | 81 | 66 |

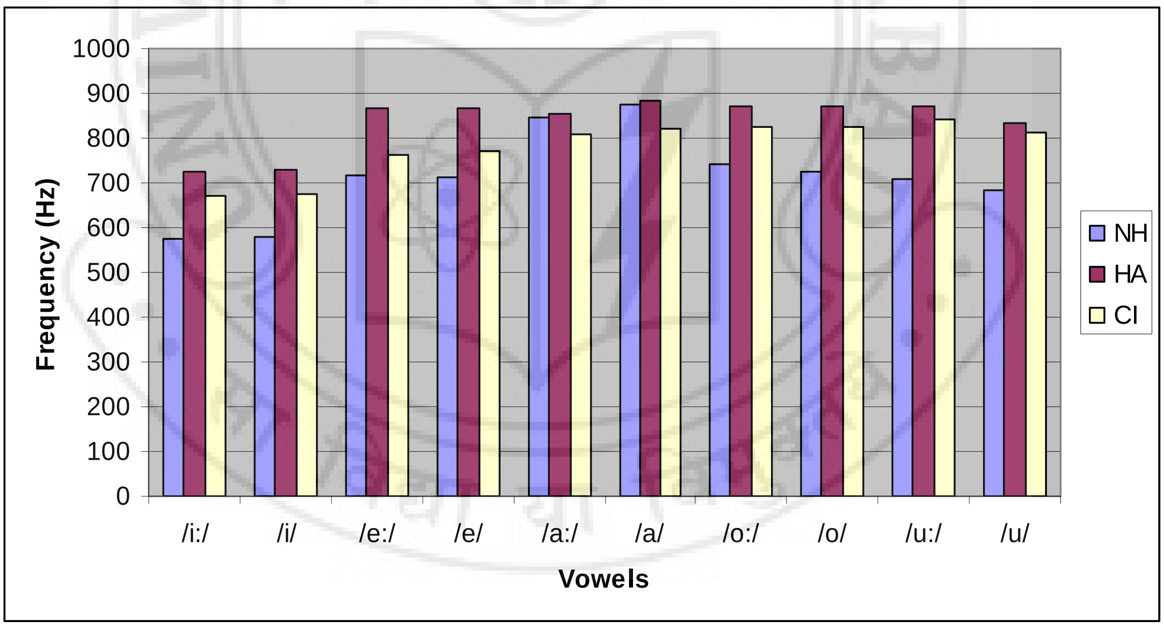


**Fig.4.3.1. Mean values of first formant frequency(F1) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.3.1. and Fig.4.3.1. show the mean values of the first formant frequencies for three different groups for the above ten vowels. The mean values of the

formant frequencies in the normal hearing children group were calculated and the highest first formant frequency was noticed for the vowel /a/ (874Hz), followed by /a:/ (846Hz), /o:/ (743Hz), /o/ (726Hz), /e:/ (715Hz), /e/ (713Hz), /u:/ (708Hz), /u/ (685Hz), /i/ (579Hz) and /i:/ (574Hz).

In the hearing impaired group using hearing aids, the highest first formant frequency was noticed for the vowel /a/ (884Hz), followed by /u:/ (872Hz), /o:/ (872Hz), /o/ (870Hz), /e/ (866Hz), /e:/ (865Hz), /a:/ (856Hz), /u/ (835Hz), /i/ (730Hz) and /i:/ (726Hz).

In the cochlear implant group, the highest first formant frequency was noticed for the vowel /u:/ (841Hz), followed by /o/ (823Hz), /o:/ (822Hz), /a/ (819Hz), /u/ (814Hz), /a:/ (808Hz), /e/ (769Hz), /e:/ (764Hz), /i/ (679Hz) and /i:/ (669Hz).

The mean first formant frequency values of the hearing aid group are higher when compared with the cochlear implant group and normal hearing group for all the vowels. The mean formant frequency values of the cochlear implant are higher than normal hearing group and lower the hearing aid group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one- way ANOVA (among the three groups and ten vowels). It revealed that the effect of group on first formant frequency for all the vowels is significant ($P<0.05$) except for vowels /a/ and /a:/. (See appendix IV-Table2 a-j).

To determine the individual difference between the groups Least significant Difference Post-Hoc paired group analysis was applied and it revealed that there was a significant difference (P<0.05) among all three groups (See appendix IV-Table2 a-j). This means that there was a significant difference in the first formant frequency for all the vowels between normal hearing group and hearing aid group. At the same time there was a significant difference between normal hearing group and cochlear implant group for /i:/, /i/,/o:/,/o/,/u:/ and /u/ (P<0.05) and no significance difference was found between the two groups for /e:/, /e/,/a:/ and /a/.(See appendix IV-Table2 a-j).

The mean values of the first formant frequency produced by the hearing impaired groups were found to be greater than that of the normal hearing subjects. The difference was significant between normal hearing group and hearing aid group (for all the vowels), normal hearing group and cochlear implant group (for vowels /i:/, /i/,/o:/,/o/,/u:/ and /u/) and cochlear implant group and hearing aid group (for vowels /i:/, /i/,/e:/,/e/,and /a/).

These findings do not support the following hypotheses

1. There is no significant difference in terms of first formant frequency of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of first formant frequency of normal hearing group and hearing aid group.
3. There is no significant difference in terms of first formant frequency of the hearing aid group and the cochlear implant group.

However, the hypothesis stating that there is no significant difference of the first formant frequency (F1) between normal hearing group and cochlear implant group is accepted for vowels /e:/, /e/, /a:/, and /a/ and between hearing aid group and cochlear implant group, and the hypothesis stating that there is no significant difference of the first formant frequency (F1) is accepted for vowels /a:/, /o:/, /o/, /u:/ and /u/.

The fundamental frequency of the vowel and the movements of the articulators and tongue height for the particular vowel determine the first formant frequency. Increased F1 means the height of the tongue is reduced (Angelocci et al. 1964). F1 was altered by the laborious movements of the articulators especially tongue (Sheela 1988 and Ryalls 2003). According to Geers (2003), F1 alters due to the vowel duration as well as tense and lax features of the tongue in an utterance. These findings are in accordance with the findings of Angelocci et al. (1964), Sheela (1988), Ryalls (2003), Geers (2003) and Ravindar (2006).

### (b) Second formant frequency (F2)

The Second formant frequencies for each of the five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ were obtained in VCV word production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.3.2. Mean and standard deviation values of Second formant frequency (F2) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| Second Formant frequency (F2) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 1707 | 1697 | 1845 | 1830 | 1618 | 1654 | 1707 | 1672 | 1568 | 1599 |
| | SD | 115 | 117 | 83 | 115 | 83 | 91 | 99 | 70 | 72 | 85 |
| HA | Mean | 1865 | 1869 | 1888 | 1903 | 1897 | 1846 | 1832 | 1819 | 1736 | 1734 |
| | SD | 88 | 101 | 111 | 103 | 113 | 85 | 93 | 103 | 112 | 120 |
| CI | Mean | 1714 | 1750 | 1776 | 1813 | 1802 | 1659 | 1712 | 1743 | 1677 | 1660 |
| | SD | 63 | 58 | 78 | 91 | 97 | 62 | 64 | 54 | 95 | 82 |

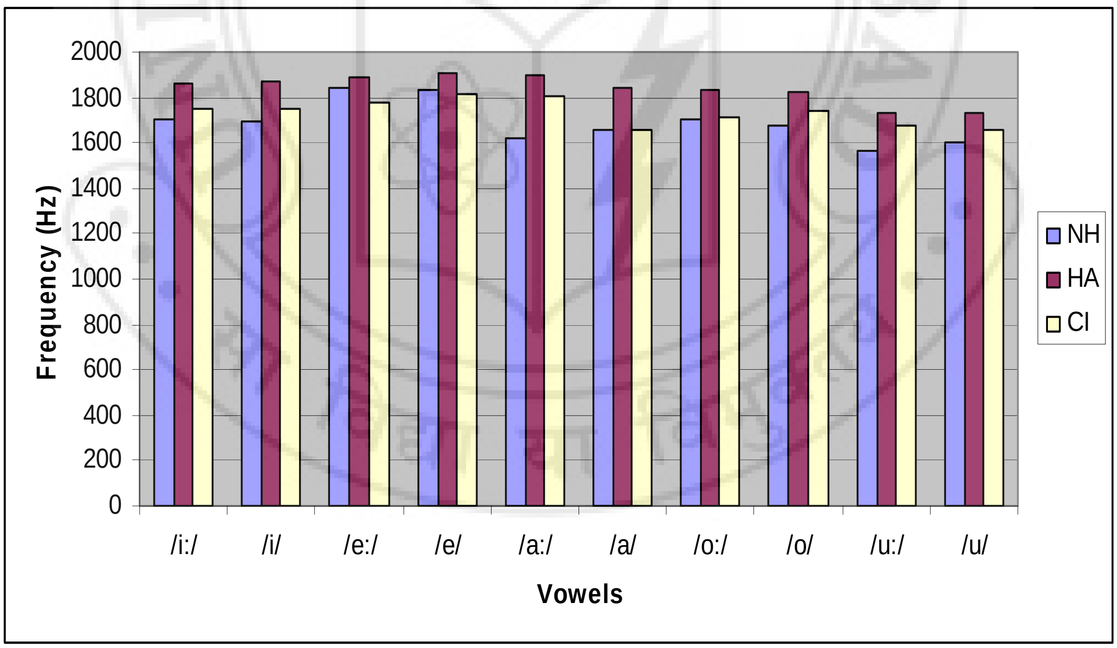


**Fig. 4.3.2. Mean values of Second formant frequency (F2) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.3.2. and Fig.4.3.2 shows the mean values of the Second formant frequencies for three different groups for the following five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ in VCV word production. The mean values of the Second formant frequencies in the normal hearing children group were calculated and highest Second formant frequency was noticed for the vowel /e:/ (1845.19Hz), /e/ (1830Hz), /i:/ (1707Hz), /o:/ (1707Hz), /i/ (1697Hz), /o/ (1672Hz), /a/ (1654Hz), /a:/ (1618Hz), /u/ (1599Hz) and /u:/ (1568Hz).

In the hearing impaired group using hearing aids, the highest Second formant frequency was noticed for the vowel /e/ (1903Hz), /a:/ (1897Hz), /e:/ (1888Hz), /i/ (1869Hz), /i:/ (1864Hz), /a/ (1846Hz), /o:/ (1832Hz), /o/ (1819Hz), /u:/ (1736Hz) and /u/ (1734Hz).

In the cochlear implant group, the highest Second formant frequency was noticed for the vowel /e/ (1813Hz) followed by /a:/ (1802Hz), /e:/ (1776Hz), /i/ (1750Hz), /o/ (1743Hz), /i:/ (1714Hz), /o:/ (1712Hz), /u:/ (1677Hz), /u/ (1660Hz) and /a:/ (1659Hz).

The mean Second formant frequency values of the hearing aid group are higher when compared with the cochlear implant group and normal hearing group for all the vowels. The mean Second formant frequency values of the cochlear implant group are higher than the normal hearing group and lower than the hearing aid group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effect of group on Second formant frequency for all the words is significant ($P<0.05$) (See appendix IV-Table 3 a-j).

To find the individual differences between the groups Least significant difference Post-Hoc paired group analysis was applied and it revealed that there was a significant difference among ($P<0.05$) all three groups. Thus, it indicates there was a significant in the second formant frequency between normal hearing group and hearing aid group, normal hearing group and cochlear implant group, and hearing aid group and cochlear implant group.

There was a significant difference in the mean values of second formant frequency between normal hearing group and hearing aid group for all the vowels except /e:/. At the same time normal hearing group and cochlear implant group significant difference was seen for vowels /e:/, /a:/, /o/, and /u:/, but no significant difference was found for vowels /i:/, /i/, /e/, /a/, /o:/ and /u/. On the other hand significant difference was observed for all the vowels except for /u:/ between hearing aid group and cochlear implant group (See appendix IV-Table 3 a-j).

Second formant frequency (F2) determines the quality and intelligibility of vowels. In the current study the hearing aid group demonstrated more abnormal variation in F2 and was followed by the cochlear implant group. However, cochlear implant group managed to produce the vowels with slightly higher F2 than the normal hearing group. In speech production the hearing impaired group tend to move their articulators more posterior in the oral cavity which results in increased tongue height and posterior oral constriction. The results of the present study are in agreement with the findings of Sheela (1988), Ryalls (2003), Geer et.al (2003) and Ravindar (2006).

Thus the following hypotheses are rejected:

1. There is no significant difference in terms of Second formant frequency of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of Second formant frequency of normal hearing group and the hearing aid groups.
3. There is no significant difference in terms of Second formant frequency of the hearing aid group and the cochlear implant group.

However, the hypothesis stating that there is no significant difference of Second formant frequency (F2) between normal hearing group and cochlear implant group is accepted for vowels /i:/, /i/, /e/, /a/, /o:/ and /u/ and between hearing aid group and cochlear implant group, the hypothesis stating that there is no significant difference of Second formant frequency (F2) is accepted for vowel /u:/.

## (c) Third formant frequency (F3)

The third formant frequencies of the five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ were obtained in VCV word production for the three groups namely production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.3.3. Mean and standard deviation values of Third formant frequency (F3) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| Third Formant frequency (F3) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 2930 | 2903 | 2928 | 2803 | 2896 | 2820 | 2815 | 2794 | 2723 | 2701 |
| | SD | 103 | 91 | 95 | 253 | 85 | 280 | 112 | 100 | 130 | 875 |
| HA | Mean | 3091 | 3066 | 3064 | 3037 | 3017 | 2995 | 2984 | 2970 | 2932 | 2929 |
| | SD | 111 | 81 | 93 | 79 | 97 | 112 | 132 | 132 | 78 | 84 |
| CI | Mean | 3016 | 3002 | 2977 | 2953 | 2877 | 2957 | 2845 | 2936 | 2907 | 2910 |
| | SD | 89 | 49 | 54 | 60 | 77 | 76 | 83 | 78 | 82 | 96 |

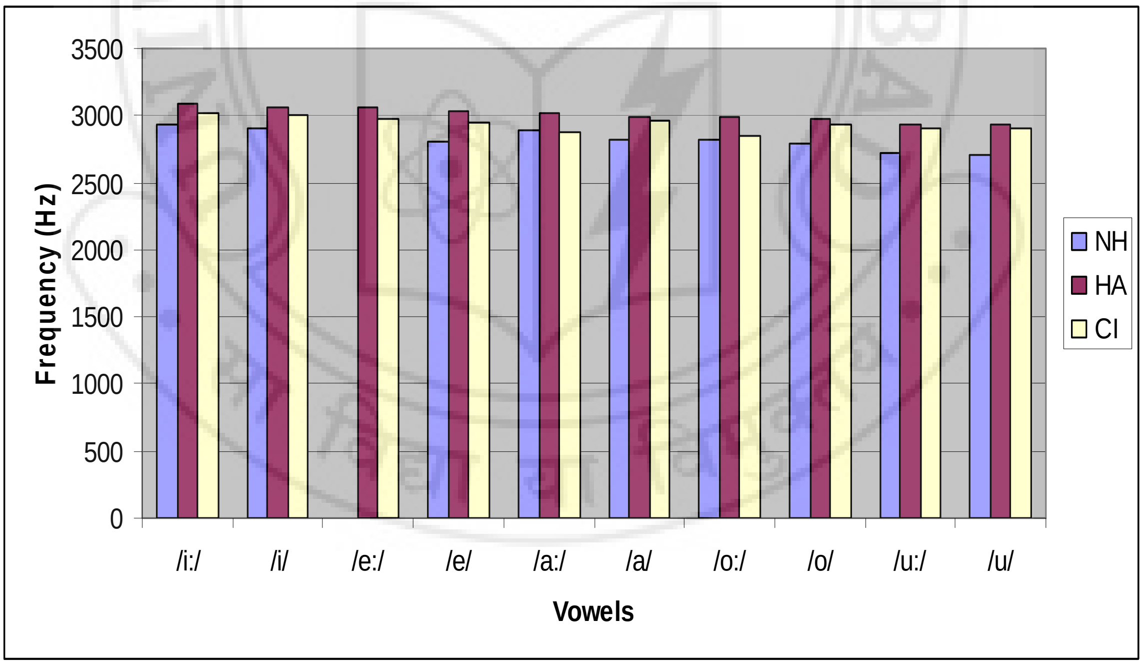


**Fig: 4.3.3. Mean values of Third formant frequency (F3) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.3.3. and Fig.4.3.3 show the mean values of the third formant frequencies for three different groups for the following five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ in VCV word production. The mean values of the third formant frequency in normal hearing children group were calculated and the highest third formant frequency was noticed for the vowel /i:/ (2930Hz), followed by /e:/ (2928Hz), /i/ (2903Hz), /a:/ (2896Hz), /a/ (2820Hz), /o:/ (2815Hz), /e/ (2803Hz), /0/ (2794Hz), /u:/ (2723Hz) and /u/ (2701Hz).

In the hearing impaired group using hearing aids the highest third formant frequency was noticed for the vowel /i:/ (3091Hz), followed by /i/ (3066Hz), /e:/ (3064Hz), /e/ (3037Hz), /a:/ (3017Hz), /a/ (2995Hz), /o:/ (2984Hz), /o/ (2970Hz), /u:/ (2932Hz) and /u/ (2929Hz).

In the cochlear implant group, the highest third formant frequency was noticed for the vowel /i:/ (3016Hz) followed by /i/ (3002Hz), /e:/ (2977Hz), /a/ (2957Hz), /e/ (2953Hz), /o/ (2936Hz), /u/ (2910Hz), /u:/ (2907Hz), /a:/ (2877Hz) and /o:/ (2845Hz).

The mean third formant frequency values of the hearing aid group are higher when compared with cochlear implant group and normal hearing group for all the vowels. The mean third formant frequency values of the cochlear implant group are higher than normal hearing group for all the vowels except /a:/ and lower than the hearing aid group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It reveal that the effect of group on third formant frequency for all the words is significant (P<0.05) (See appendix IV-Table 4 a-j).

To find the individual differences between the groups Least significant difference post – Hoc paired group analysis was applied and it revealed that there was significant difference (P<0.05) among all the three groups for all ten vowels(See appendix IV-Table 4 a-j). This means that there was a significant difference in the third formant frequency for all vowels between normal hearing group and hearing aid group, normal hearing group and cochlear implant group, and hearing aid group and cochlear implant group.

There was significant difference in the mean values of third formant frequency between normal hearing group and hearing aid group for all the vowels. At the same time between normal hearing group and cochlear implant groups significant difference was seen for vowels /i:/./i/, /e/, /a/, /o/,/u:/ and /u/ but no significant difference was found for vowels /e:/, /a:/ and /o:/. On the other hand, a significant difference was observed for vowels /i:/, /i/, /e:/, /a:/ and /o:/, but no significant difference was observed for /e/, /a/,and /o/ between hearing aid group and cochlear implant group. (See appendix IV-Table 4 a-j). These results of the present study are in agreement with the findings of Sheela (1988), Ryalls (2003), Geers (2003) and Ravindar (2006).

Therefore, the following hypotheses are rejected:

1. There is no significant difference in terms of third formant frequency of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of third formant frequency of normal hearing group and hearing aid group.
3. There is no significant difference in terms of third formant frequency of hearing aid group and cochlear implant group.

However, the hypothesis stating that there is no significant difference of third formant frequency (F3) between normal hearing group and cochlear implant group is accepted for vowels /e:/, /a:/ and /o:/ and between hearing aid group and cochlear implant group, the hypothesis stating that there is no significant difference of third formant frequency (F3) is accepted for vowels /e/, /a/ and /o/.

## 4.4. Bandwidth (B1)

The first bandwidth for each of the five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production task for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.4. . Mean and standard deviation values of first Bandwidth (B1) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| First Bandwidth (B1) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 149 | 147 | 146 | 152 | 156 | 159 | 161 | 160 | 152 | 152 |
| | SD | 18 | 18 | 18 | 16 | 17 | 16 | 19 | 17 | 20 | 21 |
| HA | Mean | 93 | 94 | 98 | 103 | 104 | 103 | 103 | 101 | 100 | 101 |
| | SD | 8 | 11 | 10 | 13 | 14 | 17 | 20 | 17 | 13 | 10 |
| CI | Mean | 104 | 108 | 111 | 115 | 114 | 116 | 118 | 120 | 116 | 116 |
| | SD | 6 | 7 | 5 | 4 | 6 | 6 | 4 | 11 | 12 | 11 |

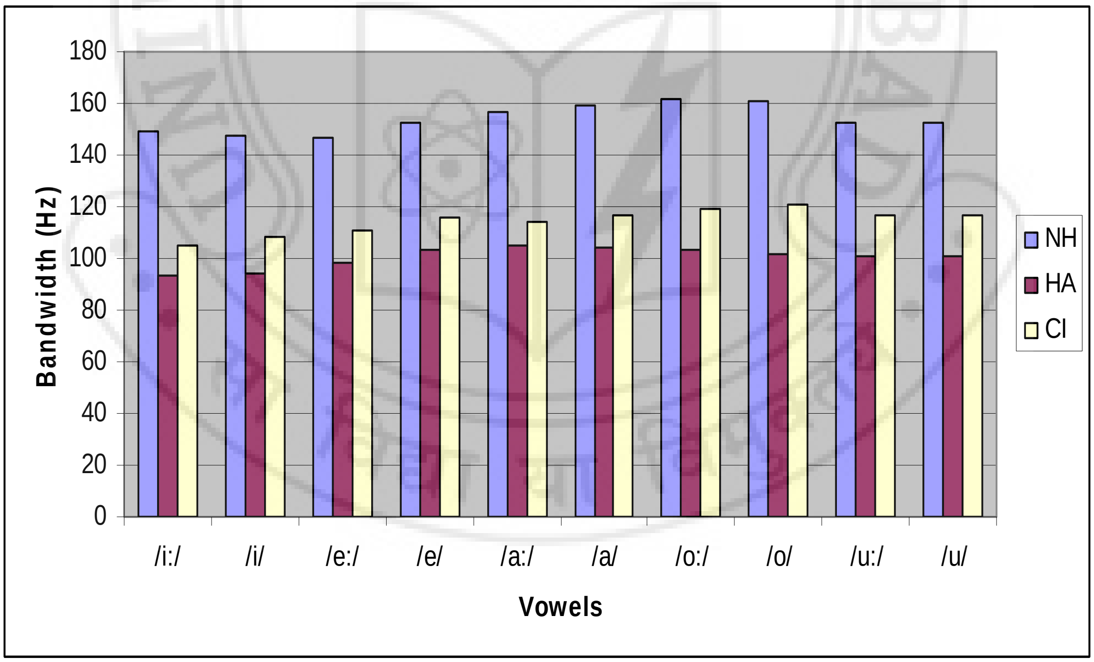


**Fig. 4.4. Mean values of first Bandwidth (B1) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.4 and Fig.4.4 shows the mean values of the first bandwidth for three different groups for the following five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ in the production of VCV words. The mean values of the first bandwidth in the normal hearing children group were calculated and the highest first bandwidth was noticed for the vowel /o:/ (161Hz), followed by /o/ (160Hz), /s/ (159 Hz), /a:/ (156Hz), /u/ (152Hz), /e/ (152Hz), /u:/ 152Hz), /i:/ (149Hz), /i/ (147Hz) and /e:/ (146Hz).

In the hearing impaired group using hearing aids, the highest first bandwidth was noticed for the vowel /a:/ (104Hz), followed by /a/ (103Hz), /e/ (103Hz), /o:/ (103Hz), /o/ (101Hz), /u/ (101Hz), /u:/ (100Hz), /e:/ 98Hz), /i/ (94Hz) and /i:/ (93Hz).

In the cochlear implant group, the highest first bandwidth was noticed for the vowel /o:/ (188Hz) followed by /o/ (120Hz), /u:/ (116Hz), /u/ (116Hz), /a/ (116Hz), /e/ (115Hz), /a:/ (114Hz), /e:/ (111Hz), /i/ (108Hz) and /i:/ (104Hz).

The first bandwidth mean values of the normal hearing group were higher when compared with the hearing aid group and cochlear implant group. On the other hand, cochlear implant group was slightly higher than the hearing aid group.

To establish whether the mean difference between these groups were significant or not, the obtained data was subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effect of groups on first bandwidth for all the vowels is significant (P<0.05). (See appendix IV Table 5 a-j).

To find the individual differences between the groups, Least Significant Difference post-Hoc paired group analysis was applied and it revealed that there was a statistically significant difference (P<0.05) in the first bandwidth among normal hearing group and hearing aid group, normal hearing group and cochlear implant group for all the vowels. On the other hand there was a significant difference for all the vowels except /a:/ and /a/ between hearing aid group and cochlear implant group). (See appendix IV Table 5 a-j). Similar findings were reported by Rathna Kumar (1998) and Crystal Chan Waiman (1997). Scharf (1970) postulated that the deviation in bandwidth characteristics in hearing impaired individuals were due to affected internal filter of the auditory system.

Thus, the following hypotheses are rejected:

1. There is no significant difference in terms of first bandwidth of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of first bandwidth of normal hearing group and hearing aid group.
3. There is no significant difference in terms of first bandwidth of hearing aid group and cochlear implant group for all the vowels except for vowels /a:/ and /a/.

However, the hypothesis stating that there was no significant difference between the hearing aid group and cochlear implant group in terms of first bandwidth was accepted for vowels /a:/ and /a/.

### 4.4.1. Second Bandwidth (B2)

The second bandwidth for each of the five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.4.1. Mean and standard deviation values of Second Bandwidth (B2) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| Second Bandwidth (B2) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 195 | 179 | 193 | 189 | 237 | 247 | 193 | 191 | 189 | 186 |
| | SD | 32 | 37 | 28 | 30 | 30 | 24 | 29 | 26 | 36 | 34 |
| HA | Mean | 121 | 114 | 124 | 130 | 139 | 144 | 130 | 121 | 121 | 128 |
| | SD | 16 | 13 | 21 | 21 | 27 | 40 | 21 | 21 | 17 | 18 |
| CI | Mean | 135 | 136 | 148 | 146 | 154 | 157 | 149 | 142 | 138 | 141 |
| | SD | 13 | 11 | 17 | 11 | 21 | 22 | 21 | 21 | 14 | 12 |

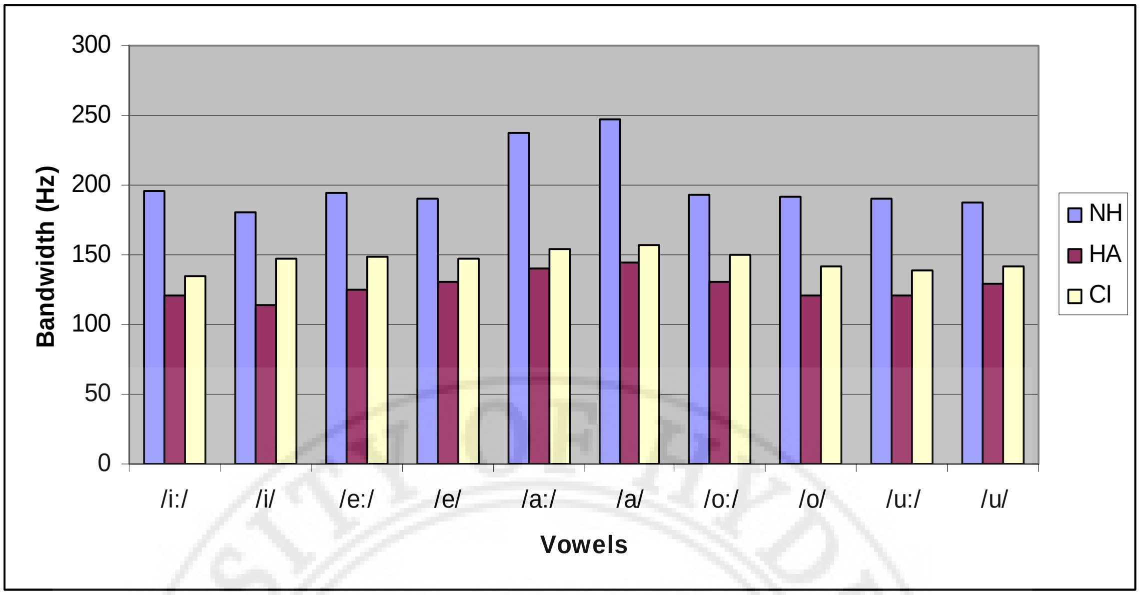


**Fig.4.4.1Means values of Second Bandwidth (B2) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.4.1 and Fig 4.4.1 shows the mean values of the second bandwidth for three different groups for the following five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ in VCV word production. The mean values of the second bandwidth in the normal hearing children group were calculated and the highest second bandwidth was noticed for the vowels /a/ (247Hz), followed by /a:/ (237Hz), /i:/ (195Hz), /e:/ (193Hz), /o:/ (193Hz), /o/ (191Hz), /e/ (189Hz), /u:/ (189Hz), /u/ (186Hz) and /i/ (179Hz).

In the hearing impaired group using hearing aids, the highest second bandwidth was noticed for the vowels /a/ (144Hz) followed by /a:/ (139Hz), /o:/ (130Hz), /e/ (130Hz), /u/ (128Hz), /e:/ (124Hz), /o/ (121Hz), /u:/ (121Hz), /i:/ (121Hz) and /i/ (114Hz).

In the cochlear implant group, the highest second bandwidth was noticed for the vowel /a/ (157Hz) followed by /a:/ (154Hz), /o:/ (149Hz), /e:/ (148Hz), /e/ (146Hz), /o/ (142Hz), /u/ (141Hz), /u:/ (138Hz), /i/ (136Hz) and /i:/ (135Hz).

The mean second bandwidth values of the hearing aid group are lower when compared with the cochlear implant group and normal hearing group for all the vowels. The mean second bandwidth values of the cochlear implant group are lower than normal hearing group and higher than the hearing aid group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data was subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effect of groups on second bandwidth for all the vowels is significant ($P<0.05$). (See appendix IV Table 6 a-j).

To find the individual differences between the groups, Least significant difference post-Hoc paired group analysis was applied and it revealed that there was a significant difference ($P<0.05$) between normal hearing group and cochlear implant group and normal hearing group and hearing aid group for all the vowels. At the same time there was also statistically significant difference in second bandwidth between the hearing aid group and cochlear implant group for vowels /i/, /e:/, /e/, /o:/, /o/, /u:/ and no significant difference was found between these two groups for vowels /i:/, /a:/, /a/, /u/.(See appendix IV Table 6 a-j).

The second bandwidth values produced by the normal hearing group (NH) were found to the greater than hearing impaired group. Similar findings were reported by Rathna Kumar (1998) and Crystal Chan Waiman (1997). Scharf (1970) postulated that, the deviation in bandwidth characteristics in hearing impaired individuals were due to affected internal filter of the auditory system.

Thus, the following hypotheses are rejected:

1. There is no significant difference in terms of second bandwidth of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of second bandwidth of normal hearing group and hearing aid group.
3. There is no significant difference in terms of second bandwidth of hearing aid group and cochlear implant group.

However, the hypothesis stating there is no significant difference between cochlear implant group and hearing aid group in terms of second bandwidth is accepted for vowels /i:/, /a:/, /a/, and /u/.

### 4.4.2. Third Bandwidth (B3)

The third bandwidth for each of the five short vowels /a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table 4.4.2. Mean and standard deviation values of third Bandwidth (B3) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

| Third Bandwidth (B3) | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 276 | 267 | 272 | 257 | 339 | 333 | 289 | 288 | 261 | 231 |
| | SD | 32 | 43 | 30 | 35 | 53 | 34 | 41 | 16 | 35 | 42 |
| HA | Mean | 177 | 172 | 176 | 167 | 185 | 193 | 193 | 188 | 175 | 179 |
| | SD | 36 | 30 | 31 | 25 | 45 | 55 | 50 | 45 | 41 | 50 |
| CI | Mean | 170 | 160 | 166 | 164 | 178 | 192 | 185 | 177 | 169 | 168 |
| | SD | 15 | 17 | 6 | 16 | 19 | 31 | 30 | 21 | 14 | 25 |

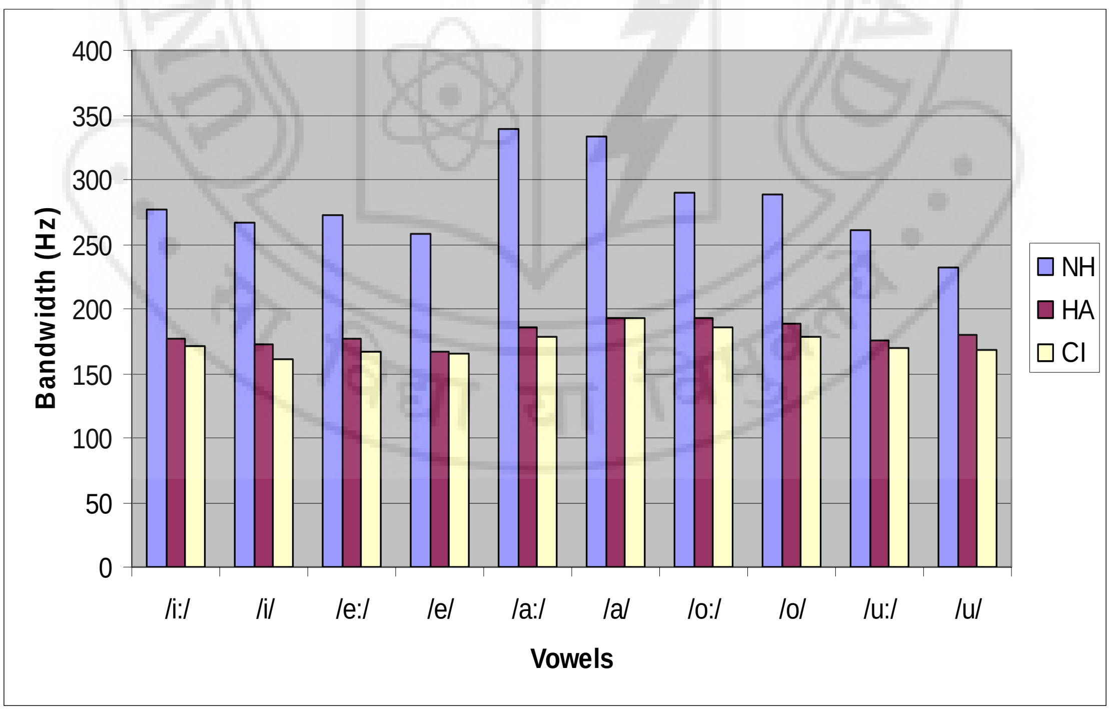


**Fig. 4.4.2. Mean values of third Bandwidth (B3) for normal hearing group (NH), hearing aid group (HA), and cochlear implant group (CI).**

Table 4.4.2 and Fig 4.4.2 shows the mean values of the third bandwidth for three different groups for the following five short vowels/a/, /i/, /u/, /e/, /o/ and five long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production. The mean values of the third bandwidth in the normal hearing children group were calculated and the highest third bandwidth was noticed for the vowel /a:/ (339Hz) followed by /a/ (333Hz), /o:/ (289Hz), /o/ (288Hz), /i:/ (276Hz), /e:/ (272Hz), /i/ (267Hz), /u:/ (261Hz), /e/ (257Hz) and /u/ (231Hz).

In the hearing impaired group using hearing aids, the highest third bandwidth was noticed for the vowel /a/ (193Hz), followed by /o:/ (193Hz), /o/ (188Hz), /a:/ (185Hz), /u/ (179Hz), /i:/ (177Hz), /e:/ (176Hz), /u:/ (175Hz), /i/ ( 172Hz) and /e/ (167Hz).

In the cochlear implant group, the highest third bandwidth was noticed for the vowel /a/ (192Hz) followed by /o:/ (185Hz), /a:/ (178Hz), /o/ (177Hz), /i:/ (170Hz), /u:/ (169Hz), /u/ ( 168Hz), /e:/ (166Hz), /e/ (164Hz) and /i/ (160Hz).

The mean third bandwidth values of the normal hearing group are higher when compared with the cochlear implant group and hearing aid group for all the vowels. The mean third bandwidth values of the cochlear implant group are higher than hearing aid group and lower than the normal hearing group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effect of group on third bandwidth for all the words is significant (P< 0.05). (See appendix IV Table 7 a-j).

To find out the individual differences between the groups, Least significant difference post-Hoc paired group analysis was applied and it revealed that there was significant difference between normal hearing group and hearing aid group and normal hearing group and cochlear implant group (P< 0.05) all the vowels. At the same time no significant difference was noticed between cochlear implant group and hearing aid group for all the vowels. (See appendix IV Table 7 a-j).

The mean bandwidth values produced by the normal hearing group were found to be greater than hearing impaired group. Similar findings were reported by Rathna Kumar (1998) and Crystal Chan Waiman (1997). Scharf (1970) postulated that, the deviation in bandwidth characteristics in hearing impaired individuals were due to affected internal filter of the auditory system.

Thus, the following hypotheses are rejected:

1. There is no significant difference in terms of third bandwidth of the normal hearing group and cochlear implant group.
2. There is no significant difference in terms of third bandwidth of normal hearing group and hearing aid group.

   However, the hypothesis stating there is no significant difference between cochlear implant group and hearing aid for all the vowels is accepted.

## 4.5. Vowel Duration:

Vowel duration is an important acoustic aspect of any ones speech. The increased or decreased duration of vowel could change the entire meaning of the word or sentence. The vowel durations of five short vowels /a/, /i/, /u/, /e/, /o/ and long vowels /a:/, /i:/, /u:/, /e:/, /o:/ was obtained in VCV word production for the three groups namely children with normal hearing group, children using hearing aid group and children using cochlear implant group.

**Table: 4.5.1 Mean and standard deviation values for total vowel duration in normal hearing group (NH), hearing aid group (HA) and cochlear implant group (CI).**

| Vowel Duration | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 258 | 155 | 291 | 174 | 254 | 158 | 258 | 171 | 269 | 165 |
| | SD | 10 | 12 | 19 | 13 | 14 | 14 | 32 | 15 | 13 | 14 |
| HA | Mean | 605 | 410 | 617 | 403 | 614 | 412 | 606 | 406 | 625 | 419 |
| | SD | 30 | 23 | 33 | 34 | 28 | 37 | 41 | 36 | 36 | 39 |
| CI | Mean | 413 | 312 | 430 | 311 | 421 | 322 | 415 | 314 | 433 | 325 |
| | SD | 25 | 23 | 34 | 36 | 29 | 29 | 56 | 39 | 39 | 37 |

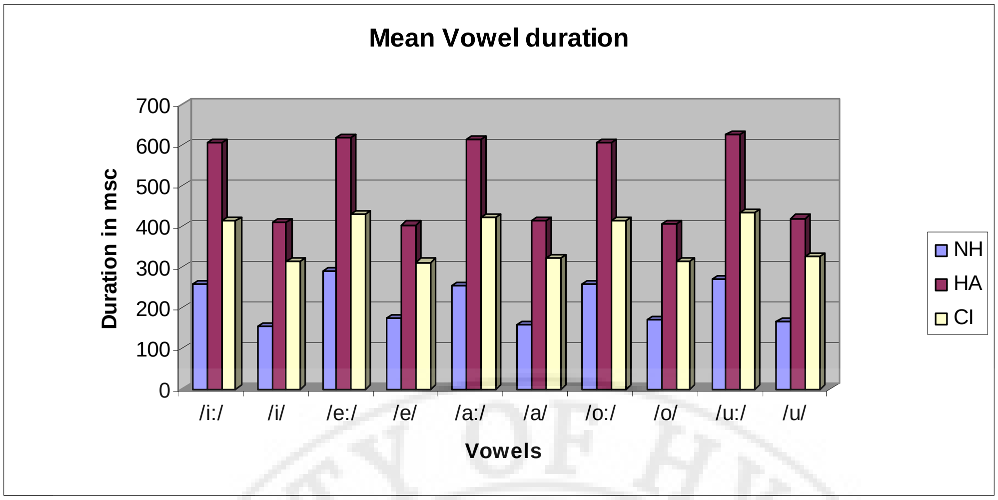


**Fig. 4.5.1. Mean values for total vowel duration in normal hearing group (NH), hearing aid group (HA) and cochlear implant group (CI).**

Table 4.5.1, and Fig. 4.5.1, shows the mean values of vowel duration for three different groups for short vowels /a/, /i/, /u/, /e/, /o/ and long vowels /a:/, /i:/, /u:/, /e:/, /o:/. As depicted in the table, the Mean values of the vowel duration in the normal hearing children group, the highest vowel duration was noticed for the vowel /e:/ (291msec), followed by /u:/ (269msec), /o:/ (258 msec), /i:/ (258 msec), /a:/ (254 msec), /e/ (174 msec), /o/ (171 msec), /u/ (165 msec), /a/ (158 msec), and /i/ (155 msec).

In the hearing impaired group using hearing aid , the highest vowel duration was noticed for the vowel /u:/ (625 msec), followed by /e:/ (617 msec), /a:/ (614 msec), /o:/ (606 msec), /i:/ (605 msec), /u/ (406 msec), /a/ (412 msec), /i/ (410 msec), /o/ (406 msec), /e/ (403 msec).

In the hearing impaired group using cochlear implant (CI), the highest vowel duration was noticed for the vowel /u:/ (433 msec), followed by /e:/ (430 msec),

/a:/ (421 msec), /o:/ (415 msec), /i:/ (413 msec), /u/ (325 msec), /a/ (322 msec), /o/ (314 msec), /i/ (312 msec), and /e/ (311 msec).

The mean vowel duration values for the hearing aid group are higher when compared with the cochlear implant and normal hearing group. The vowel duration values of the cochlear implant group are higher than the normal hearing group and lower than the hearing aid group for all the vowels.

To establish whether the mean differences between these groups for this parameter were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten vowels). It revealed that the effects of group on vowel duration for all vowels are significant ($P < 0.00$). This means that there is a significant difference in vowel duration for all the vowels across the group. (See appendix IV- Table 8 a-j).

To find the individual differences between all the three, that is, normal hearing group versus hearing aid group, normal hearing group versus cochlear implant group and hearing aid group verses cochlear implant group, Least significant difference post – Hoc paired group analysis was applied and it revealed that there was a significant difference ($P<0.00$) among all three groups for all ten vowels. . (See appendix IV- Table 8 a-j).

These findings are in accordance with the findings of Smith (1975), Konefal et al. (1982), Calvert (1962), Ryalls (2003), Tobey et al. (1991) and Osberger & Mc Garr (1982). Similar findings were also observed in Indian studies by Rajanikant (1986), Sheela (1988) and Ravindar (2006).

Thus, the following hypotheses are rejected:

1. There is no significant difference in terms of vowel duration of the normal hearing and cochlear implant groups.

2. There is no significant difference in terms of vowel duration of normal hearing and the hearing aid groups.

3. There is no significant difference in terms of vowel duration of the hearing aid and the cochlear implant groups.

The increased vowel duration in the production of hearing impaired children may be due to the imitation task where there are highly dependent on visual cues and lack voicing perception in their own production (self monitoring of voice) (Ryalls 2003).

In the case of cochlear implant group, the vowel duration obtained was lesser than that of hearing aid group, which may be because, they simultaneously perceive the voicing feature and are less dependent on the visual cues when compared to hearing aid group (Geers 2003).

The longer vowel duration reported in case of hearing impaired children can also be attributed to the reason that vowel duration is longer at lower and higher fundamental frequency than at optimal frequency. It was seen that on an average these children had higher fundamental frequency than that of normal hearing children (Nataraja and Jagadish 1984).

## 4.6. Word duration

Word duration is the duration of whole VCV syllable. It is the sum of vowel duration, consonant duration and pause duration. The unit used to measure is msec. The duration of the word affects the overall speech fluency, which in turn influences the intelligibility of speech. The word durations are measured for each of the ten VCV words /i:ta/, /idi/, /e:du/, /etu/, /a:ku/, /adi/, /o:da/, /oka/, /u:ta/, /upa/ for the three groups namely, children with normal hearing group, children using hearing aids group and children using cochlear implants group.

**Table - 4.6.1. Mean values for total word duration in normal hearing group (NH), hearing aid group (HA) and cochlear implant group (CI).**

| Word Duration | | /i:/ | /i/ | /e:/ | /e/ | /a:/ | /a/ | /o:/ | /o/ | /u:/ | /u/ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| NH | Mean | 517 | 475 | 514 | 476 | 579 | 531 | 586 | 497 | 586 | 477 |
| | SD | 58 | 64 | 38 | 59 | 68 | 90 | 70 | 73 | 82 | 63 |
| HA | Mean | 1484 | 1389 | 1478 | 1381 | 1540 | 1441 | 1523 | 1431 | 1533 | 1426 |
| | SD | 90 | 79 | 93 | 80 | 79 | 75 | 81 | 85 | 89 | 88 |
| CI | Mean | 1008 | 923 | 1016 | 922 | 1059 | 1024 | 1055 | 996 | 1070 | 964 |
| | SD | 113 | 137 | 97 | 110 | 143 | 213 | 149 | 184 | 138 | 120 |

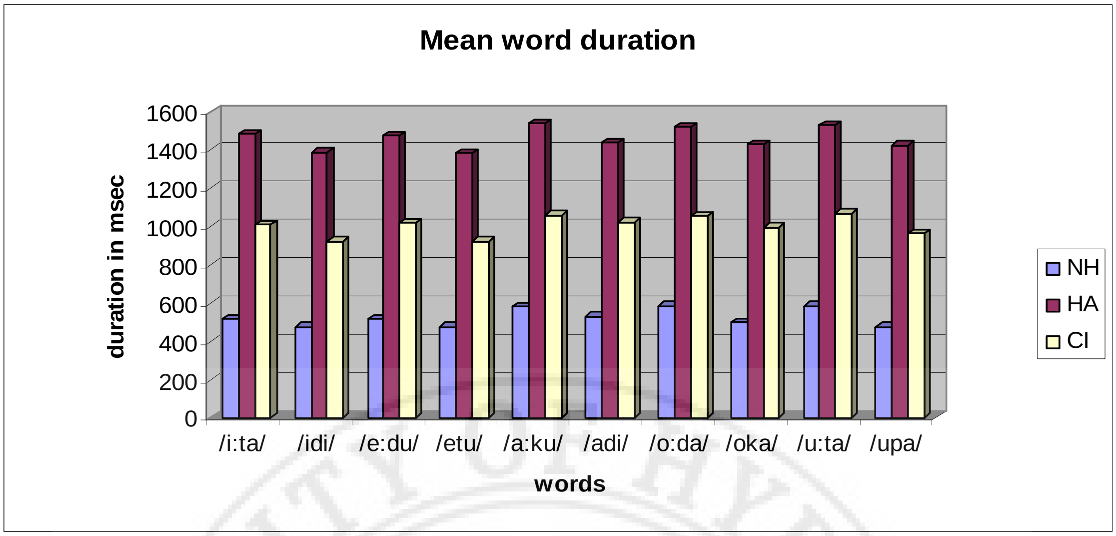


**Fig. 4.6.1. Mean values for total word duration in normal hearing group (NH), hearing aid group (HA) and cochlear implant group (CI).**

Table 4.6.1, and Fig. 4.6.1 shows the mean values of word duration for three different groups, for the following VCV words. /i:ta/, /idi/, /e:du/, /etu/, /a:ku/, /adi/, /o:da/, /oka/, /u:ta/, /upa/. As depicted in the table, the mean values of the word duration in the normal hearing children group, the highest word duration was noticed for the word /o:da/ (586msec), followed by /u:ta/ (586msec), /a:ku/ (579msec), /adi/ (531msec), /e:du/ (514msec), /i:ta/ (517msec), /oka/ (497msec), /upa/ (477msec), /etu/ (476msec), and /idi/ (475msec).

In the hearing impaired group using hearing aid , the highest word duration was noticed for the word /a:ku/ (1540msec), followed by /u:ta/ (1533msec), /o:da/ (1523 msec), /i:ta/ (1484msec), /e:du/ (1478msec), /adi/ (1441msec), /oka/ (1431msec), /upa/ (1426msec), /idi/ (1389msec), /etu/ (1381msec).

In the hearing impaired group using cochlear implant, the highest word duration was noticed for the word /u:ta/ (1070msec), /a:ku/ (1059msec), /o:da/ (1055msec), /adi/ (1024msec), /e:du/ (1016msec), /i:ta/ (1008msec), /oka/ (996msec), /upa/ (964msec), /idi/ (923msec), /etu/ (922msec).

The mean word duration values for the hearing aid group are higher when compared with the cochlear implant group and normal hearing group. The word duration values of the cochlear implant group are higher than normal hearing group and lower than the hearing aid group for all the vowels.

To establish whether the mean difference between these groups were significant or not, the obtained data were subjected to further statistical analysis using one-way ANOVA (among the three groups and ten words). It revealed that the effect of group on word duration for all the words is significant ($P < 0.05$) (See appendix IV Table 9 a-j).

To find the individual differences between the groups, least significant difference post – Hoc paired group analysis was applied and it revealed that there was a significant difference ($P<0.05$) among all three groups for all ten words. This means that there is a significant difference in word duration for all the words between normal hearing group and hearing aid group, normal hearing group and cochlear implant group, and hearing aid group and cochlear implant group. (See appendix IV Table 9 a-j).

The mean word duration produced by the hearing impaired were found to be longer than that of the normal hearing subjects agrees well with results reported by Sheela (1988), Jagadish (1989), Rajanikanth (1986) and Rathna Kumar (1998).

Thus, the following hypotheses are rejected:

1. There is no significant difference in terms of word duration of the normal hearing group and cochlear implant group.

2. There is no significant difference in terms of word duration of normal hearing group and the hearing aid groups.

3. There is no significant difference in terms of word duration of the hearing aid group and the cochlear implant group.

The increased word duration in the production of hearing impaired children may be due to the excessive prolongation of segments (increased duration of phonemes) and insertion of improper and often prolonged pauses within utterances (Gold 1980). Osberger and McGarr (1982) reported prolongation of speech segment was present in the production of phonemes, syllables and words in the speech of hearing impaired.

The duration of the speech segment is altered in hearing impaired speakers because of the imitation task where there are highly dependent on visual cues and lack voicing perception in their own production (self monitoring of voice) (Calvert 1961 and Ryall 2003). Stomberg et al. (1979) observed syllable prolongations in the speech productions of hearing impaired children due to prolongation of vowels.

In the case of cochlear implant group, the word duration obtained was lesser than that of hearing aid group, which may be because, they simultaneously perceive the voicing feature and are less dependent on the visual cues when compared to hearing aid group (Geers 2003). Poissant (2006) concluded that following the implantation, hearing impaired children rely to some extent on auditory feedback from the implant to control durational aspects.

# CHAPTER – V

# SUMMARY AND CONCLUSION

## 5.1 Introduction

The function of hearing is the foundation stone which our intricate human communication system has been constructed. The human baby appears to be born with "preexistent knowledge" of language-specialized neural structures in the brain that wait for auditory experience with language to trigger them into functioning. These structures are dependent on auditory stimulation for their emergence, providing of course that other developmental factors are normal. The normal hearing child is continuously exposed to sounds from birth. It is through this continuous auditory stimulation that a normal child attains speech. The task is, however, very difficult for a child born deaf. Thus hearing controls speech and without hearing speech fails to develop. Hearing impairment has a marked effect on the child's ability to acquire speech.

Hearing is essential for the natural development of speech and language and communication is interfered with by the presence of a hearing loss. Hearing loss in the children is a silent, hidden handicap. It is hidden because children, especially infants and toddlers, cannot tell us that they are not hearing well. It is a handicap because, if undetected, hearing loss in children can lead to delayed speech and language development, social and emotional problems and academic failure.

The oral communication skills of the hearing impaired children have long been of concern to Educators of the hearing impaired, Speech pathologists and audiologists because, the adequacy of such skills can influence the social, educational and career opportunities available to these individuals.

In the last decade, advancements have been made in studying the speech of the hearing impaired. This is largely due to the development of sophisticated processing and analysis techniques in speech science and computer science hat have increased our knowledge of normal speech production. In turn, these technological progresses have been applied to the analysis of the speech of the hearing impaired as well as to the development of clinical assessment training procedures.

Several researchers (Voelkar 1973, Hudgins and Numbers 1942, Boone 1966, Nober 1967, Markids 1970, Smith 1975, Geffner 1980, Angelocci et al 1964, Ravishanker 1985, Shukla 1987, Sheela 1988, Rashitha 1994, Vasantha 1995, Rahul 1997, Rathna Kumar 1998, Ravindar, 2006) have attempted to describe the speech characteristics of individuals with severe to profound hearing impairment. But the knowledge in this area is far from complete. Acoustic analysis of speech production is extremely useful to researchers since the methodologies employed are typically noninvasive, relatively basis with regard to instrumentation, and may be used routinely to depict changes in the physical characteristics of frequency, intensity and duration of speech segments. Therefore, it was considered that it will be useful to study the acoustic aspects of speech of Telugu speaking hearing impaired children, as it would contribute our knowledge of teaching speech to the hearing impaired, especially to the Telugu language.

The present study is an attempt to investigate some of acoustic characteristics of Telugu speaking hearing impaired children. 48 children in the age range of 6 to 12 years were selected and placed in three experimental groups namely, normal hearing group (NH), hearing aid group (HA) and Cochlear implant group (CI). Each group comprised of 16 children (male- 8, female – 8). The test material consisted to ten Telugu VCV words having the short vowels /a/,/i/,/u/,/e/, & /o/ and long vowels /a:/,/i:/,/u:/,/e:/, & /o:/. The speech samples of all the children are recorded and the samples were analyzed using PC based PRAAT speech analysis software) version 4.5.06; Paul and David, 2006; University of Amsterdam).

A one-way analysis of variance (ANOVA) was done for all the parameters to study the effect of group. Further, Least Significant Difference post-hoc paired group analysis was performed to examine individual group differences. The parameters analyzed were the following:

1. Fundamental frequency (F0)
2. Formant frequencies (F1, F2 and F3)
3. Bandwidths (B1, B2 and B3)
4. Vowel duration
5. Word duration

## 5.2. Conclusion

The results of the present study lead to the following conclusions:

### 5.2.1. Fundamental frequency (F0)

A significant difference in the fundamental frequency was found for all the vowels between normal hearing group (NH) and hearing aid group (HA), normal hearing group (NH) and cochlear implant group (CI) and hearing aid group (HA) and cochlear implant group (CI).

### 5.2.2. Formant frequencies

**(a). First formant Frequency (F1)**

A significant difference in the first formant frequency (F1) was found for all the vowels between normal hearing and hearing aid group.

A significant difference in the first formant frequency (F1) was found between normal hearing group and cochlear implant group for vowels /i:/. /i/, /o:/, /o/, /u:/ and /u/ but no significant difference was found between the two groups for vowels /e:/, /e/, /a:/, and /a/.

A significant difference in the first formant frequency (F1) was found between hearing aid group and cochlear implant group for vowels /i:/, /i/, /e:/, /e/ and /a/ but not no significant difference was found between the two groups for vowels /a:/, /o:/, /o/, /u;/ and /u/.

**b. Second formant frequency (F2)**

A significant difference in the second formant frequency (F2) was found between normal hearing group for all the vowels except /e:/.

A significant difference in the second formant frequency (F2) was found between normal hearing group and cochlear implant group for vowels /e:/, /a/;/, /o/ and /u:/ but no significant difference was found for vowels /i;/, /i/, /e/, /a/, /o:/ and /u/.

A significant difference in the second formant frequency (F2) was observed for all the vowels except for vowels /u: / between hearing aid group and cochlear implant group.

**c. Third formant frequency (F3)**

A significant difference was found in the third format frequency (F3) between normal hearing group and hearing aid group for all the vowels.

A significant difference was seen in the third formant frequency (F3) between normal hearing group and cochlear implant group for vowels /i;/, /i/, /e/, /a/, /o/, /u:/, and /u/ but no significant difference was found for vowels /e:/, /a:/, and /o:/.

A significant difference was observed in the third format frequency (F3) between hearing aid group and cochlear implant group for vowels /i;/, /i/, /e:/, /a:/ and /o:/ but no significance difference was observed for /e/, /a/ and /o/.

### 5.2.3 Bandwidth Characteristics

**a. First bandwidth (B1)**

A significant difference in the first bandwidth (B1) was found among normal hearing group and hearing aid group, normal hearing group and cochlear implant group for all the vowels. On the other hand there was a significant difference for all the vowels except /a:/ and /a/ between hearing aid group and cochlear implant group.

**b. Second bandwidth (B2)**

A significant difference in the second bandwidth (B2) was found between normal hearing group and cochlear implant group and normal hearing group and hearing group and hearing aid group for all the vowels.

A significant difference in the second bandwidth (B2) was found between the hearing aid group and cochlear implant group for vowels /i/, /e:/, /e/, /o:/, /o/ and /u:/ but no significant difference was found between these two groups for vowels /i:/, /a:/, /a/ and /u/.

**c. Third bandwidth (B3)**

A significant difference in the third bandwidth (B3) was found between normal hearing group and hearing aid group, normal hearing group and cochlear implant group all the vowels.

No significant difference was noticed in third bandwidth (B3) between cochlear implant group and hearing aid group for all the vowels.

### 5.2.4 Vowel Duration

A significant difference in the vowel duration was found for all the vowels between normal hearing group and hearing aid group, normal hearing group and cochlear implant group, and hearing aid group and cochlear implant group.

### 5.2.5 Word Duration

A significant difference in the word duration was observed for all the words between normal hearing group and hearing aid group, normal hearing group and cochlear implant group, and hearing aid group and cochlear implant group.

## 5.3. Implications and usefulness of this study:

The findings of the study have implication for Audiologists, Speech Pathologists, Educators and Researches.

1. The training program designed to improve the speech characteristics of hearing impaired children must take note of the hierarchy of development of structures under consideration in both normal hearing children and hearing impaired children establishing such hierarchy however, awaits further research.
2. The information obtained from this study would help in understand the normal and abnormal acoustic characteristics of speech sounds in normal and children with hearing impairment.

3. The information from acoustics analysis will also help in making use of the advances in cochlear implant technology as in with maximal effectiveness.

4. It helps in facilitating the oral production skills of the children with hearing impairment.

5. The information from the study determines the acoustic parameters that are deviated and also the extent of deviation.

6. It acts as a precursor to plan therapy accordingly, to improve the speech intelligibility.

7. The information on the speech of children with hearing impairment using hearing aids and cochlear implants helps to determine the effectiveness of the type of listening devices used by the hearing impaired.

## 5.4. Limitations of the study:

- The sample size was small.
- Age of intervention was not controlled, i.e. age at which the intervention was started for the hearing impaired group.
- Method of instruction (oral-aural approach, multi-sensory approach and oral communication) was not controlled.
- The type of amplification used by the subject (analog-digital) and the type of speech processor and number of channels used in the cochlear implant group were not controlled.

## 5.5. Recommendations for further research:

- Similar studies on a larger population may be undertaken.
- Other parameters like Voice Onset Time (VOT), Formant transition, closure duration, burst duration, pause duration etc. may also be studied using various VCV combinations.
- The study may be done across ages to delineate the development stages of speech acquisition in the hearing impaired.
- Various spectral parameters and their relations to the factors affecting speech intelligibility, in the hearing impaired children may be studied. Such information may be useful in planning therapy for children with hearing impairment.
- The variables such as age at which hearing aid are cochlear implant fitting was done, type of hearing aid used, analog or digital hearing aid, type of speech processor, number of channels can be controlled in further investigations.
- A similar study can be carried out on a different group of subjects.
- A similar study can be carried out in different Indian Languages.
- Future research can be done in phrase and sentence level.

# GLOSSARY

**Acoustic feedback:** sound produced when the amplified sound from a device receiver is picked up again by the microphone and preamplifier; a high pitched squeal.

**Acquired hearing loss:** Hearing loss that is acquired after birth.

**Adventitious hearing loss:** Hearing loss occurring after birth.

**Aspirated:** Describes a stop sound with a release of closure that precedes the onset of voicing of a following vowel long enough so that noise is produced during the interval.

**Assistive listening device:** ALD; instrument designed to provide awareness and/ or identification of environmental signals and speech and to improve signal – to – noise ratio;

**Audiogram:** A graphic representation of hearing thresholds as function of stimulus frequency

**Back vowel**: A vowel made with the tongue retracted towards the back of the oral cavity.

**Cardinal vowels**: A system for describing vowels in relation to the highest and lowest front and back vowels that can be produced.

**Centering glide:** A postvocalic glide or off glide that terminates in shwa.

**Cantering vowel:** A vowel made with the tongue positioned midway between the most forward and the most retracted position for vowels.

**Cochlear implant.:** Device implanted in the skull that permit persons with deafness to receiver stimulation of the auditory mechanism; typically comprised of a microphone, a speech processor, and an electrode array that is inserted in to the cochlea; directly stimulates the auditory nerve by means of electrical current.

**Communication:** The act of exchanging messages; may entail the use of speech, sign, writing, or hand gestures.

**Conductive hearing loss:** A hearing impairment caused by a lesion of the conductive mechanism (outer and middle ear).

**Consonant:** A sound produced by restricting or blocking the flow of air through the vocal tract.

**Deaf:** Having minimal or no hearing.

**Denasalise:** Describes the quality of sound produced when nasal resonance is influenced by a blockage inn the nasal cavity.

**Denasalizing:** The production of nasal consonants with a blockage in the nasal cavity. Results in a replacement of nasal quality by stop quality, or hypo-nasality.

**Dental**: Indicates a sound involving articulator contact with the teeth, as in labiodentals and inter dental.

**Decibel:** Unit of sound

**Devoicing:** The production of voiced consonants with partial or complete loss of vocal fold vibration.

**Diphthong:** A sound made by shifting from the position for one vowel to another one within the same syllable.

**Disability:** A limitation in function. It may not cause a handicap.

**Distorted:** A sound used for normal /r/ that shares feature of /r/ and /w/.

**Final consonant deletion**: A phonological process that results in the omission of word-final consonants; also called postvocalic consonant deletion.

**Final consonant devoicing:** A phonological process that results in the omission off voicing on word final consonants, also called postvocalic consonant devoicing.

**Formant:** A resonance in the vocal tract results in some frequencies in the speech signal having more energy than other frequencies.

**Formant 1:** The first frequency band above the fundamental frequency that demonstrates high energy in the speech signal.

**Formant 2:** The second frequency band above the fundamental frequency that demonstrates high energy in the speech signal.

**Formant frequency:** The frequency bands above the fundamental frequency that demonstrates high energy in the speech signal.

**Frequency:** The number of regular repeated events in a given unit of time; usually measured in cycles per second and expressed in Hertz (Hz).

**Front vowel**: A vowel made with the tongue advanced toward the front of oral cavity.

**Fronting glide:** A postvocalic glide, or off glide, that terminates near the /i/ vowel. Not to be confused with the phonological process of the same name.

**Fronting:** A phonological process that results in the substitution of alveolar consonants for velar consonants.

**Fundamental frequency:** The pure tone of lowest frequency is a group of periodic waves.

**Glide**. A sound made by shifting from one vowel position to another within the same syllable. May be an offglide or ann onglide.

**Gliding**: A phonological process which results in the substitution of glides /w/ and /j/ for the liquids /r/ and /l/.

**Handicap:** obstacles to every day function that result from a disability.

**Hard of hearing:** Having a hearing loss up to 70 dB.

**Hearing aid:** An electronic instrument that amplifies sound for a hearing – impaired user.

**Hearing disability:** functional limitation imposed on an individual as a result of hearing loss.

**Hearing impaired:** Abnormal / reduced hearing sensitivity.

**Hearing handicap:** Difficulties in everyday functioning that arise an a result of hearing loss.

**Hearing loss:** A total / partial loss of ability to perceive auditory stimulus.

**Hearing loss, mild:** Hearing thresholds between 25 and 40 dB HL.

**Hearing loss, moderate:** Hearing thresholds between 41 and 55 dB HL.

**Hearing loss, moderate – to- severe:** Hearing thresholds between 55 and 70 dB HL.

**Hearing loss, sever:** Hearing thresholds between 70 and 90 dB HL

**Hearing loss, profound:** Hearing loss greater than 90 dB HL.

**High vowel:** A vowel made with the tongue raised toward the palate**.**

**Hyper-nasality:** Excessive nasal quality in the production of non nasal consonant or vowel, or the nasalizing of such sound.

**Hypo-nasality**: Loss of nasal quality in the production of nasal consonants, or the denasalizing of such sounds.

**Intervocalic**: Describes a consonant produced between vowels.

**Lax vowel**: A vowel made with reduced tension in the tongue muscle.

**Locus**: Location of the second formant, frequency in the vowel transition that is characteristic of a particular place of articulation.

**Low vowel**: A vowel made with tongue lowered toward the floor of the oral avity.

**Mid vowel**: A vowel made with the tongue midway between the palate and the floor of the oral cavity.

**Misarticulation:** An error in speech production. May result n the replacement, deletion, distortion, or addition of sounds or the deletion of syllables.

**Nasalization**: The production of non-nasal consonants or vowels with excessive nasal quality, or hyper-nasality; also called nasalizing.

**Offglide**: A postvocalic glide produced by shifting from a more prominent to a less prominent vowel within the same syllable.

**Onglide**: A prevocalic glide produced by shifting from a less prominent to a more prominent vowel within the same syllable. Also referred to as a glide and generally classified as a consonant.

**Plosive**: A term sometimes used instead of stop particularly when there is a release of air pressure following a blockage of the vocal tract.

**Post release:** A phase in stop consonant production during which articulator is moving away from the contact position.

**Postvocalic:** Describes a consonant following a vowel.

**Precontact**: A phase in stop consonant production during which articulators are moving toward contact for closure.

**Prelingual:** in reference to hearing loss, loss acquired during the stage of spoken language acquisition.

**Prevocalic consonant voicing**: A phonological process that result in the voicing of voiceless consonants in prevocalic position.

**Prevocalic:** Describe a consonant preceding a vowel.

**Pure – tone average:** PTA: Average of hearing thresholds at 500Hz, 1000 Hz, and 2000 Hz.

**Rehabilitation:** Helping a handicapped person to restored/ partially restored function by means of therapy, prosthesis etc.

**Retracting glide**: A postvocalic glide, or offglide, that terminates near /u/.

**Residual hearing:** The hearing remaining in a person who has hearing loss.

**Rounded**: Describes sound made with a narrowing of the lip opening.

**Schwa**: A mid central vowel which includes relatively wide range of variants in the unstressed syllables of word like ‘above’, ‘below’, ‘today’, and ‘conceive’.

**Sensory neural hearing loss:** A hearing impairment caused by a lesion of the hair cells in the cochlea and the neurons of auditory part of cranial nerve VIII.

**Spectrograph:** An electronic instrument that produces a three – dimensional graph of speech; frequency is the Y – axis, time is the x – axis and intensity is shown by the darkness of tracing

**Spectrum:** The audible frequencies present in a sound.

**Stop**. A consonant produced by blocking the airflow through the vocal tract so as to increase the air pressure which may or may not be released.

**Syllabic consonant**: A consonant that functions as the nucleus, or peak of sonority of a syllable.

**Syllabication:** The production of a consonant as the nucleus, or peak of sonority, of a syllable.

**Syllable reduction**: A phonological process that involves the omission of a weak syllable or it is vowel in a word.

**Syllable**: A perceptual unit of speech with a nucleus, usually a vowel, which is marked by a peak of sound energy or sonority and may proceeded and followed by one or more consonants, usually marked by minima of sound energy of sonority.

**Tense vowel:** A vowel made with the tongue muscles relatively tense.

**Transition**: Articulator movement to a consonant from a vowel or to a vowel from a consonant.

**Un aspirated:** Describes a stop sound with release of closure at either slightly precedes or occurs simultaneously with voicing onset so that only brief or no aspiration noise is produced.

**Unrounded**: Describes sounds made with the lips with a relatively long horizontal opening.

**Variant:** A variation in the production of a speech sound.

**Velarizing:** The production of alveolar sound with approximation of the tongue dorsum to the velum, or soft palate.

**Vocalization:** A phonological process which results in the substitution of a vowel for a post vocalic or syllabic liquid; also called vocalization.

**Voice bar**: Low frequency bar in a spectrogram that looks like a formant but reflects low frequency energy of voicing.

**Voice onset time**: Abbreviation for VOT, the interval between the release of a prevocalic stop consonant and the onset of vocal fold vibration for a following vowel.

**Vowel**: A speech sound that is produced with relatively open vocal tract resonance and functions as the nucleus of the syllable.

**Source: R.N Ohde and D.J Sharf (1992). Phonetic analysis of normal and abnormal speech. New York: Macmillan press.**

**Source: Tye – Murray, N. (1998). Foundations of aural rehabilitation. Singular publishing group San Diego. London.**

**Source: Katz, J. (1985). Hand book of clinical Audiology. Williams & Wilikins.**

# APPENDIX-I

## DATA SHEET

Name: Age/sex:

D.O.B: Address:

Father's name/occupation:

PROVISIONAL DIAGNOSIS:

Type of amplification: hearing aid

If hearing aid, what type of hearing aid are you using?

Age at which he/she was fitted with hearing aid?

Cost of the hearing aid?

Duration of hearing aid usage.

Language exposure to the child?

Does he or she attend speech therapy?

If yes, since how many years and the age at which the therapy was started?

Educational background:_________ normal school ________special school.

Medium of instruction inn school:

Scholastic performance of the child:

_____poor ______fair_______good _________excellent

Remarks/opinions of the parents regarding the amplification, if any?

## APPENDIX-II

## DATA SHEET

Name: Age/sex:

D.O.B: Address:

Father's name/occupation:

PROVISIONAL DIAGNOSIS:

Type of amplification: cochlear implant

If cochlear implant, what type of cochlear implant are you using?

Age at which he/she was implanted?

Where was the implantation done?

Cost of the implant?

Did he/she use any hearing aid earlier to the implantation?

_________yes__________no

If yes what type of hearing aid?

Duration of hearing aid usage.

Language exposure to the child?

Does he or she attend speech therapy?

If yes, since how many years and the age at which the therapy was started?

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Educational background:_________ normal school ________special school.

Medium of instruction inn school:

Scholastic performance of the child:

_____poor ______fair_______good _________excellent

Remarks/opinions of the parents regarding the amplification, if any?

# APPENDIX – III

## TESTMATERIAL

### VOWELS

| | |
|---|---|
| / i:/ | / i:ta/ |
| /i/ | /idi/ |
| /e:/ | /e:du/ |
| /e/ | /etu/ |
| /a:/ | /a:ku/ |
| /a/ | /adi/ |
| /o:/ | /o:da/ |
| /o/ | /oka/ |
| /u:/ | /u:ta/ |
| /u/ | /upa/ |

## First Bandwidth Frequency (B1)

**Table. 5. a. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /i: /**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 27679.875 | 2 | 13839.93 | 92.65 | .00 |
| Within group | 6721.43 | 45 | 149.36 | | |
| **Total** | 34401.31 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| **Between the group** | **Difference** | **Standard error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | 55.688 | 4.321 | Significant |
| NH Vs CI | 44.250 | 4.321 | Significant |
| HA Vs CI | -11438 | 4.321 | Significant |

**Table 5.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Between Groups | 23906.16 | 2 | 11953.08 | 68.36 | .00 |
| Within group | 7867.75 | 45 | 174.83 | | |
| **Total** | 31773.91 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | 52.625 | 4.675 | Significant |
| NH Vs CI | 39.125 | 4.675 | Significant |
| HA Vs CI | -13.500 | 4.675 | Significant |

**Table 5.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /e: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 19859.62 | 2 | 9929.81 | | |
| Within group | 7000.18 | 45 | 155.56 | 63.83 | .00 |
| **Total** | 26859.81 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | 48.188 | 4.410 | Significant |
| NH Vs CI | 35.063 | 4.410 | Significant |
| HA Vs CI | -13.125 | 4.410 | Significant |

**Table 5.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 20695.62 | 2 | 10347.93 | 66.24 | .00 |
| Within group | 7028.93 | 45 | 156.19 | | |
| **Total** | 27724.81 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 48.750 | 4.419 | Significant |
| NH Vs CI | 36.938 | 4.419 | Significant |
| HA Vs CI | -11.813 | 4.419 | Significant |

**Table 5.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /a: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 24583.87 | 2 | 12291.93 | 68.29 | .00 |
| Within group | 8099.43 | 45 | 179.98 | | |
| **Total** | 32683.31 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 51.938 | 4.743 | Significant |
| NH Vs CI | 42.750 | 4.743 | Significant |
| HA Vs CI | -9.188 | 4.743 | Significant |

**Table 5.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /a/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 26637.04 | 2 | 13319.52 | 65.28 | .00 |
| Within group | 9180.43 | 45 | 204.01 | | |
| **Total** | 35817.47 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 55.188 | 5.050 | Significant |
| NH Vs CI | 42.188 | 5.050 | Significant |
| HA Vs CI | -13.000 | 5.050 | Significant |

**Table 5.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /o: /**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 29155.79 | 2 | 14577.89 | 52.385 | .00 |
| Within group | 12552.68 | 454 | 278.28 | | |
| **Total** | 41678.47 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 58.313 | 5.898 | Significant |
| NH Vs CI | 42.688 | 5.898 | Significant |
| HA Vs CI | -15.625 | 5.898 | Significant |

**Table 5.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 28808.04 | 2 | 14404.02 | 58.76 | .000 |
| Within group | 11030.62 | 45 | 245.12 | | |
| **Total** | 39836.66 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 58.688 | 5.535 | Significant |
| NH Vs CI | 40.188 | 5.535 | Significant |
| HA Vs CI | -18.500 | 5.535 | Significant |

**Table 5.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /u: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 21943.04 | 2 | 10971.52 | 42.22 | .00 |
| Within group | 11691.62 | 45 | 259.81 | | |
| **Total** | 336634.66 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 51.188 | 5.699 | Significant |
| NH Vs CI | 35.188 | 5.699 | Significant |
| HA Vs CI | -16.000 | 5.699 | Significant |

**Table 5.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Bandwidth Frequency (B1) for /u/**

| Source of variance | Sum of variance | Df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 22342.875 | 2 | 111741.43 | | |
| Within group | 10700.93 | 45 | 237.79 | 46.97 | .005 |
| **Total** | 33043.81 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 51.563 | 5.452 | Significant |
| NH Vs CI | 35.813 | 5.452 | Significant |
| HA Vs CI | -15.750 | 5.452 | Significant |

# First Formant Frequency (F1)

**Table 2.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /i:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 189050.792 | 2 | 94525.396 | 20.996 | .000 |
| Within group | 202595.125 | 45 | 4502.114 | | |
| **Total** | 391645.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -152.1875 | 23.7227 | Significant |
| NH Vs CI | -94.8750 | 23.7227 | Significant |
| HA Vs CI | -57.3125 | 23.7227 | .020 |

**Table 2.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 187293.375 | 2 | 93646.688 | 21.549 | .000 |
| Within group | 195555.938 | 45 | 4345.688 | | |
| **Total** | 382849.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -151.5000 | 23.9752 | Significant |
| NH Vs CI | -57.3125 | 23.7227 | Significant |
| HA Vs CI | 57.1875 | 23.3069 | Significant |

**Table 2.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /e:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 186962.000 | 2 | 93481.000 | 16.192 | .000 |
| Within group | 259797.313 | 45 | 5773.274 | | |
| **Total** | 446759.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -149.7500 | 27.9744 | Significant |
| NH Vs CI | -48.2500 | 26.8637 | .079 |
| HA Vs CI | 101.5000 | 26.8637 | Significant |

**Table 2.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 193258.167 | 2 | 96629.083 | 14.480 | .000 |
| Within group | 300307.500 | 45 | 6673.500 | | |
| **Total** | 493565.667 | 47 | | | |

**LSD post-hoc paired group analysis**

**s**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -153.5000 | 29.7453 | Significant |
| NH Vs CI | -55.6250 | 28.8823 | .060 |
| HA Vs CI | 97.8750 | 28.8823 | Significant |

**Table 2.e.One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /a:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 19728.167 | 2 | 9864.083 | 1.595 | 214 |
| Within group | 278255.750 | 45 | 6183.461 | | |
| **Total** | 297983.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -10.0000 | 27.8017 | Significant |
| NH Vs CI | 37.1250 | 27.8017 | .188 |
| HA Vs CI | 47.1250 | 27.8017 | .097 |

**Table 2.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /a/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **P** |
|---|---|---|---|---|---|
| Group | 38896.542 | 2 | 19448.271 | 2.426 | .100 |
| Within group | 360757.438 | 45 | 8016.832 | | |
| **Total** | 399653.979 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -10.8125 | 31.6560 | Significant |
| NH Vs CI | 54.2500 | 31.6560 | .093 |
| HA Vs CI | 65.0625 | 31.6560 | Significant |

**Table 2.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /o:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 135350.792 | 2 | 67675.396 | 9.163 | .000 |
| Within groups | 332357.688 | 45 | 7385.726 | | |
| **Total** | 467708.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -128.8750 | 31.1246 | Significant |
| NH Vs CI | -79.6875 | 30.3845 | Significant |
| HA Vs CI | 49.1875 | 30.3845 | .112 |

**Table 2.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /o/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **P** |
|---|---|---|---|---|---|
| Group | 172502.167 | 2 | 86251.083 | | |
| Within group | 286535.313 | 45 | 6367.451 | 13.546 | .000 |
| **Total** | 459037.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -143.8750 | 28.7716 | Significant |
| NH Vs CI | -97.3750 | 28.2123 | Significant |
| HA Vs CI | 46.5000 | 28.2123 | .106 |

**Table 2.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /u:/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **P** |
|---|---|---|---|---|---|
| Group | 241608.792 | 2 | 120804.396 | 15.483 | .000 |
| Within group | 351109.188 | 45 | 7802.426 | | |
| **Total** | 592717.979 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -163.4375 | 31.2298 | Significant |
| NH Vs CI | -132.8750 | 31.2298 | Significant |
| HA Vs CI | 30.5625 | 31.2298 | .333 |

**Table 2.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for First Formant frequency (F1) for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 210588.500 | 2 | 105294.250 | 17.270 | .000 |
| Within group | 274366.813 | 45 | 6097.040 | | |
| **Total** | 484955.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -149.8750 | 27.6067 | Significant |
| NH Vs CI | -128.7500 | 27.6067 | Significant |
| HA Vs CI | 21.1250 | 27.6067 | .448 |

## APPENDIX – IV

## STATISTICAL ANALYSIS

**Table 1.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /i:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between Group | 106650.167 | 2 | 53325.083 | 101.559 | 000 |
| With in group | 23627.813 | 45 | 525.063 | | |
| **Total** | 130277.979 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -114.8750 | 8.1014 | Significant |
| NH Vs CI | -67.5000 | 8.1014 | Significant |
| HA Vs CI | 47.3750 | 8.1014 | Significant |

**Table 1.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /i/**

<table>
<tr><th>Source of variance</th><th>Sum of variance</th><th>df</th><th>Mean Squares</th><th>F</th><th>P</th></tr>
<tr><td>Between Group</td><td>140015.167</td><td>2</td><td>70007.583</td><td rowspan="3">49.882</td><td rowspan="3">.000</td></tr>
<tr><td>With in Group</td><td>21018.750</td><td>45</td><td>467.083</td></tr>
<tr><td>sp<br>**Total**</td><td>161033.917</td><td>47</td><td></td></tr>
</table>

**LSD post-hoc paired group analysis**

| **Between the groups** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -129.8750 | 7.6410 | Significant |
| NH Vs CI | -86.7500 | 7.6410 | Significant |
| HA Vs CI | 43.1250 | 7.6410 | Significant |

**Table 1.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /e:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Between Group | 88422.167 | 2 | 44211.083 | 85.883 | .000 |
| With in Group | 23165.313 | 45 | 514.785 | | |
| **Total** | 111587.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -105.1250 | 8.0217 | Significant |
| NH Vs CI | -53.6250 | 8.0217 | Significant |
| HA Vs CI | -51.5000 | 8.0217 | Significant |

**Table 1.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 133086.292 | 2 | 66543.146 | 111.394 | .000 |
| With in group | 26881.625 | 45 | 597.369 | | |
| **Total** | 159967.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -127.1250 | 8.6412 | Significant |
| NH Vs CI | -44.6875 | 8.6412 | Significant |
| HA Vs CI | 44.6875 | 8.6412 | Significant |

**Table 1.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /a:/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **P** |
|---|---|---|---|---|---|
| Group | 201988.792 | 2 | 100994.396 | | |
| Within group | 10577.875 | 45 | 235.064 | 429.647 | .000 |
| **Total** | 212566.667 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -154.6875 | 5.4206 | Significant |
| NH Vs CI | -108.8125 | 5.4206 | Significant |
| HA Vs CI | 45.8750 | 5.4206 | Significant |

**Table 1.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /a/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 200704.292 | 2 | 100352.146 | 458.107 | .000 |
| Within group | 9857.625 | 45 | 219.058 | | |
| **Total** | 210561.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -154.1250 | 5.2328 | Significant |
| NH Vs CI | -108.6875 | 5.2328 | Significant |
| HA Vs CI | 45.4375 | 5.2328 | Significant |

**Table 1.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /o:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 152362.167 | 2 | 76181.083 | 241.802 | .000 |
| Within group | 14177.500 | 45 | 315.056 | | |
| **Total** | 166539.667 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -136.3750 | 6.2755 | Significant |
| NH Vs CI | -86.5000 | 6.2755 | Significant |
| HA Vs CI | 49.8750 | 6.2755 | Significant |

**Table 1.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 98000.292 | 2 | 49000.146 | 213.071 | .000 |
| Within group | 10348.688 | 45 | 229.971 | | |
| **Total** | 108348.979 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -110.1875 | 5.3616 | Significant |
| NH Vs CI | -64.1250 | 5.3616 | Significant |
| HA Vs CI | 46.0625 | 5.3616 | Significant |

**Table 1.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /u:/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 89724.667 | 2 | 44862.333 | 150.654 | .000 |
| Within group | 13400.313 | 45 | 297.785 | | |
| Total | 103124.979 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -105.5000 | 6.1011 | Significant |
| NH Vs CI | -60.7500 | 6.1011 | Significant |
| HA Vs CI | 44.7500 | 6.1011 | Significant |

**Table 1.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for fundamental frequency for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 103872.875 | 2 | 51936.438 | 223.277 | .000 |
| Within group | 10467.438 | 45 | 232.610 | | |
| **Total** | 114340.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -113.7500 | 5.3922 | Significant |
| NH Vs CI | -62.6875 | 5.3922 | Significant |
| HA Vs CI | 51.0625 | 5.3922 | Significant |

## Second Bandwidth Frequency (B2)

**Table 6.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /i: /**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 50373.87 | 2 | 25186.93 | | |
| Within group | 22276.43 | 45 | 495.03 | 50.87 | .00 |
| **Total** | 72650.31 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | 74.750 | 7.866 | Significant |
| NH Vs CI | 60.438 | 7.866 | Significant |
| HA Vs CI | -14.313 | 7.866 | .075 |

**Table 6.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | P |
|---|---|---|---|---|---|
| Group | 35619.04 | 2 | 17809.52 | | |
| Within group | 25166.87 | 45 | 559.26 | 31.84 | .00 |
| **Total** | 60785.91 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 65.688 | 8.361 | Significant |
| NH Vs CI | 43.000 | 8.361 | Significant |
| HA Vs CI | -22.6888 | 8.361 | Significant |

**Table 6.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /e: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 39473.16 | 2 | 19736.58 | 38.24 | .00 |
| Within group | 23224.75 | 45 | 516.10 | | |
| **Total** | 62697.91 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 69.125 | 8.032 | Significant |
| NH Vs CI | 45.375 | 8.032 | Significant |
| HA Vs CI | -23.750 | 8.032 | Significant |

**Table 6.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 30367.16 | 2 | 15183.58 | 30.15 | .00 |
| Within group | 22658.50 | 45 | 503.52 | | |
| **Total** | 53025.66 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 59.625 | 7.933 | Significant |
| NH Vs CI | 43.250 | 7.933 | Significant |
| HA Vs CI | -16.375 | 7.933 | Significant |

**Table 6.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /a: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 89211.29 | 2 | 44605.62 | 61.66 | .00 |
| Within group | 32553.37 | 45 | 723.40 | | |
| **Total** | 121764.7 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 97.813 | 9.509 | Significant |
| NH Vs CI | 83.375 | 9.509 | Significant |
| HA Vs CI | -14.438 | 9.509 | .136 |

**Table 6.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /a/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 100991.6 | 2 | 50495.81 | | |
| Within group | 40657.18 | 45 | 903.49 | 55.890 | .00 |
| **Total** | 141648.8 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 103.25 | 10.627 | Significant |
| NH Vs CI | 90.188 | 10.627 | Significant |
| HA Vs CI | -12.938 | 10.627 | .230 |

**Table 6.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /o: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 32661.12 | 2 | 16330.56 | 27.27 | .00 |
| Within group | 26941.68 | 45 | 598.70 | | |
| **Total** | 59602.81 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 62.375 | 8.651 | Significant |
| NH Vs CI | 43.188 | 8.651 | Significant |
| HA Vs CI | -19.188 | 8.651 | Significant |

**Table 6.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 41324.62 | 2 | 20662.31 | 37.61 | .00 |
| Within group | 24721.18 | 45 | 549.36 | | |
| **Total** | 66045.81 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 69.938 | 8.287 | Significant |
| NH Vs CI | 49.313 | 8.287 | Significant |
| HA Vs CI | -20.625 | 8.287 | Significant |

**Table 6.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /u: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 40805.167 | 2 | 20402.58 | 33.192 | .00 |
| Within group | 27660.75 | 45 | 614.683 | | |
| **Total** | 68465.917 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 68.750 | 8.366 | Significant |
| NH Vs CI | 51.125 | 8.366 | Significant |
| HA Vs CI | -17.625 | 8.366 | Significant |

**Table 6.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Bandwidth Frequency (B2) for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 29785.042 | 2 | 14892.521 | 26.720 | .00 |
| Within group | 25080.938 | 45 | 557.354 | | |
| **Total** | 54865.979 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 58.188 | 8.347 | Significant |
| NH Vs CI | 45.000 | 8.347 | Significant |
| HA Vs CI | -13.188 | 8.347 | .121 |

# Second Formant Frequency (F2)

**Table 3.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second formant frequency (F2) for /i:/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **P** |
|---|---|---|---|---|---|
| Group | 252270.167 | 2 | 126135.083 | 15.015 | .000 |
| Within group | 378015.750 | 45 | 8400.350 | | |
| **Total** | 630285.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -156.8750 | 34.1088 | Significant |
| NH Vs CI | -6.3750 | 32.4044 | .845 |
| HA Vs CI | 150.5000 | 32.4044 | Significant |

**Table 3.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /i/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 249047.542 | 2 | 124523.771 | 13.550 | .000 |
| Within group | 413540.938 | 45 | 9189.799 | | |
| **Total** | 662588.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -172.1875 | 35.3785 | Significant |
| NH Vs CI | -52.7500 | 33.8928 | .127 |
| HA Vs CI | 119.4375 | 33.8928 | Significant |

**Table 3.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /e:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 102500.667 | 2 | 51250.333 | 5.996 | .005 |
| Within group | 384607.813 | 45 | 8546.840 | | |
| **Total** | 487108.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -43.5000 | 32.6857 | Significant |
| NH Vs CI | 68.7500 | 32.6857 | Significant |
| HA Vs CI | 112.2500 | 32.6857 | Significant |

**Table. 3.d: One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 72911.625 | 2 | 36455.813 | 3.376 | .043 |
| Within group | 485869.187 | 45 | 10797.093 | | |
| **Total** | 558780.812 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -72.9375 | 36.7374 | Significant |
| NH Vs CI | 16.8750 | 36.7374 | .648 |
| HA Vs CI | 89.8125 | 36.7374 | Significant |

**Table. 3.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /a:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 643281.792 | 2 | 321640.896 | 32.828 | .000 |
| Within group | 440902.688 | 45 | 9797.838 | | |
| **Total** | 1084184.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -278.8125 | 34.9961 | Significant |
| NH Vs CI | -184.1875 | 34.9961 | Significant |
| HA Vs CI | 94.6250 | 34.9961 | Significant |

**Table 3.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /a/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 383495.375 | 2 | 191747.688 | 29.477 | .000 |
| Within group | 292725.938 | 45 | 6505.021 | | |
| **Total** | 676221.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -192.0625 | 28.6004 | Significant |
| NH Vs CI | -5.0000 | 28.5154 | .862 |
| HA Vs CI | 87.0625 | 28.5154 | Significant |

**Table 3.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /o:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 161388.875 | 2 | 80694.438 | 10.604 | .000 |
| Within group | 342426.438 | 45 | 7609.476 | | |
| **Total** | 503815.313 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -125.7500 | 30.8510 | Significant |
| NH Vs CI | -5.6875 | 30.8413 | .855 |
| HA Vs CI | 20.0625 | 30.8413 | Significant |

**Table. 3.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 173701.792 | 2 | 86850.896 | 13.968 | .000 |
| Within group | 279794.125 | 45 | 6217.647 | | |
| **Total** | 453495.917 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -147.3125 | 27.8784 | Significant |
| NH Vs CI | -70.6875 | 27.8784 | .015 |
| HA Vs CI | 76.6250 | 27.8784 | Significant |

**Table. 3.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /u:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 232392.125 | 2 | 116196.063 | 12.892 | .000 |
| Within group | 405591.125 | 45 | 9013.136 | | |
| **Total** | 637983.250 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -167.8750 | 33.5655 | Significant |
| NH Vs CI | -109.4375 | 33.5655 | .002 |
| HA Vs CI | 58.4375 | 33.5655 | Significant |

**Table. 3.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for Second Formant frequency (F2) for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 148146.792 | 2 | 74073.396 | 7.772 | .001 |
| Within group | 428883.688 | 45 | 9530.749 | | |
| **Total** | 577030.479 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -135.8750 | 34.5158 | Significant |
| NH Vs CI | -61.4375 | 34.5158 | .082 |
| HA Vs CI | 74.4375 | 34.5158 | Significant |

## Third Bandwidth Frequency (B3)

**Table 7.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /i: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 113438.5 | 2 | 56719.271 | 64.640 | .00 |
| Within group | 39485.938 | 45 | 877.465 | | |
| **Total** | 152924.5 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 99.688 | 10.473 | Significant |
| NH Vs CI | 106.250 | 10.473 | Significant |
| HA Vs CI | 6.563 | 10.473 | Significant |

**Table 7.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 109062.2 | 2 | 54531.083 | 52.228 | .00 |
| Within group | 46984.500 | 45 | 1044.100 | | |
| **Total** | 156046.7 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 94.875 | 11.424 | Significant |
| NH Vs CI | 106.375 | 11.424 | Significant |
| HA Vs CI | 11.500 | 11.424 | .319 |

**Table 7.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /e:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 109840.7 | 2 | 54920.333 | 83.890 | .000 |
| Within group | 29460.313 | 45 | 654.674 | | |
| **Total** | 139301.0 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 96.250 | 9.046 | Significant |
| NH Vs CI | 106.000 | 9.046 | Significant |
| HA Vs CI | 9.750 | 9.046 | .287 |

**Table 7.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 89960.167 | 2 | 44980.083 | | |
| Within group | 33002.500 | 45 | 733.389 | 61.332 | .000 |
| **Total** | 122962.7 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 90.625 | 9.575 | Significant |
| NH Vs CI | 93.000 | 9.575 | Significant |
| HA Vs CI | 2.375 | 9.575 | .805 |

**Table 7.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /a: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 265104.0 | 2 | 132552.021 | 74.752 | .00 |
| Within group | 79795.438 | 45 | 1773.232 | | |
| **Total** | 344899.5 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 154.000 | 14.888 | Significant |
| NH Vs CI | 161.063 | 14.888 | Significant |
| HA Vs CI | 7.063 | 14.888 | .638 |

**Table 7.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /a/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 209725.8 | 2 | 104862.896 | 59.704 | .00 |
| Within group | 79036.688 | 45 | 1756.371 | | |
| **Total** | 288762.5 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | 139.813 | 14.817 | Significant |
| NH Vs CI | 140.625 | 14.817 | Significant |
| HA Vs CI | .813 | 14.817 | .957 |

**Table 7.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /o: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 107194.8 | 2 | 53597.396 | 30.729 | .00 |
| Within group | 78489.188 | 45 | 1744.204 | | |
| **Total** | 185684.0 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 95.938 | 14.766 | Significant |
| NH Vs CI | 104.063 | 14.766 | Significant |
| HA Vs CI | 8.125 | 14.766 | .585 |

**Table 7.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 119128.7 | 2 | 59564.333 | 63.486 | .00 |
| Within group | 42220.000 | 45 | 938.222 | | |
| **Total** | 161348.7 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 99.750 | 10.829 | Significant |
| NH Vs CI | 110.750 | 10.829 | Significant |
| HA Vs CI | 11.000 | 10.829 | .315 |

**Table 7.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /u:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 83767.042 | 2 | 41883.521 | 31.346 | .00 |
| Within group | 47902.438 | 45 | 1064.499 | | |
| **Total** | 131669.5 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 85.500 | 11.535 | Significant |
| NH Vs CI | 91.438 | 11.535 | Significant |
| HA Vs CI | 5.938 | 11.535 | .609 |

**Table 7.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Bandwidth frequency (B3) for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 36646.625 | 2 | 18323.313 | 10.932 | .00 |
| Within group | 75424.188 | 45 | 1676.093 | | |
| **Total** | 112070.8 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | 52.375 | 14.475 | Significant |
| NH Vs CI | 63.313 | 14.475 | Significant |
| HA Vs CI | 10.938 | 14.475 | .454 |

## Third Formant frequency (F3)

**Table 4.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant frequency (F3) for / i: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 207273.292 | 2 | 103636.646 | 9.995 | .000 |
| Within group | 466604.188 | 45 | 10368.982 | | |
| **Total** | 673877.479 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the groups | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -160.8125 | 36.0017 | Significant |
| NH Vs CI | -86.4375 | 36.0017 | Significant |
| HA Vs CI | 74.3750 | 36.0017 | Significant |

**Table 4.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant frequency (F3) for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 216646.125 | 2 | 108323.063 | 18.662 | .000 |
| Within group | 261199.125 | 45 | 5804.425 | | |
| **Total** | 477845.250 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -163.3125 | 26.9361 | Significant |
| NH Vs CI | -99.1875 | 26.9361 | Significant |
| HA Vs CI | 64.1250 | 26.9361 | Significant |

**Table 4. c. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant Frequency (F3) for /e: /**

| Source of Variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 152634.125 | 2 | 76317.063 | 11.074 | .000 |
| Within group | 310122.875 | 45 | 6891.619 | | |
| **Total** | 462757.000 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -136.4375 | 29.3505 | Significant |
| NH Vs CI | -49.5625 | 29.3505 | .098 |
| HA Vs CI | 86.8750 | 29.3505 | Significant |

**Table 4.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant Frequency (F3) for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 448085.792 | 2 | 224042.896 | 9.084 | .000 |
| Within group | 1109883.688 | 45 | 24664.082 | | |
| **Total** | 1557969.479 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -233.6250 | 55.5249 | Significant |
| NH Vs CI | -149.5625 | 55.5249 | Significant |
| HA Vs CI | 84.0625 | 55.5249 | .137 |

**Table 4.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant Frequency (F3) for /a: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 185715.042 | 2 | 92857.521 | 12.238 | .000 |
| Within group | 341448.938 | 45 | 7587.754 | | |
| **Total** | 527163.979 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -121.0000 | 30.7972 | Significant |
| NH Vs CI | 19.6875 | 30.7972 | .526 |
| HA Vs CI | 140.6875 | 30.7972 | Significant |

**Table 4.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant Frequency (F3) for /a/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 270776.542 | 2 | 135388.271 | 4.176 | .022 |
| Within group | 1458925.375 | 45 | 32420.564 | | |
| **Total** | 1729701.917 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -174.8125 | 63.6598 | Significant |
| NH Vs CI | -137.0625 | 63.6598 | Significant |
| HA Vs CI | 37.7500 | 63.6598 | .556 |

**Table 4.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant frequency (F3) for /o: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 259642.792 | 2 | 129821.396 | 10.496 | .000 |
| Within group | 556613.125 | 45 | 12369.181 | | |
| **Total** | 816255.917 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -169.1250 | 39.3211 | Significant |
| NH Vs CI | -30.8125 | 39.3211 | Significant |
| HA Vs CI | 138.3125 | 39.3211 | Significant |

**Table 4.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant frequency (F3) for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 279340.542 | 2 | 139670.271 | 12.412 | .000 |
| Within group | 506367.125 | 45 | 11252.603 | | |
| **Total** | 785707.667 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| NH Vs HA | -176.0625 | 37.5043 | Significant |
| NH Vs CI | -142.2500 | 37.5043 | Significant |
| HA Vs CI | 33.8125 | 37.5043 | Significant |

**Table 4.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for Third Formant frequency (F3) for /u:/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 415917.167 | 2 | 207958.583 | 20.788 | .000 |
| Within group | 450164.750 | 45 | 10003.661 | | |
| **Total** | 866081.917 | 47 | | | |

**LSD Post-Hoc Paired Group Analysis**

| Between the group | Difference | Standard error | Interpretation |
|---|---|---|---|
| H Vs HA | -208.8750 | 35.3618 | Significant |
| NH Vs CI | -183.6250 | 35.3618 | Significant |
| HA Vs CI | 25.2500 | 35.3618 | Significant |

# Vowel Duration

**Table 8.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /i: /**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 969291.82 | 2 | 484645.896 | | |
| Within group | 25056.688 | 45 | 556.815 | 870389 | .00 |
| **Total** | 999348.5 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -347.438 | 8.343 | Significant |
| NH Vs CI | -155.375 | 8.343 | Significant |
| HA Vs CI | 192.063 | 8.343 | Significant |

**Table 8.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /i/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 531291.2 | 2 | 265645.583 | 626.564 | .00 |
| Within group | 19078.750 | 45 | 423.972 | | |
| **Total** | 550369.9 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -255.375 | 7.280 | Significant |
| NH Vs CI | -157.625 | 7.280 | Significant |
| HA Vs CI | 97.750 | 7.280 | Significant |

**Table 8.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /e: /**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 858341.2 | 2 | 429170583 | 479.738 | .00 |
| Within group | 40256.750 | 45 | 894.594 | | |
| **Total** | 898597.9 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -326.375 | 10.575 | Significant |
| NH Vs CI | -139.145 | 10.575 | Significant |
| HA Vs CI | 187.250 | 10.575 | Significant |

**Table 8.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /e/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 425384 | 2 | 212692.188 | 408.292 | .00 |
| Within group | 40537.625 | 45 | 900.836 | | |
| **Total** | 465922.0 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -229.063 | 10.612 | Significant |
| NH Vs CI | -137.500 | 10.612 | Significant |
| HA Vs CI | 91.563 | 10.612 | Significant |

**Table 8.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /a: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 1035480 | 2 | 517739.813 | 808.206 | .00 |
| Within group | 28827.187 | 45 | 640.604 | | |
| **Total** | 1064307 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -359.438 | 8.948 | Significant |
| NH Vs CI | -166.313 | 8.948 | Significant |
| HA Vs CI | 193.125 | 8.948 | Significant |

**Table 8.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /a/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 532305.2 | 2 | 266152.583 | 321.804 | .00 |
| Within group | 37217.813 | 45 | 827.063 | | |
| **Total** | 66569523.0 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -254.375 | 10.168 | Significant |
| NH Vs CI | -164.250 | 10.168 | Significant |
| HA Vs CI | 90.125 | 10.168 | Significant |

**Table 8.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /o: /**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 969988.5 | 2 | 484994.250 | 244.265 | .00 |
| Within group | 89348.500 | 45 | 1985.522 | | |
| **Total** | 1059337 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the groups** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -347.625 | 15.754 | Significant |
| NH Vs CI | -156.375 | 15.754 | Significant |
| HA Vs CI | 191.250 | 15.754 | Significant |

**Table 8.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /o/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 449698.6 | 2 | 224849.313 | 214.634 | .00 |
| Within group | 47141.688 | 45 | 1047.593 | | |
| **Total** | 496840.3 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -235.188 | 11.443 | Significant |
| NH Vs CI | -143.563 | 11.443 | Significant |
| HA Vs CI | 91.625 | 11.443 | Significant |

**Table 8.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /u: /**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 1012604 | 2 | 506301.813 | 495.019 | .00 |
| With in group | 46025.688 | 45 | 1022.793 | | |
| **Total** | 1058629 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -355.438 | 11.307 | Significant |
| NH Vs CI | -164.313 | 11.307 | Significant |
| HA Vs CI | 191.125 | 11.307 | Significant |

**Table 8.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for vowel duration for /u/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 528265.5 | 2 | 264132.771 | | |
| With in group | 47437.438 | 45 | 1054.165 | 250.561 | .00 |
| **Total** | 575703.0 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -254.188 | 11.479 | Significant |
| NH Vs CI | -159.750 | 11.479 | Significant |
| HA Vs CI | 94.438 | 11.479 | Significant |

# Word Duration

**Table 9.a. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /i: ta/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 7482274 | 2 | 3741137.021 | 458.836 | .00 |
| With in group | 366908.9 | 45 | 8153.532 | | |
| **Total** | 7849183 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -967.063 | 31.925 | Significant |
| NH Vs CI | -491.00 | 31.925 | Significant |
| HA Vs CI | 476.063 | 31.925 | Significant |

**Table 9.b. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /idi/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 6682122 | 2 | 3341061.083 | 340.910 | .00 |
| With in group | 441019.5 | 45 | 9800433 | | |
| **Total** | 7123142 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -913.875 | 35.001 | Significant |
| NH Vs CI | -448.375 | 35.001 | Significant |
| HA Vs CI | 465.500 | 35.001 | Significant |

**Table 9.c. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /e: du/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 7440616 | 2 | 3720308.146 | | |
| With in group | 295329.2 | 45 | 6562.871 | 566.872 | .00 |
| **Total** | 7735945 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -964.125 | 28.642 | Significant |
| NH Vs CI | -502.188 | 28.642 | Significant |
| HA Vs CI | 461.938 | 28.642 | Significant |

**Table 9.d. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration /etu/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 6552677 | 2 | 3276338.521 | | |
| With in group | 331674.9 | 45 | 7370553 | 444517 | .00 |
| **Total** | 6884352 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -905.000 | 30.353 | Significant |
| NH Vs CI | -445.813 | 30.353 | Significant |
| HA Vs CI | 459.188 | 30.353 | Significant |

**Table 9.e. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /a: ku/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 7377605 | 2 | 3688802.688 | 350.943 | .00 |
| With in group | 472999.9 | 45 | 10511.108 | | |
| **Total** | 7850605 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -960.313 | 36.248 | Significant |
| NH Vs CI | -479.500 | 36.248 | Significant |
| HA Vs CI | 480.813 | 36.248 | Significant |

**Table 9.f. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /adi/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 6638915 | 2 | 3319457.521 | 167.195 | .00 |
| With in group | 893421.9 | 45 | 19853.821 | | |
| **Total** | 7532337 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -909.938 | 49.817 | Significant |
| NH Vs CI | -492.500 | 49.817 | Significant |
| HA Vs CI | 417.438 | 49.817 | Significant |

**Table 9.g. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /o: da**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 7019069 | 2 | 3509534.313 | 309.957 | .00 |
| With in group | 509519.4 | 45 | 11322.653 | | |
| **Total** | 7528588 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -936.688 | 37.621 | Significant |
| NH Vs CI | -468.625 | 37.621 | Significant |
| HA Vs CI | 468.063 | 37.621 | Significant |

**Table 9.h. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /oka/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 6987988 | 2 | 3493994.146 | | |
| With in group | 699324.2 | 45 | 15540.538 | 224.831 | .00 |
| **Total** | 7687312 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -933.875 | 44.075 | Significant |
| NH Vs CI | -499.063 | 44.075 | Significant |
| HA Vs CI | 434.813 | 44.075 | Significant |

**Table 9.i. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration /u: ta/**

| **Source of variance** | **Sum of variance** | **df** | **Mean Squares** | **F** | **p** |
|---|---|---|---|---|---|
| Group | 7172800 | 2 | 3586400.146 | 317.059 | .00 |
| With in group | 509015.6 | 45 | 11311.458 | | |
| **Total** | 7681816 | 47 | | | |

**LSD post-hoc paired group analysis**

| **Between the group** | **Difference** | **Standard Error** | **Interpretation** |
|---|---|---|---|
| NH Vs HA | -946.813 | 37.602 | Significant |
| NH Vs CI | -483.875 | 37.602 | Significant |
| HA Vs CI | 462.938 | 37.602 | Significant |

**Table 9.j. One way ANOVA [group (3) x vowel (10)] (n = 16), for word duration for /upa/**

| Source of variance | Sum of variance | df | Mean Squares | F | p |
|---|---|---|---|---|---|
| Group | 7212376 | 2 | 3606187.896 | 408.292 | .00 |
| With in group | 397456.7 | 45 | 8832.371 | | |
| **Total** | 7609832 | 47 | | | |

**LSD post-hoc paired group analysis**

| Between the group | Difference | Standard Error | Interpretation |
|---|---|---|---|
| NH Vs HA | -949.375 | 33.227 | Significant |
| NH Vs CI | -487.938 | 33.227 | Significant |
| HA Vs CI | 461.438 | 33.227 | Significant |

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