LANGUAGE IN INDIA
Strength for Today and Bright Hope for Tomorrow
Volume 13 : 1 January 2013
ISSN 1930-2940

Managing Editor: M. S. Thirumalai, Ph.D.
Editors: B. Mallikarjun, Ph.D.
Sam Mohanlal, Ph.D.
B. A. Sharada, Ph.D.
A. R. Fatihi, Ph.D.
Lakhan Gusain, Ph.D.
Jennifer Marie Bayer, Ph.D.
S. M. Ravichandran, Ph.D.
G. Baskaran, Ph.D.
L. Ramamoorthy, Ph.D.
Assistant Managing Editor: Swarna Thirumalai, M.A.

Acoustic Characteristics of Vowels in Telugu

Krishna. Y., Ph.D.
Associate Professor
Department of Speech & Hearing
Manipal College of Allied Health Sciences
Manipal University, Manipal – 576 104
Karnataka, India
krishna.y@manipal.edu

Acoustic Characteristics of Vowels in Telugu

Thesis Submitted to Manipal University

for the award of the degree of

Doctor of Philosophy

By

Krishna. Y
Associate Professor
Department of Speech and Hearing
MCOAHS, Manipal University
Manipal – 576104
Karnataka, India

2009

Certificate

This is to certify that the thesis entitled **"Acoustic characteristics of vowels in Telugu "** submitted by **Krishna Y.** (**Reg No. 051100002)** for the award of the degree of Doctor of Philosophy, Manipal University is a bonafide work done under my guidance.

Date :

Place :

DR. B. Rajashekhar
Guide
Manipal College of Allied Health Sciences
Manipal University, Manipal – 576104
Karnataka, India

प्रज्ञानं ब्रह्म
Manipal
INSPIRED BY LIFE

Certificate

This is to certify that the thesis entitled **"Acoustic characteristics of vowels in Telugu "** submitted by **Krishna Y.** (**Reg No. 051100002)** for the award of the degree of Doctor of Philosophy, Manipal University is a bonafide work done under Dr. B. Rajashekhar at the Department of Speech and Hearing, Manipal College of Allied Health Sciences, Manipal.

Date :

Place :

____

DR. B. Rajashekhar
DEAN
Manipal College of Allied Health Sciences
Manipal University, Manipal – 576104
Karnataka, India

प्रज्ञानं ब्रह्म
Manipal
INSPIRED BY LIFE

DECLARATION

I hereby declare that this thesis entitled "Acoustic characteristics of vowels in Telugu" is outcome of the original research work undertaken and carried out by me, under the guidance of DR. B. Rajashekhar, Dean, Manipal College of Allied Health Sciences, Manipal University, Manipal. I also declare that the material of this dissertation has not formed in anyway, the basis for the award of any degree or discipline of this country or any other country.

Date :

Place :

Krishna Y.
Associate Professor
Department of Speech and Hearing
MCOAHS, Manipal University
Manipal – 576104
Karnataka, India

Rose is beautiful, by its layers of petals
Rose is colorful, by its layers of petals
Rose is adorable, by its layers of petals

My life, existence, and little contribution to Knowledge Ocean is only
Because of layers of great souls surrounding me
Without their love, support, sacrifice, my existence is meaningless

I dedicate my work to all those great SOULS.

ACKNOWLEDGMENTS

The following thesis, while an individual work, benefited from the insights and direction of several people. This thesis could not have been written without **Dr. Rajashekar. B** who not only served as my guide but also encouraged and challenged me throughout my academic program Many thanks to my guide, who read my numerous revisions and helped make some sense of the confusion.

Next, I wish to thank the complete Thesis Committee at Manipal College of Allied Health Sciences and at Manipal University for accepting and providing insights that guided, challenged my thinking and substantially improve my thesis.

I also wish to thank Dr. Vasantha D, Dr. Savithri S R, Dr. Vidhyanathan, Dr. Santhosh, who have all taught me techniques of analyzing samples and writing. Each one of them helped me in fine tuning my thoughts, draft and critical comments so as to substantiate my findings relevant to the field of communication disorders. Also, they have patiently guided me through the dissertation process, never accepting less than my best efforts. I thank them all.

Special thanks to Mr, Vasu for introducing me to appropriate statistical methods; Dr Srikumaran Nair and his team from department of Statistics, Manipal University, for their valid comments to present my data effectively and accurately.

I wish to thank Mr. Suresh, who has given shape by formatting and adding colors to give acceptable finishing touches for my thesis.

A friend in need is a friend indeed. I have received timely assistance from my friends, Mr. Christopher Sudhakar, for involving in valuable discussions with me when needed, Dr. Shivanda Nayak, Dr. Animesh Burman, and Dr. J F Thomas for support and encouragement.

I wish to thank all my colleagues at the Department of Speech and Hearing, especially Ms. Kanaka G, for reviewing my work and non-academic staff, Manipal College of Allied Health Sciences, for their constant support and concern during this work.

I wish to thank my father-in-law, Mr. Krishnaji Rao Ch and Mr. Sridhar Murthy uncle for helping me in data collection. Also, to all my participants, without whom this work would not have been possible.

Thanks to my parents (Shri. Y Suryanarayana Rao, Smt. Y Ahalyamma), my life partner (Santhi Sheela), daughter (Sushumna), my in-laws (Sri Ch. Krishnaji Rao, Smt Ch. Purna kumari), Sri and Smt. K.S. Prasad uncle and other family members who endured this long process with me, always offering support and love.

Finally I wish to thank all who have helped me directly and indirectly in completing this project in time and contributing a small bit of information to the academic ocean.

TABLE OF CONTENT

LIST OF TABLES

LIST OF TABLES IN APPENDIX

LIST OF FIGURES

LIST OF APPENDIX

1

Introduction

CHAPTER 1

INTRODUCTION

I have not come here to accomplish miracles, but to show, lead the way, help, on the road to a great inner change of our human nature, the outer change in the world is only possible if and when that inner transmutation is effected and extends itself.

– Sri Aurobindo

1.1 Introduction

Speech, a form of verbal communication, is unique to human beings. This unique act of communication has drawn the attention of linguists, psychologists, speech scientists, speech language pathologists, audiologists, neurologists, computer scientists and other professionals involved in human communication in understanding and visualizing the speech. Stetson (1928) said that “speech is movement made audible”. In other words, movement of vocal folds generates audible sound which is further modified by the articulators (tongue, lips) to produce speech. The speech thus produced is a complex acoustic signal, with diverse applications in phonetics, speech synthesis, automatic speech recognition, speaker identification, communication aids, speech pathology, speech perception, machine translation, hearing research, rehabilitation and assessment of communication disorders and many more.

Speech sounds consist of vowels and consonants. Vowels carry maximum energy and play a major role in speech understanding. Consonants carry less energy but have meaningful message in speech communication. “Vowel is a conventional vocal sound in the production of which the speech organs offer little obstruction to the air stream and form a series of resonators above the level of the larynx” (Mosby, 2008). The organs involved in the production of speech sounds develop over the period of life span, and there are structural variations among genders and races, which contribute in producing different vocal quality. Linguistic, syntactic and phonological rules of each language further contribute to the complexity of the speech sound. Ladefogeds' (1975) comments that the vowels of different languages though perceived as same, with subtle acoustic differences between them, have relevance to the study of their acoustic and temporal characteristics in different languages and age groups. Information on acoustic characteristics of speech sounds will further enable understanding their articulatory nature and their perception (Pickett, 1980). Analysis of the acoustic characteristics of speech sounds of Indian languages is needed to understand their production and perception (Savithri, 1989). It will further be useful in perceptual studies, speech processing strategies, diagnosis and rehabilitation of various communication disorders.

1.2 Telugu Language

Telugu belongs to the South Dravidian group of languages (Krishnamurti, 2003) and is the second most widely spoken language in India (Hussain, Durrani & Gul, 2005). Article 343 of Indian constitution recognizes Telugu as one of the 22 official languages in India and it has recently been declared as an official classical language (Wikimedia Foundation, 2008a). Known as the "Roman of the East", it is very easy to learn, speak and write. It is widely spoken not only in the state of Andhra Pradesh* but also in the neighboring states, *viz.,* Karnataka and Tamil Nadu. Since a considerable number of Telugu speaking minorities live in other states of India and other parts of the world *viz*., Maharashtra, Orissa, Madhya Pradesh, West Bengal, United States of America, Australia and Europe, Telugu speaking population as a group is high across the country and the world.

Andhra Pradesh consists of three distinct regions: Coastal region, generally called Andhra, Interior region, known as Rayalaseema and the Telengana region. The three ancient languages, Sanskrit, Persian and Urdu have had their own influence on the language and is reflected in Telugu dialects from different regions of Andhra Pradesh. Telugu has many dialects; however, they are largely grouped into three, *viz.,* Telengana, Coastal Andhra and Rayalaseema (Prahallad & Patel, 2006; Wikimedia Foundation, 2008d). On the basis of vocabulary studies (Krishnamurti, 1998) there are four dialects – Northern (Telengana), Southern (Rayalaseema), Eastern(Coastal), and Central(Andhra). Modern standard Telugu, which is used in the literature and mass media, is based on the

* One of the 28 states of India.

dialect of literate people of the central area. The dialect of the coastal districts is accepted as the standard variety for all written purposes and formal discourses.

Officially, there are eighteen vowels, thirty-six consonants, and three dual symbols in Telugu (Wikimedia Foundation, 2008c). In modern Telugu, two short and long vowels (/æ/, /æ:/) were introduced by Krishnamurthi (1961). According to Nagamma Reddy (1986), ten vowels (long and short: i, e, a, o, u) and seventeen consonants (six plosives: p, b, t, d, k, g; two retroflex stops: t_l, d_l; two affricates: tʃ, dʒ; two fricatives: s, ʃ; two nasals: m and n; one lateral: l; and two semi-vowels: /w/ and /y/) can be said to represent the common core of Telugu language.

1.3 Vowel Characteristics

The acoustic theory of speech production proposed and expounded by Fant (1960) views speech as the product of source and filter or transmission function. Vowels are produced by voiced excitation of the open vocal tract. During the production of a vowel, the vocal tract normally maintains a relatively stable shape and offers minimal obstruction to the airflow. The energy thus produced can be radiated through the mouth or nasal cavity without audible friction or stoppage. In other words, during the vowel production, the tongue and articulators are so positioned as to create a uniform cross-sectional area along the length of vocal tract. As the vocal tract changes in length for various vowel positions, the resonance frequencies change in odd-quarter wavelength formula (Kent & Read, 1995). Hence, longer vocal tract has lower resonance frequencies and smaller vocal tract, higher resonance frequencies, respectively.

Vowels are classified based on the tongue height, position of the tongue, lip position, soft palate position, phonemic length, articulators' tension and pitch. They are generally classified as high, mid, low based on the relative height of the tongue; front, central, back based on the relative position of the constriction of the tongue in the oral cavity; spread, rounded, unrounded based on the relative position of the lips; nasal and oral based on the position of the soft palate; short and long based on the phonemic length of the vowel; lax and tense based on the tenseness of the articulator; and high, mid, low based on the relative pitch of the vowel.

Acoustically, vowels are characterized by changing formant pattern, formant bandwidth, duration, amplitude and fundamental frequency. Among these, it is believed that formant pattern, duration and fundamental frequency play a major role in vowel perception (Pickett, 1980). In Indian languages, vowels are modified for quantity, quality and other distinctive features. In certain Indian languages, the phonological contrast between the pairs of vowels has distinguishing features in quality and quantity or both (Nagamma Reddy, 1998).

1.4 Speech Analysis

Earlier acoustic analyses used non-digital or analog methods while currently, with the technological advances, computers are being used widely. In 1920s, 1940s and 1950s, Oscillograph and Spectrograph were commonly used respectively to analyze the speech signal. With the introduction of Digital Signal Processing (DSP) in 1970s, there has been a marked improvement in techniques of speech analysis. Various techniques, such as Waveform analysis, Fast Fourier Transform (FFT)/Linear Predictive Coding (LPC), Pitch extraction, Digital Spectrogram, Cepstrum etc., are being used to analyze the speech signals.

Acoustic analysis of speech helps in early identification (Bosma, Truby & Lind, 1965) differential diagnosis of various communication disorders (Hoasjoe, Martin, Doyle & Wong, 1992; Premalatha, Shenoy & Anantha, 2007; Tomik, Krupinski, Glodzik-Sobanska, Bala-Slodowska, Wszolek, Kusiak et.al., 1999; Rosen, Kent, Delaney & Duffy, 2006); laryngeal diseases (Murry & Doherty, 1980), understanding phonological process and vowel space in hearing impaired (Duggirala, 1995, 2005), assessing progress in the rehabilitation process and to improve naturalness and intelligibility of artificial speech (Nagamma Reddy, 1998).

Acoustic characteristics of vowels are generally studied based on their Fundamental Frequency, Formant Frequencies, Vowel Duration and Intensity. Acoustic studies illuminate the subtle differences in the production problems experienced not only by the hearing impaired but also in normal individuals and different languages (Edward & Valter, 2006 & 2007; Duggirala, 1995; Ladefoged, 1975).

1.5 Acoustic (Temporal and Spectral) Characteristics

1.5.1 Vowel Duration

Vowel duration may not enable identification of any individual vowel, but does help the listener to distinguish spectrally similar vowels or place vowels in large categories (Kent & Read, 1995). Klatt (1976) based on his experiments reported that, factors such as tense-lax feature of the vowel, vowel height, syllable stress, speaking rate, voicing of a preceding or following consonant, place of articulation of a preceding or following consonant and various syntactic or semantic factors influence the vowel duration.

Nagamma Reddy (1986) reported that, the ratio of short and long vowel duration in word-initial to word-medial vowels of Telugu is more than 1:2. In a single case study, on the duration of vowels in Telugu in different consonant environments, Girija & Sridevi (1995) reported that the duration of a long vowel is approximately twice the duration of a short vowel and the ratio between the short and long vowels is 1:2.1. The longest among short vowels is /o/ and the shortest is /u/ and the longest among long vowels is /a:/ and the shortest is /e:/. These studies do not reflect the vowel duration in different age groups, gender variations and dialectal variations.

1.5.2 Vowel Fundamental Frequency

Vowels are produced by the sustained phonation and variation in the oral cavity. The fundamental frequency (F0) depends upon the tension on the vocal folds, effective mass of the vocal folds, and the sub-glottal pressure. The effective mass of the vocal folds is progressively larger from children to women to adult males, which in turn affects the fundamental frequency (Pickett, 1996). The fundamental frequency varies not only with reference to the gender but also varies for different vowels (Kent & Read, 1995). It also varies based on the linguistic stress, speaker's emotion and intonation. Based on the height of the vowel, it has been reported that high vowels have higher fundamental frequency than the lower vowels (Lehiste & Peterson, 1961; Peterson & Barney, 1952).

The most significant factor influencing F0, as reported, is the tongue height (O'Shaughnessy, 1976; Thorsen, 1976; Pierrehumbert, 1980). Studies have revealed that with the tongue position being high in the oral cavity, the tendency is to have higher fundamental frequency than for the low vowels. Venkatesh (1995) reported that females have one octave higher F0 than males and that the F0 was significantly different across the vowels in Kannada, another Dravidian language. He also reported that F0 increases as the tongue height increases. As reported in the literature for English and Kannada for understanding the variations of F0 across the age group, height of the vowel and dialectal variations do not exist in Telugu.

1.5.3 Vowel Formants

The formants also referred to as the natural frequency of the vocal tract depend on the shape and size of the tract during the production of vowels (Fant, 1960; Fry, 1979). During the production of vowels in our vocal tract, there are infinite number of formants, but for practical purposes, only the lowest three to four formants are of interest and are extensively studied. Each formant is labeled as F1, F2, F3, F4… and are described by two characteristics. They are the center frequency, also known as the formant frequency and the bandwidth (the breadth of energy in the frequency domain). The formant frequencies of a vowel relate to the observable features of the articulatory activity used in the generation of the vowel.

In general, low vowels have a high F1 frequency and high vowels, a low F1 frequency. Back vowels have a low F2 and typically a small F2-F1 difference, whereas front vowels have a relatively higher F2 frequency and a large F2-F1 difference. General rule of thumb is that F1 varies mostly with tongue height and F2 varies mostly with tongue advancement, with exceptions however (Kent & Read, 1995).

In Telugu, all vowels, except /o/, can occur in all the three positions of a meaningful word (Initial, Medial and Final). It has been reported that F3 is considerably higher in long vowel series than in short vowel series. F1 is slightly higher for short vowels (except for /a/) than for long vowels. F2 is also higher for front long vowels than for corresponding short vowels (Nagamma Reddy, 1986). Other studies (Kostić, Mitter & Krishnamurti, 1977; Girija & Sridevi, 1995; Prabhavathi Devi, 1990) concerning Telugu do not reflect formant frequencies observed across different age groups, genders and dialectal variations.

1.5.4 Vowel Formant Bandwidth

During vowel production, each formant has a bandwidth. The bandwidth is a measure of the frequency band of a sound, especially resonance. It is noted that greater the damping of the sound, greater the bandwidth of the sound. During vowel production, each formant has a bandwidth. Usually, bandwidth is calculated based on “half-power point” or width of the formant at 3 dB below the peak. Experiments have shown that changes in the bandwidth of formants have very little effect on vowel perception. It is also reported that formant bandwidth increases with formant number. Higher formants have larger bandwidths as compared to the lower formants (Kent & Read, 1995). No studies on bandwidth in Telugu across the age groups, gender and dialectal variations have been reported in the literature.

1.6 Role of acoustic characteristics of vowels in human communication and the need for the study

Literature survey reveals that, vowels are the significant components of human speech. They carry a lot of energy and have their own unique features. Some of the features are fundamental frequency, formant frequencies, vowel duration, and formant bandwidth (Nagamma Reddy, 1998; Pickett, 1980). They play a stellar role in human communication and synthetic speech and are also influenced by developmental, linguistic, cultural, social and emotional factors (Kent & Read, 1995; Klatt, 1976; Ladefoged, 1975; Nagamma Reddy, 1998; Prahallad & Patel, 2006; Savithri, 1989; Sreenivasa Rao & Yegnanarayana, 2004). These features are also reported to play a major role in assessment, differential diagnosis and rehabilitation of communication disorders (Duggirala, 1983-1984, 1995, 2005; Edward & Valter, 2006, 2007; Hoasjoe, Martin, Doyle & Wong, 1992; Premalatha, Shenoy & Anantha, 2007). Analysis of speech sounds is increasingly used in recent years to assess the anatomical and neuro-muscular maturation of speech mechanism (Duggirala, 1983-1984). With the help of iso-vowel lines, graphic comparisons of formant frequencies of disordered speech with normal subjects can be done (Kent, 1976) to assist in understanding the human production and perception in normal, adverse listening conditions and when used with different assistive listening devices.

Most of the studies on acoustic analysis of Telugu vowels in the literature (Kostić, Mitter & Krishnamurti, 1977; Nagamma Reddy, 1998, 1999; Prabhavathi Devi, 1990; Girija & Sridevi, 1995; Sreenivasa Rao, Suryakanth, Gangashetty, & Yegnanarayana, 2001) have been done only on adults or children, in limited consonant contexts, in limited sample size, selected from one region/dialect, with no comment on gender variations. However, these factors (age, dialectal variations, and consonant context) play significant role on the acoustic characteristic of vowels. With recent advances in the rehabilitation of communication disorders, knowledge on acoustic characteristics of speech sounds in each age group, language, dialects, and gender will assist the clinician in assessing, diagnosing and rehabilitating communication impaired individuals. The paucity of comprehensive data on the acoustic characteristics of vowels in Telugu across different age group on the most essential features (vowel duration, formant frequencies, and bandwidth), has prompted the current study.

1.7 Aim of the study

1. To investigate the temporal and spectral characteristics of vowels in Telugu language.

1.8 Objectives of the study

a) To analyze differences in the temporal and spectral characteristics of vowels in Telugu across age groups (Group I (children): 6 to 9 years; Group II (adolescent): 13 to 15 years; Group III (adult): 20 to 30 years)

b) To analyze the temporal and spectral differences between males and females.

c) To analyze the temporal and spectral differences in the vowels produced by speakers belonging to different regions in Andhra Pradesh.

d) To survey the temporal and spectral differences in the production of vowels occurring in different consonant contexts.

e) To delineate the clinical research implications of the data within the field of communication disorders.

2

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

2.1 Introduction

"For mankind, speech with a capital S is especially meaningful and committing, more than the content communicated. The outcry of the newborn and the sound of the bells are fraught with mystery more than the baby's woeful face or the venerable tower."

- Goodman (1911 - 1972)

Communication is not only the essence of being human, but also a vital property of life. Speech sounds produced by our ancestors over 100,000 years ago differ in their production, quality and also complexity of the language. Whitehead (1861), a British mathematician, rightly said "*Speech is human nature itself, with none of the artificiality of written language*".

Communication is the process of generation, transmission, or reception of messages to oneself or another, usually via a mutually understood set of signs. Human speech communication consists of various speech sounds, which are coded. To understand speech communication, one needs to have knowledge of the speech code. The speech code differs based on linguistic rules of the language and organs involved in speech production. Normal sensory abilities are the pre requisites of the normal development of communication. Adequate vision is necessary for the development of writing, reading and non vocal communication and adequate hearing is necessary for the development of speech communication.

Speech involves producing sounds from the larynx. Human language requires both anatomical apparatus (larynx, articulatory system) and neurological changes in brain. Anthropologists and linguists believe that, modern human language developed around 50,000 years. Some scholars believe that the L – shaped tract in human skull was seen in hominid bipedalism around 3.5 million years ago. The shape of the tract and the larynx lower in the neck are necessary prerequisites for many of the sounds humans make, particularly vowels. Other researchers' view considers the lowering of the larynx as irrelevant to the development of speech (Wikimedia Foundation, 2008b).

Mastery of the speech sounds, especially vowels occurs during the first six months of life (Irwin, 1943). Vowels play an important role in human speech communication right from birth. In any language, the purpose of vowels in relation to the human speech are, to help in determining the syllable/syllabification, transmit maximum acoustic energy during the production, emphasize the meaningfulness of a sentence by preceding the content words, play important role in determining the intelligibility of speech, act as link between consonants, enable speaker normalization and play an important role in supra segmental features of speech (Vorperian & Kent, 2007).

2.2 Speech

Speech sounds consist of vowels and consonants. Both meaningful and non-meaningful speech consists of vowel sounds of varying duration. Vowels carry maximum energy in speech communication and play a major role in speech understanding. Consonants carry less energy but meaningful message in speech communication. The production of human speech is well explained by the source-filter theory, initially proposed by Johannes Müeller in the 19th century and later by Fant (1960), which formed the basis for the current interpretations of speech analysis. It describes speech production as a two stage process involving the generation of a sound source, with its own spectral shape and spectral fine structure, which is then shaped or filtered by the resonant properties of the vocal tract. Glottal sound sources can be periodic (voiced), aperiodic (whisper and /h/) or mixed (eg., breathy voice). Periodic and aperiodic sources can be generated simultaneously to produce typical speech sounds such as voiced fricatives. In voiced speech, the fundamental frequency (perceived as vocal pitch) is a characteristic of the glottal source acoustics whilst features such as vowel formants are characteristics of the vocal tract filter (resonances). A voiced glottal source has its own spectrum which includes spectral fine structure (harmonics and some noise) and a characteristic spectral slope (sloping downwards at approximately -12dB/octave). The spectral characteristics of each sound thus differ based on the vocal tract filter. The source filter theory and speech organs are diagrammatically represented in Figure 2.1.

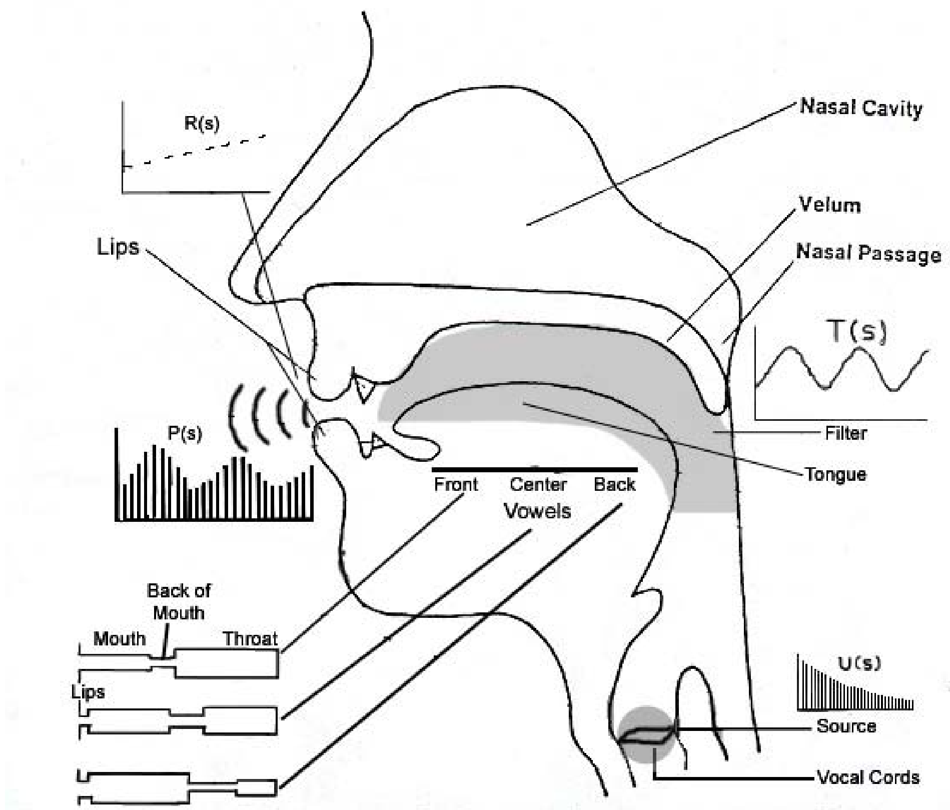


Figure 2.1: Articulatory structures involved in source - filter theory.

2.2.1 *Anatomy and Physiology*

In humans, the air in the lungs is pressed upon by the muscles of thorax and abdomen, resulting in its flow to the larynx. Larynx consists of vocal folds, which generate voice. This voice is modulated by the articulators in the vocal tract to produce various voiced speech sounds. The air stream from the lungs passes through a narrow constriction to produce turbulent sound or suddenly releases from a constriction in the vocal tract to generate turbulent speech sounds (fricatives) or transient speech sounds (stops). For the production of consonants, articulators constrict more than the vowels. Thus, the open state of articulators produces vowels, while their closed state produces consonants (Pickett, 1996).

"Vowel is a conventional vocal sound in the production of which the speech organs offer little obstruction to the air stream and form a series of resonators above the level of the larynx" (Mosby, 2008). During the vowel production, the vocal tract normally maintains a relatively stable shape and offers minimal obstruction to the airflow with voiced excitation. The energy produced radiates through the mouth or nasal cavity without audible friction or stoppage. In other words, during the vowel production, the tongue and articulators are so positioned to create a uniform cross-sectional area along the length of the vocal tract.

Scripture (1935) in his study of observing the sound production of English vowels, commented that, a vowel stretch is composed of contiguous vibratory bits. Each vibratory bit consists of vibratory movements that start strong and fade rapidly. A vibration of this kind is termed as free vibration whose amplitude depends on the force that starts it, its period and its decrement and on the factors of the vibratory system itself. A vowel bit is produced by a momentary impulse and vibratory system. The impulse is the puff of air from the glottis and the vibratory system is in the air of the vocal cavity. By changing the shape, size and openings of the vocal cavity, various forms of vowel bits are produced. The walls of the vocal cavity play a role in decrement of the vibrations. Vowel production is well explained with the source filter theory (Fant, 1960), according to which, vowels are the resultant of a filtering action of the pharyngeal-oral tract on the sound source produced by the glottis.

The vowels thus produced are complex acoustic signals with amplitude and frequency information. The graphical representation of sound (in this case, vowel) and its components can be done by Spectrum. Thus, vowels can be represented by amplitude-frequency spectrum or frequency spectrum or simply, spectrum. If the sound wave consists of a fundamental frequency and its multiples (known as harmonics), then, each harmonic is represented by a line. Sound waves produced by the vocal tract to produce speech sounds in any language, can be analyzed by spectral analysis using the sound spectrograph, an instrument used for analyzing the spectrum of complex speech sounds (Pickett, 1996).

Speech sounds are produced with various pulsing rates of the vocal cords in the glottis. Each pulse causes damped oscillations of the vocal tract air column. The number of glottal pulses per second determines the fundamental frequency of the sound, and the resonances in the vocal tract are known as formants. The typical vibratory rate of glottal pulse of an adult female speaker is about 200 per second while it is 125 per second for an adult male speaker. The simple integer multiples of the fundamental frequency are known as harmonics. The amplitude of the spectrum components are determined by the resonant frequency of the damped oscillation and by the amount of damping (Pickett, 1996).

2.2.2 Developmental changes

Human vocal tract develops from the time of birth to adulthood. Infant vocal tract is not simply the miniature of an adult vocal tract but also resembles that of lower primates. Infant vocal tract has an appreciably shorter vocal tract, shorter pharyngeal cavity, anterior tongue mass, a gradual bend of the oropharyngeal channel, high larynx and approximation of velopharynx and epiglottis (Kent & Ann, 1982). The anatomical development of speech organs develops most rapidly between 3 to 5 years of age and then, the development of larynx is gradual until puberty (Eguchi & Hirish, 1969). The human vocal tract differs in growth trend of segments and between genders with male laryngeal structures larger than that of female (Kahane, 1978 & Vorperian et al., 2009). In humans, from the onset of babbling until adulthood, speech production system undergoes substantial modifications. Anatomical changes, and motor control refinement, yield various acoustic patterns. The formant frequencies in children differed due to sexual differences in pharynx size, jaw opening and larynx position. Gross indices of body size resulting in larger vocal tract also contributed for the formant frequency changes in children (Bennett, 1980).

Anatomical changes and motor control refinement in children have shown to produce less intelligible speech than adults. The overall vocal tract length (from the larynx to the lips) is about 8 cm at birth and 17 cm in adult males (Goldstein, 1980). Hirano, Kurita & Nakashima (1981) have reported that, vocal fold length increases from 4 mm in the newborn to about 18 mm and 12 mm for an average man and woman respectively.

The quality of vowel depends on the shape of the cavities of the pharynx, mouth, nose and positioning of soft palate, tongue and lips. For various vowel positions, the vocal tract length varies and offer variations in the resonance frequencies. Longer vocal tract has lower resonance frequencies and smaller vocal tract, higher resonance frequencies.

Literature is replete with studies on the developmental changes occurring in human vocalization from birth to old age. From birth till one year of age, infant vocalization is dominated by vowel production. Early stages of speech development are classified as phonation stage (birth to 1 month), cooing stage (2 to 3 months) and expansion stage (4 to 6 months) (Oller, 1980). Vowels are the first sounds to be mastered by the infants, who acquire most of the vowels and half of the consonants in the second quarter of the first year. In a pilot study on English speaking American population to understand the changes in vocal tract due to aging and its acoustic correlates, the oral cavity length and volume of elderly speakers have been reported to be significantly increased as compared to their young cohorts (Xue & Hao, 2003).

From literature, it may be concluded that vowel development is expressed as establishment of a language-appropriate acoustic representation; F1-F3 more sensitive to changes due to age and possibly gender; gradual reduction in formant frequencies and F1-F2 area; reduction in formant frequency variability; emergence of differences in formant frequencies between genders by 4 years of age, becoming more apparent by 8 years and discrete by 16 years; decline in fundamental frequency after 1st year of life, with more rapid decline during early childhood (birth to 3 years) and adolescence; distinct F0 differentiation between genders is after the age of 12 years; F0 relatively stable between 3 to 12 years; maturation of velopharyngeal function by about 1 year of age (Vorperian & Kent, 2007).

2.2.3 Acoustic Characteristics of Speech

Acoustically, vowels are characterized by formant pattern, spectrum, duration, bandwidth, amplitude and fundamental frequency. Among these, it is believed that, formant pattern, duration and fundamental frequency play a major role in the vowel perception (Pickett, 1980).

Vowels are generally described as:

- Front, Central, Back – based on the relative position of the constriction of the tongue in the oral cavity
- High, Mid, Low – based on the relative height of the tongue

- Spread, Rounded, Unrounded – based on the relative position of the lips
- Oral and Nasal - based on the position of the soft palate
- Short and Long – based on the phonemic length of the vowel
- Lax and Tense – based on the tenseness of the articulator, and
- High, Mid, Low – based on the relative pitch of the vowel.

Vowels are also classified based on their fundamental frequency and formant frequencies. Many models have been proposed using different combinations of fundamental frequency and formant frequencies. Miller (1989) and his colleagues classified vowels based on perceptual "target zones" in three dimensional space, Syrdal & Gopal (1986) based on normalization scheme and linear discriminant analysis technique and Hillenbrand & Gayvert (1993) based on quadratic discriminant classification technique.

Hasegawa-Johnson, Pizza, Alwan, Cha & Hake (2003) finding relationship between palate height, tongue height, and oral area in categorizing vowels, have concluded that, the palate height, tongue height and oral area are dependent on vowel place of articulation. A small oral area variance is characterized by smaller inter-talker area variance. In the production of pharyngeal vowels (/a/, /æ/), tongue is low in the oral cavity; however, it is higher for palatal vowels (/i/, /e/). Tongue height is not correlated with the palate height during the production of velar, uvular and pharyngeal vowels.

Among the acoustic characteristics of vowels, Fundamental Frequency, Formant Frequencies, Vowel Duration and Intensity are generally studied for the purpose of normative data and differentiation between the vowels. The vowels of different languages are perceived as same, but there are subtle differences between them (Ladefoged, 1975). With the presence of such subtle differences, it would be worthwhile to study the acoustic characteristics of vowels in each language so as to understand the differences that exist between them. Further, analysis of acoustic characteristics of speech sounds of Indian languages is the present need to understand the production and perception of the speech sound in their culture (Savithri, 1989). This will be useful, in perceptual studies, speech processing strategies and diagnosis and rehabilitation of various speech and language disorders. The phonetic and phonemic variations seen in Indian languages and the need for studying the quantitative and qualitative data in distinguishing vowels among the languages have been emphasized (Nagamma Reddy, 1998).

The effect of dialects in a language on the vowels and vowel space are not clear and it's assumed that, the perception of sound depends upon the production. Hence, it would be useful to measure the vowel spaces and their perceptual values from different dialects. (Whalen, Magen, Pouplier, Min Kang & Iskarous, 2004).The dialect has been reported to affect production more than perception.

2.3 Speech Analysis

Earlier acoustic analysis used non-digital or analog methods while currently, with the technological advancements in electronics, computers are being used widely in the analysis of speech. In 1920s, 1940s and 1950s, Oscillograph, Fourier analysis and Spectrographs were used respectively to analyze the speech signal. With the introduction of Digital Signal Processing in 1970s, there has been a marked improvement in techniques of speech analysis. Various techniques, such as Waveform analysis, Fast Fourier Transform (FFT)/Linear Predictive Coding (LPC), Pitch extraction, Digital Spectrogram, Cepstrum etc., are being used to analyze the speech signals currently.

Analysis of speech has drawn the interest of the researchers even earlier to 20th century. However, modern history of acoustic analysis of speech began with oscillograms during 1930s and 1940s. Generally, vowels were analyzed using this method. The sounds were represented as pressure variations over time. Since they were not represented against frequency, the distinction between the speech sounds was difficult using this technique (Kent & Read, 1995).

Further advancements in the acoustic analysis have helped in developing better methods. The Henrici Analyzer is one such method that has given a better insight and further increase in the understanding of speech acoustics. Another method which provided frequency information is Filter bank analysis, which depends upon the number of filters used and their bandwidths (Kent & Read, 1995).

The limitations of earlier techniques were overcome by using variable band pass filter in the Sound Spectrograph. The first method of the sound spectrograph was proposed by Potter (1946). Koenig, Dunn & Lacy (1946) reported that, filter widths of about 200 cycles would be adequate to smooth the resonance bands for an adult male voice while 300 cycles was adopted as a compromise and adequate for most voices. They also commented that, the time and frequency dimensions of spectrograms were originally chosen so as to give adequate resolution.

The spectrogram is a three dimensional graph of time, frequency, and amplitude. Frequency is represented on the vertical axis, time in the horizontal axis and the amplitude by the degree of darkening of the frequency regions respectively. The dark horizontally running bands are known as formants. The spectrogram displays dynamic properties of the articulators during speech, unlike writing. The fundamental frequency is the lowest band represented in the spectrogram. A lower F0 results in closely packed harmonics, which means that the formants are better defined. Different styles of spectrograms are available and modern spectrographic analysis software allows fine adjustments to the various settings in order to get better resolution and better reading of parameters (Hewlett, Beck & Beck, 2006).

Spectral analysis of the speech signal has been further refined and made easier with the advent of computers and digital signal processing methods. The spectra can be computed using various methods such as the FFT, Cepstrum, LPC and filtering. Filtering, sampling and quantization are the basic operations in digitizing the speech signal. Speech analysis is faster and accurate, in addition to what earlier spectrographs did.

A speech signal, which is analog, needs to be converted to digital signal so as to be processed by the computer. This process of converting analog signal to digital signal is known as analog to digital conversion and is done by an analog to digital converter. During this stage, sampling and quantization of the analog signal are done simultaneously. Sampling is the process in which the analog signal is converted into a series of samples; the rate at which it is done is known as the sampling rate. According to Nyquist's sampling theorem (Nyquist, 1928), if a good sampling rate is chosen, there will not be any loss of information. A sampling rate of at least twice the highest frequency of interest is recommended. Assigning discrete values/increments to a continuous varying analog signal is quantization. Higher the quantization levels, the more accurately the analog signal gets digitized (Kent & Read, 1995). Kent & Read (1995) recommended determining the highest frequency of the signal, filtering the energy above the highest frequency, sampling the signal at a rate of at least twice the highest frequency and quantizing the speech signal at minimum 12 bit (4,096 quantization levels) as necessary steps in speech signal processing.

2.4 Telugu Language and its vowel system

Telugu, one the four major Dravidian languages (the others being Kannada, Tamil and Malayalam), is the second most widely spoken language in India. (Duggirala, 2005). It is one of the 22 official languages of India, since 1966 (Wikimedia Foundation, 2008a) and is the official language of Andhra Pradesh, a state in India, formed in 1956. It is also known as the **"Roman of the East"** and is very easy to learn to speak and write.

Though some collections were found during the first century, it was only from the 7th century that clear Telugu literature emanated with the writing of Nannaya on Telugu Mahabharata in the 11th century being considered the hallmark. There has been prolific literature ever since, but the golden age is considered by many to be the 16th century, under the patronage of the "Vijayanagar" Emperor, Krishna Deva Raya (Kostić, Mitter & Krishnamurti, 1977).

The modern day writing scripts in Kannada# and Telugu originated from Kadamba*. This writing system is known as syllabic alphabets in which, each syllable is represented as a main unit. Syllabic alphabets consist of two kinds of graphemes: vowels and consonants. In syllabic alphabet systems, a written symbol denoting speech syllable is called as graphic syllable or a syllabogram. The speech syllable and graphic syllable differ in few languages. According to Coulmas (1999), the unit of speech syllable and the unit of written representation i.e., graphic syllable differ from one another (Duggirala, 2005).

Another Dravidian language
* Kadamba is an ancient royal dynasty that ruled parts of Karnataka (present day Uttara Kannada) during 345 – 525 CE.

Andhra Pradesh consists of three distinct regions *viz.,* coastal region, generally called Andhra, the interior region, known as Rayalaseema and Telengana region. The three ancient languages, Sanskrit, Persian and Urdu have had their own influence on the language which is reflected in Telugu dialects from different regions of the state. Telugu has many dialects; however, they are largely grouped into three dialects, *viz.,* Telengana, Coastal Andhra and Rayalaseema (Prahallad & Patel, 2006; Udaya Shankar, 1987; Venkateswara Sastry, 1990-1991; Wikimedia Foundation, 2008d). On the basis of vocabulary studies done, it has been reported that there are four dialects – Northern (Telengana), Southern (Rayalaseema), Eastern (Coastal), and Central (Andhra) (Krishnamurti, 1998). Modern standard Telugu, which is used in literature and mass media, is based on the dialect of literate people of the central area. The language of the coastal district is accepted as the standard variety for all written purposes and formal discourses.

Telugu has ten basic vowels, among which, five are short and five long (Prabhavathi Devi, 1990; Duggirala, 2005). In modern Telugu, two short and long vowels (/æ/, /æ:/) have been introduced (Krishnamurti, 1961).

The vowel /æ/, described as low front vowel, is acquiring phonemic status in the Rayalaseema dialect due to the influence of Coastal speakers. This vowel is not present in Telengana dialect. The absence of /æ/ is identified by other vowel, and also, there is no grapheme for this vowel in the syllabary (Venkateswara Sastry, 1990-1991).

Stress pattern in Telugu is peculiar in nature. The second syllable, which is generally a vowel, in a trisyllabic and polysyllabic word, is unstressed. In Coastal and Rayalaseema dialects, this unstressed vowel is retained in the form of /ə/, but not in Telengana dialect. Most of the Telugu dialects have syllable-timed rhythm, but Telengana dialect differs and appears to have stress-timed rhythm (Venkateswara Sastry, 1990-1991).

It has been reported that, in Telugu, tongue hump position in the front vowel is somewhat further forward for long vowels than for short ones and for the back vowels, it is more retracted for long vowels than for short vowels. Further, no difference between low and front mid vowels except for quantity has been reported (Nagamma Reddy, 1998). It has also been reported that, the high and mid back vowels are rounded and others are unrounded. Open vowels had longer duration than corresponding close vowels and diphthongs about the same duration as that of long vowels. Vowel duration in Telugu is subject to a number of contextual effects (Duggirala, 2005). Normal children whose native language is Telugu are reported to acquire all the major vowel phonemes except /æ/ by 1 year 6 months (Duggirala, 2005; Nirmala, 1981). The description, frequency of occurrence, the phonetic context they appear and the formant frequencies as reported in the literature are given in Appendix I.

2.5 Vowel Duration

2.5.1 Introduction

Vowel Duration is defined as the time duration between the initial regular vibration (the appearance of the first clearly visible negative peak) to the final regular vibration (last clearly visible negative peak) associated with the vowel. Figure 2.2 depicts the vowel duration of vowel /a:/ in the word /kaaki/ in Telugu (meaning Crow).

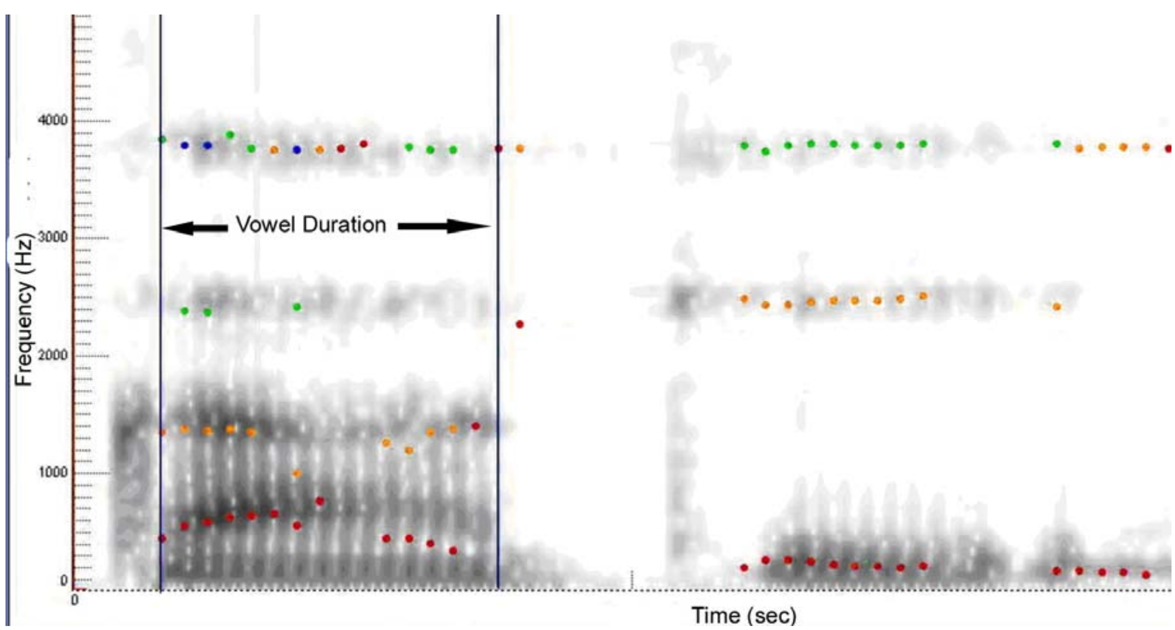


Figure 2.2: Vowel Duration of vowel /a:/

Vowel duration may be taken as the difference in time between the onset of the first identifiable period and the offset of the last identifiable period in the vocalic segment which can be better identified by wideband spectrograms using a resolving filter of 293 Hz bandwidth (Manwal, Gilbert & Lerman, 2001).

Gopal (1987) defines vowel duration as the duration from the onset of the vowel to the offset of the vowel. The onset and the offset of a vowel are determined by the presence and absence of clearly visible first two formants on the spectrogram respectively. He also commented that describing and quantifying the effects of various factors of vowel duration leads to predictive rules that could be effectively used in speech recognition and in speech synthesis.

Krause (1982) defines vowel duration as the difference between the vowel onset and vowel offset, where vowel onset is defined by the initiation of formant structure coincident with periodic energy and vowel offset defined by the end of second formant energy.

The vowel duration is an important parameter which provides information on the prosodic as well as linguistic aspects of speech. Vowel duration can be used to signal the stressed syllable (Fry, 1955), mark the word boundaries (Lehiste, 1959), identify the syntactic units (Gaitenby, 1965), to distinguish between similar phonetic segments (Denes, 1955; Lisker & Abramson, 1964) and determine phonetic quality (Lehiste, 1970).

Vowel duration and intonation play an important prosodic feature in the quality of synthesized speech (Sreenivasa Rao & Yegnanarayana, 2004). The vowel is considered as a nucleus of a syllable, and consonants may present on either side of it. The duration of the vowel is influenced by the position, phonological and contextual factors. Other factors such as gender, psychological state, age, relative novelty in the words affect its duration.

In American English, vowel duration is a major acoustic cue in the perception of voicing contrast in post vocalic consonants, and also differentiates voiced and voiceless obstruents in adults. Not only adults but children as young as 2 years also displayed the use of vowel duration to differentiate final consonant voicing (Krause, 1982).

Vowel duration has been used as an index of deterioration of vowel precision in various adult speakers and has been reported to be reduced during normal aging (Strom, Thomson, Boutsen & Pentz, 2005).

2.5.2 Studies on Vowel Duration

Among the earlier studies in English language, Black (1949) observed that vowel duration varied between connected speech and words. He concluded that vowel duration in /hvd/ syllables are two-thirds longer than those measured in connected speech. House (1961), studied the vowel duration in American English. He used 12 American English vowels in bisyllabic nonsense utterances in 14 symmetrical consonantal contexts produced by three male speakers. The consonant environment consisted of voiced and voiceless versions of three stops, one affricate, and three fricative consonant articulations. Vowel duration was found to be more in tense vowels, vowels before voiced consonants and also in open vowels and in vowels before fricative consonant.

Research studies have shown that consonant environment influences vowel duration in English and is an important temporal constraint (House, 1961; House & Fairbanks, 1953; Peterson & Lehiste, 1960). Smith (1978) noted that although vowel durations do vary according to the consonant environment, it is the final consonant that affects vowel durational characteristics i.e., vowels preceding a voiced consonant are longer in duration than those preceding voiceless consonant. Further, vowels are longer in duration when occurring before a fricative consonant than before a plosive consonant. There also appears to be a slight place of articulation effect, in that vowels within a labial stop environment are shorter than vowels in dental, alveolar or velar stop context (House & Fairbanks, 1953).

It is recognized that the temporal characteristics of vowels are important in providing cues to the perception of neighboring consonants (Raphael, 1972). In American

English vowels, significantly shorter vowel duration was noted for men when compared to either women or children (Hillenbrand, Getty, Clark & Wheeler, 1995).

Dialectal or regional variations have an effect on acoustic characteristics of vowels. Study of acoustic measures (duration, first and second formant frequencies) from six regional varieties of American English, revealed a consistent variation due to region of origin, particularly with respect to the production of low vowels and high back vowels. Vowel system of American English is better characterized by the region of origin than in terms of single set (Clopper, Pisoni, & de Jong, 2005).

The actual duration of any particular vowel will depend on its height, its tonal or accentual properties, its position in the word, the nature of the adjoining segments, word length, grammatical complexity, speaking rate and the psychological and physical state of the individual (Maddieson, 1993). The approximate configuration for tense vowels is said to require a longer period than that for lax vowels, which results in relatively longer vowel duration for tense vowels as compared to lax vowels (Mitleb, 1984).

In English language, lax/short vowels have much shorter vowel duration than long/tense vowels. It is also reported that, the discrepancy between the longest of the short vowel (/ɛ/, 185 ms) and the shortest of the long vowel (/u:/, 225 ms) is 40 ms (Hongyan, 2007).

Research on the influence of place of articulation on duration has established that, vowel duration is dependent on the extent of the following consonant (Fischer-Jorgensen, 1964). The greater the extent of the movement to produce the following consonant, the longer the vowel duration. For example, vowels are shorter before /b/ than before /d/ and /g/, as there is no time delay in moving the articulator (i.e. the tongue) from vowel target to consonant (Vowel + bilabial). It's also reported that back of the tongue is not as mobile as the tip of the tongue which further results in durational variations.

In English, vowels preceding voiceless consonants are shorter in duration than those before voiced. Vowel duration before stops and fricatives could be due to some inherent articulatory influences (House, 1961). It's hypothesized that articulation of stop consonants might represent less muscular adjustment from a physiological rest position of the vocal tract and might consequently require relatively less muscular effort than the production of sounds requiring more deviation from the rest position.

Halle & Stevens (1967) in their study on English symmetrical CVC syllables reported that vowels before nasals had the shortest duration. Vowels before voiced consonants had greater duration than before voiceless ones. They attributed the differences to the vocal fold movement. According to them, during voiceless consonants, there is a wide separation of the vocal folds and can be achieved rapidly, than finely adjusted smaller separation for a voiced consonant.

The influence of the manner of articulation of a consonant upon the duration of a preceding vowel seems to be largely dependent on the language of the speakers. In English, vowels are shortest before voiceless stops, and their duration increases as they are preceded by voiceless fricatives, nasals, voiced stops and voiced fricatives (House & Fairbanks, 1953).

Peterson & Lehiste (1960) reported that in some languages, the duration of a sound may be determined by the linguistic environment and may be associated with preceding or following segmental sounds, initial or final positions in an utterance, or type and degree of stress. Such durational changes in turn may become cues for the identification of the associated phonemes.

Lisker (1974), in his experiment reported that, there was a tendency for duration to increase with increase in first formant frequency. i.e., /i/ and /u/ have shorter duration than /a/. He also supported two well accepted assumptions (1) vowel duration varies directly with degree of opening and (2) vowel duration depends on the following consonant, especially on its voicing status. He provided the following explanations for the variations in vowel duration in different following consonants.

1. According to the rule of constant energy expenditure for the syllable, vowels are longer before voiced and shorter before voiceless consonants, as longer vowels and voiceless consonants need greater articulatory energy.

2. Vowels are lengthened before voiced stops to allow time for laryngeal readjustment needed if voicing is to be maintained during oral closure.
3. Vowels are shorter before voiceless consonants due to articulatory closure durations required.

Crystal & House (1982) in their study reported that, in English, duration of vowels preceding stops vary as a function of the voicing characteristic of the stop. Long (tense) vowels preceding stops had greater vowel duration compared to short (lax) vowels when preceding stops. This effect is not seen when the vowels are preceded by fricatives. The authors could not attribute the variations in vowel duration to the sample constraints, syllabic boundary characteristics or other unaccounted parameters expected to influence voicing.

Krause (1982) reported that, intrinsic vowel duration increased as the place of articulation of the post vocalic consonant moved posteriorly. She also reported that, age and voicing feature of the postvocalic consonant influenced on total vowel duration. English words spoken by 3 year old, 6 year old and adult with normal speech, language hearing were analyzed to see if vowel duration was a cue to postvocalic consonant voicing. It was observed that, vowel duration preceding voiced stops decreased sharply with age, but not with voiceless stops.

Whitehead, Schiavetti, Whitehead & Metz (1995) studied vowel duration and consonant effect on vowels in 10 normally hearing adult males. They used 8 experimental CVC words and included the vowels /a/ and /I/. It was revealed that vowel duration was longer for /a/ than /I/ and was longer when the experimental CVC final consonant was voiced. The vowel by place of articulation interaction reflected longer vowel duration before alveolar than before bilabials for the vowel /a/ but not for the vowel /I/.

Clopper et al., (2005) studied the acoustics characteristics of the vowel systems in six regional varieties of American English. In this study, acoustics measures of duration and first and second formant frequencies were obtained from five repetitions of 11 different vowels produced by 48 talkers representing both genders and six regional variety of American English. Results revealed consistent variation due to region, particularly with respect to the production of low vowels and high back vowels.

Vowels have longer vowel duration in clear speech and the ratio was 1.4 compared to unclear speech. The interpretation is that, intelligible talkers use longer word and vowel durations than the less intelligible talkers (Ferguson & Kewley-Port, 2007).

The absolute vowel duration decreases with age (Kent & Forner, 1980; Krause, 1982; Smith, 1978). Vowel duration preceding voiced consonants decreases with increase in age (Krause, 1982; Smith, 1978).

Vowel duration in Australian female speakers has been found to be longer than their male counterparts and attributed to the rate of speaking (Cox, 2004).

In Greek vowels, high vowels are shortest and non high vowels are longest. Vowels in stressed syllables are longer and have greater intensity than in unstressed syllables. Tense vowels are relatively longer than lax vowels (Daver, 1980). In another study on five male adult Greek speakers, F0 varied from high to low corresponding to the progression from high to low tongue position in the slow-focus position only. F0 did not show any statistically significant effect on vowel quality and interactions. It was concluded that, Greek does not accept hierarchical distribution of intrinsic F0, i.e., high vowels having higher F0 than low vowels (Fourakis, Botinis & Katsaiti, 1999).

Stålhammar, Karlsson & Fant (1973) and Fant, Stålhammar & Karlsson (1974) studied the duration of short and long vowels in stressed and unstressed conditions occurring in isolation, in a /hV1/ and in connected speech of Swedish language. They found that the duration of long vowels did not change much between isolated condition (350 ms) and monosyllabic context (315 ms), but changed markedly from monosyllabic to connected speech (120 ms). Unstressed vowel duration can be represented by the following equation

$$V(short) = 30 + 0.5 \times V(long)$$

for values of long vowels not less than 60 ms, averaged across all the contexts. At values of 60 ms, there was no difference between stressed long and short vowels. The researchers suggested that there existed an invariant linear relation between long and short vowel duration.

Maddieson (1993) carried out a study on Vowel duration in LuGanda Language. He found a significant difference between the short vowel and compensatorily lengthened vowels and long vowels. However, the compensatory lengthened vowels were much closer to the duration of the long vowels than that of the short vowels. Both lengthened and long vowels were twice in their length when compared to the short vowels, whereas a lengthened vowel was only 40 ms shorter than a long vowel and had 80% of its duration. The mean duration of the compensatorily lengthened vowel in words was 191 ms, whereas it was 73 ms in short vowel words and 237 ms in long vowel words.

In Sukuma language, the compensatory lengthened vowels fell almost halfway between the duration of the long and short vowels; in fact, the mean for the lengthened vowel was slightly closer to the duration of short vowel. The mean duration of the compensatory lengthened vowel in words was 200 ms, whereas in short vowel it was 129 ms. The long vowels were over twice the length of short vowels in this data, but length and vowels were only about one and half times the length of the short tones (Maddieson, 1993).

In Hebrew, as vowel height decreased, vowel duration increased. No significant differences were reported between men and women; however, duration of vowels in adults was significantly shorter than that of the vowels produced by children. Among children, vowel duration was longer in girls than for boys (Most, Amir & Tobin, 2000).

Gendrot & Adda-Decker (2007) in their study of automated formant analysis of oral vowels in eight languages reported that the tendency to reduction for vowels of short duration clearly emerges for all languages, with notably less magnitude for Arabic. They also reported that, there was no clear evidence either for an effect of inventory size on the global acoustic space between peripheral vowels. It has been shown for consonants that large systems tend to use new articulatory dimensions and it seems reasonable that large vowel systems are also based on analogous mechanisms using dimensions such as nasality, diphthongisation or voice quality.

2.5.3 Studies on Vowel Duration in Indian (Dravidian) Languages

The Dravidian family of languages includes approximately 73 languages that comprises of Tamil (official language of Tamil Nadu state), Telugu (official language of Andhra Pradesh), Kannada (official language of Karnataka state) and Malayalam (official language of Kerala state), and are mainly spoken in Southern India and North-Eastern Sri Lanka, as well as certain areas in Pakistan, Nepal, Bangladesh, and Eastern and Central India, as well as in parts of Afghanistan, Iran, and in other countries such as Malaysia and Singapore. It has been epigraphically attested since the 6^{th} century BC. Current review of literature is limited to the acoustic characteristics of four (Tamil, Telugu, Kannada, and Malayalam) Dravidian families of languages spoken in Southern India.

Savithri (1984) reported that a low vowel had longer duration than a high vowel in Kannada. Further, on durational analysis of Kannada vowels it was reported that, duration of long vowels (180 ms) was approximately twice that of the short vowels (80 ms) (Savithiri, 1986). It was also reported that, female participants had longer vowel durations than their male participants. Vowel duration was longer when preceded by strongly aspirated stops, voiced stops, retroflex stops as compared to slightly aspirated stops, voiceless stops, and velar stops.

In Kannada, vowel duration of the test vowel in simple syllable structure was longer than the vowel in a clustered syllable. It was also reduced by the nasality of the post vocalic consonant. The ratio between the duration of short and long vowels was 1 : 1.6 (Savithri, 1989).

Venkatesh (1995) reported that in Kannada, each vowel has its own intrinsic duration. High vowels have short duration and long vowels, the longest duration; in other words, the vowel duration varied with the height of the tongue. Openness vs closeness and rounded vs un-roundedness of the vowel affected its duration. His findings also revealed that long vowels were approximately twice the duration of short vowels. No gender variations were noted with short vowels; however, females had longer vowel duration than their male counterparts for long vowels.

Rashmi (1985) studied the vowel duration of /i/ in /VCV/ context in Kannada speaking children and found that both males and females showed consistent decrease in vowel duration as a function of age.

In Kannada language, females in all the age groups (6 – 9 years; 14 – 15 years and 20 – 30 years), had longer vowel duration than males. Age influences on vowel duration were also reported, i.e., vowel duration reduced from children to adults. Adults had longer vowel duration when compared to adolescents. However, the difference was attributed to the sample. The developmental variations were stronger in short vowels than in long vowels. Long vowels were almost twice the duration of the short vowels in adults (Sreedevi, 2000).

Jenson & Menon (1972) examined the vowel duration of Malayalam vowels which contrast phonemically in length. Acoustic parameters (formant frequency, fundamental frequency, and intensity) that contribute on vowel duration were studied. It has been reported that the average duration of long vowels was approximately twice that of their short vowel counterparts and inferred that the linguistic distinction between short and long vowels may reside in the single parameter of duration.

Jenson & Menon (1972) reported that, in Malayalam language, the average duration of each long vowel tends to be approximately twice that of its short vowel counterpart. They concluded that, in Malayalam language, the perceptual distinction between short and long vowel resides directly and singularly in vowel duration. They also found that, vowel duration of short vowels increases directly in proportion to the degree of mouth opening, with the exception of /o/ which shows the longest duration.

Velayudhan (1975) in his study of Malayalam speaking population, reported that short and long vowels had ratio within the range of 1:2. Duration of vowel, irrespective of short or long, was found to be shorter when followed by an occlusive rather than non-occlusive consonants.

Vowel duration decreased with increase in height and central vowels were the longest in Malayalam (Sashidharan, 1995). Gender variations in vowel duration were also reported. The vowel duration in females was longer when compared to males. The vowel duration ratio of the short and long vowels was 1: 1.89. The ratio differed when the vowel position was in initial position (1: 1.85) vs medial position (1: 1.93).

Ampathu (1998) reported that there was a significant shortening of word duration as age advanced from 7-8 years to 20-25 years in Malayalam language. Vowel duration showed a similar trend, but the difference was not significant between age groups.

An attempt to develop normative data of the acoustic characteristics of 10 Malayalam vowels (Riyamol, 2007), revealed that, vowel duration of long vowels was approximately twice than the short vowels. Vowel duration decreased with increase in height. Central vowels had longest vowel duration. It was also reported that, vowel duration in females was longer as compared to males.

Balasubramanian (1981) in his study on duration of vowels in Tamil, reported that, phonemically long vowels were almost twice as the corresponding short vowels in identical environment. Vowel duration was longer when followed by retroflex consonant as compared to bilabial consonant. Vowel duration was longer in simple syllabic structure as compared to cluster. Further, open vowels had longer duration than close vowels.

In Sanskrit, duration of the long vowels (180 ms) was reported to be approximately twice that of the short vowels (Savithri, 1989). Vowels preceding strongly aspirated stops, voiced stops, and retroflex stops were longer than, slightly aspirated stops, voiceless stops and velar stops. She also found that, in Sanskrit, females had longer vowel duration when compared to their male counterparts.

Summarizing the earlier research findings, Duggirala (2005) stated that, vowel duration of a vowel is longer when preceded by voiced consonant than those preceded by voiceless consonant; longer vowel duration is observed, when vowel is followed by an aspirated consonant than unaspirated consonant; a vowel in word final position is longer than the same vowel in the other word positions; longer vowel duration is observed when a vowel occurs as a first syllable of a disyllabic word than in trisyllabic word; a vowel has longer vowel duration in a stressed syllable than in an unstressed syllable.

Sreenivasa Rao, Suryakanth, Gangashetty & Yegnanarayana (2001) in their study of durational analysis of Telugu language, reported that, duration and intonation are two most important features responsible for quality of synthesized speech (Huang, Acero & Hon, 2001). They also reported that syllables with voicing nature have more duration variation compared to their unvoiced counterpart. Among the voiced and unvoiced categories, durational variations were noted based on manner and place of articulation and the vowel present.

Nagamma Reddy (1988) reported that vowel duration ratio in Telugu is more than 1:2 in word initial and medial position. It varies from one and half to three times depending upon the phonetic context. The vowel duration in isolation and continued speech for all the short and long vowels are represented in Table 2.1.

Table 2.1: Vowel duration (sec) of vowels in Telugu

	/a/	/i/	/u/	/e/	/o/	/a:/	/i:/	/u:/	/e:/	/o:/
Isolation	9	7	7.5	10	10	28	25	26	26.5	27
Connected speech	5	6	4.5	6.5	5.5	13	11	11	11	11

Girija & Sridevi (1995) in a single case studied vowel duration in various contexts in Telugu and the results are tabulated in Table 2.2. They inferred that, the duration of long vowel is approximately twice the duration of a short vowel and the ratio between the short and long vowels is 1:2.1. The longest among short vowels was /o/ and the shortest was /u/. The longest among long vowels was /a:/ and the shortest was /e:/. A low-open vowel was longer than a high-close vowel. The vowel before a voiced consonant was longer than the vowel before a voiceless consonant. The vowel /a/ before voiceless consonant was longest and /o/ is the shortest. The vowel /e/ before voiced consonant is longest and /i/ is the shortest.

Table 2.2: Vowel duration (ms) of the short and long vowels in the initial position

Vowel	/i/	/i:/	/e/	/e:/	/a/	/a:/	/o/	/o:/	/u/	/u:/
Duration (in ms)	86	178	87	176	80	217	129	200	77	183

Prabhavathi Devi (1990) reported that, the duration of a long vowel is approximately twice the duration of the corresponding short vowel. The ratio between short and long vowel is 1:2. Table 2.3 gives the duration values of ten long and short vowels and their ratio.

Table 2.3: Duration of the short and long vowels

Test Vowel	**Duration (ms)**	**Ratio**
i/i:	93/223	1:2.3
e/e:	103/207	1:2
a/a:	107/253	1:2.3
o/o:	143/243	1:1.6
u/u:	90/187	1:2

The open vowel /a:/ is the longest of all the vowels in Telugu. Front vowels /i:/, /e:/ are slightly longer than /u:/, /o:/. The vowel followed by a voiced consonant is longer than the same vowel followed by a voiceless consonant. Vowel that occurs after an aspirated plosive is shorter than the one after unaspirated plosives. In Telugu language, the duration of the vowel is longest when it occurs in the final position of the word as compared to its length in initial and medial positions. The syllabic structure also influences the vowel duration. The duration of the vowel in the first syllable of a disyllabic word is the longest when compared to the same either in trisyllabic or tetrasyllabic words. Suprasegmental features such as stress have a significant role in shaping the vowel duration (Prabhavathi Devi, 1990).

In Telugu, there is interaction between phonation type and vowel duration. Vowel duration is shortest when it occurs before voiceless aspirated and longest when it occurs before voiced unaspirated consonants. Shorter vowel duration is noted before consonant sequences (including germinates) as seen in most languages (Nagamma Reddy, 1999).

2.5.4 Clinical importance of Vowel Duration

Cervera, Miralles & Álvarez (2001) based on their study of acoustical analysis of Spanish vowels produced by laryngectomees reported that, the vowel duration of the five Spanish vowels in patients with Tracheo-oesphageal shunt were longer than the other population studied.

Manwal et al., (2001) in their study of understanding of which of the acoustic characteristics contribute to better perception in alaryngeal speakers found that, vowel duration, though longest in the esophageal speakers as compared to normal was not used by the Cantonese speakers in perception.

Variations in the vowel durations were examined in order to examine the role of hearing status on regulating coarticulation in adulthood in hearing impaired and cochlear implantees. The implant users had reduced vowel duration, than prosthetic hearing aid users but consistently longer than those of the hearing control speakers. No evidence was found in reduced vowel duration in cochlear implantees. However, it has been suggested that implant users may be trying to enhance intelligibility by speaking slowly (Lane, Matthies, Perkell, Vick & Zandipour, 2001). In a study that used duration as one of the parameters to assess the speech production accuracy and perceived intelligibility following disruption in auditory feedback in cochlear implantees, it was revealed that cochlear implantees rely on the auditory cues provided by a cochlear implant to control and modify duration to maintain speech intelligibility (Poissant, Peters & Robb, 2006).

Duggirala & Barbara (2007) used vowel height, vowel place and vowel duration as contrast measures in studying the perceptual factors in phonological disorders. The authors have stated that, information on different contrasts in different languages which are simultaneously in use, will not only help in planning and monitoring the progress during therapy in phonologically disordered individuals but also in understanding the robustness of the clues in normal hearing individuals with different background noises.

Collins, Rosenbek & Wertz (1983) in their spectrographic analysis of apraxic speech, reported that, vowel duration was significantly longer in apraxics as compared to normal speakers. However, the vowel duration decreased as length of the word increased. They interpreted that vowel reduction is a robust phenomenon which resists impairment in apraxia of speech.

Studies on vowel duration and their role in perception will help in understanding the process for normal perceptual development in normal and clinical population. Further, this data will direct diagnostic and therapeutic applications with speech and language impaired children (Krause, 1982).

2.6 Fundamental Frequency

2.6.1 Introduction

Fundamental frequency of voice is the acoustic correlate of the frequency of vocal fold vibration. The frequency at which the vocal folds vibrate will determine the fundamental frequency of the sounds generated by a particular individual. Any voiced speech sound has a fundamental frequency. Vowels are produced by the sustained phonation and variation in the oral cavity. The frequency at which the vocal folds vibrate determines the fundamental frequency of the voice, in this case the vowel. Acoustic analysis of vowels facilitates the study of vocal fold vibration and the acoustic modulation of pulmonary air in the vocal tract.

There have been various theories put forward to explain the variations in F0 in vowels. One of the earliest theories by Taylor (1933) attributed higher pitch in high vowels to transference of muscle tension in the tongue to the muscles in the larynx via a kind of sympathetic resonance or radiation. Mohr (1971) attributed the variations in F0 to the build up of air pressure behind the vowel constriction and suggested that a constriction in the pharynx, as found in a low back vowel, would result in a rise of pressure behind the constriction, reduce the air flow, and thus decrease the rate of vocal fold vibration.

However, constriction in the oral cavity, as seen in a high front vowel, would not have the same effect. The greater the distance between the constriction and the glottis, the longer it will take for the air pressure to build up behind the constriction and consequently reduces F0. This theory could not provide explanation for variations in F0 for all vowels.

Later theories (Atkinson, 1972; Lieberman, 1970) attributed the variations to acoustic coupling between vocal tract and vocal cords. According to them, when the F0 was close to the first formant, as seen in high vowels, the F0 of vocal cords gets closer to the frequency of the first formant. In other words, vocal tract configuration which produces a low first formant ought to induce higher pitch. Another explanation was given by Ladefoged (1964) and Lehiste (1970) who attributed the mechanical pull of tongue on larynx causing tensing of vocal cords (Tongue pull theory) and thus increasing the F0. This theory was further supported by Ohala (1972, 1973), who stated that, energy of the vowel gets distributed across the frequencies due to varying acoustic modulation by the vocal tract. Interestingly, the energy distribution lies within a range of frequencies of the vocal tract resonance and harmonics. He also reported that, fundamental frequency (F0) of a given vowel is more or less constant.

Ewan (1979), supporting the tongue pull theory, reported that the supra laryngeal cavities are expanded actively by downward pull of the larynx so as to produce low F0 in /u/. However, he attributed changes in F0 in vowel /u/ when preceded by nasal consonants to the acoustic coupling theory. Crelin (1987) in his book on *The Human vocal tract: Anatomy, function, development and evolution* reported that, the infant vocal tract is markedly different from the older child and mature adult human, which in turn has an effect on fundamental frequency.

The fundamental frequency depends upon the tension on the vocal folds, effective mass of the vocal folds, and on the sub-glottal pressure. The effective mass of the vocal folds is progressively larger from children to women to adult males, which in turn affects the fundamental frequency (Pickett, 1996).

The cricothyroid joint is the main framework for F0 control. Fluctuations of F0 play a role in signaling segmental information. This is often called microprosody, which includes F0 variation due to consonants and intrinsic vowel F0. Speakers intend to produce higher F0 after voiceless stops to realize the auditory cue of the sounds. Small, variations in fundamental frequency of the vowels are seen due to linguistic stress, speaker emotions, and intonations (Dyhr, 1990; Honda, 2004).

Fundamental frequency information of the vowel plays an important role in perceptually segregating clues from different sources and helps in perception. In normal hearing listeners, the perception of fundamental frequency is primarily on temporal fine structure information, and resolving of lower order harmonics in peripheral auditory system (Qin & Oxenham, 2005).

In hearing impaired individuals and cochlear implant users, resolving fundamental frequency is an issue and thus affects the perception of the vowels. In a study that used fundamental frequency as one of the acoustic parameter to assess the speech production accuracy and perceived intelligibility following disruption in auditory feedback in cochlear implantees, it was revealed that, cochlear implantees relied on the auditory cues provided by a cochlear implant to control and modify F0 to maintain speech intelligibility (Poissant et al., 2006).

2.6.2 Studies on Fundamental Frequency

The average F0 values for men and women typically differed by only a few Hz when compared to the corresponding vowels recorded by Peterson & Barney (1952). F0 values for children averaged lower. They also reported of high vowels such as /i/ and /u/ showing the tendency to have higher fundamental frequencies than the low vowels such as /a/ and /æ/.

According to Lehiste & Peterson (1961) and Peterson & Barney (1952), the fundamental frequency varies with vowel height. That is, on an average, high vowels have a higher fundamental frequency than low vowels. They also reported that, these fundamental frequency differences may not play a major role in vowel recognition, but may provide secondary cues.

The frequency at the onset of voicing after the release of stop closures varies according to the preceding consonant: voiced stops are followed by low F0, while voiceless stops are followed by high F0 (Dyhr, 1990; Honda & Fujimura, 1991; House & Fairbanks, 1953; Lehiste & Peterson, 1961).

Eguchi & Hirish (1969) estimated fundamental frequencies of English vowels across the age group and reported that, fundamental frequency was as high as 300 Hz at age 3 and remarkably decreased at the rate of 30 Hz between 3 to 6 years of age. There was a gradual decrease after 6 years of age up to 13 years. Average fundamental frequency of boys at 13 years of age was 220 Hz which further decreased to male adult fundamental frequency, while for girls it was 240 Hz, which was not significantly different from female adults. Strong correspondence between the fundamental frequency and length of the vocal cords was also reported. Bennett (1983) reported no significant changes in F0 in 7 – 11 year old school children. Further, in a comparative study on comparing average F0 and F0 variability in spontaneous speech production in the ages of 11 and 25 months, Robb & Saxman (1985) reported that F0 variability decreased significantly as the age increased, but not average F0. The authors have attributed this to small age group.

Studies have revealed that with the tongue position being high in the oral cavity, the tendency is to have higher fundamental frequency than for the low vowels. Thus, the most significant factor influencing F0, is the tongue height (O'Shaughnessy, 1976; Thorsen, 1976; Pierrehumbert, 1980).

Kent (1976) reported that, children have high F0 which causes large error in the estimation of formant frequencies especially lower formants, as they are closer. The magnitude of the error declines with the age. The hypothetical error of formant estimation related to F0 is equal to F0/4.

The fundamental frequency varies not only with reference to gender of the speaker but also varies for different vowels (Kent & Read, 1995). The fundamental frequency also varies based on the linguistic stress, consonant context, speaker's emotion, and intonation. Umeda (1981) studied the segmental factors which determine the fundamental frequency of vowels in fluent readings. He reported that voiceless stops had higher peak F0 on their following vowel than voiceless fricatives and voiceless stops had significantly higher peak F0 than voiced stops. These results do not agree with the studies done in isolated context (Lehiste & Peterson, 1961). Results of Umeda (1981) infer that, proper F0 control of segmental factors in speech production models would help in the intelligibility of consonants.

F0 of the vowel varied in individual word production, sentences, stressed Vs un stressed syllables with in sentence, different positions in the sentence and rate of speech (Shadle, 1985; Umeda, 1981). Cooper, Soares, Ham & Damon (1983) in their study reported higher F0 peaks for fast speakers and emphatic stress speech.

Research has been carried out in understanding the relationship between the fundamental frequency and tongue height, lip rounding, formant structure, vowel duration, jaw openings, glottal airflow and various other anatomical and physiological variations. It was assumed that F0 was an automatic consequence of vowel production (Fischer-Jorgensen, 1990; Honda & Fujimura, 1991; Nataraja & Jagadish, 1984; Ohala, 1973; Zhi & Lee, 1990).

A comparative study of male and female larynges, proposed two scale factors to explain the differences in fundamental frequency, sound power, mean airflow and glottal efficiency (Titze, 1989). A scale factor of 1.6 was given to F0, primarily based on the membranous length of the vocal folds, while a scale factor of 1.2 was given to mean airflow, sound power, glottal efficiency and amplitude of vibration in relation to overall size of the larynx.

Yoshiyuki (1982a) in his study on English vowels reported that the mean F0 of the vowels, although non-significant, was higher F0 for the high vowels (/i/ and /u/) than the low vowels (/æ/, /a/ and /o/).

Whalen & Levitt (1995) in their extensive study across 31 languages, stated that F0 is not a deliberate enhancement of the signal but rather a direct result of the vowel articulation. Vowels can be produced with any F0 in a speaker's range; however, the high vowels tend to be produced with a higher F0 than low vowels. This "intrinsic F0" (IF0) has been found in every language that has been examined for it.

In Hebrew language, F0 values decreased as vowel height decreased. The F0 values of the adults were significantly lower than those of the children, and men had significantly lower values than women (Most, Amir & Tobin, 2000).

In Yoruba, an African language, intrinsic F0 differences between high and low vowels are smaller when these vowels are realized with a low tone as opposed to a high tone contradicting the tongue-pull theory. Other cues than steady state F0 are used to identify tones in Yoruba language (Hombert, 1977).

2.6.3 Studies on Fundamental Frequency on Indian population

Studies on F0 in the Indian population supported the western studies with reference to its varying from birth to adults. Studies by different researchers indicated that, F0 gradually decreased till 13 to 15 years of age (Rashmi, 1985; Samuel, 1973; Usha, 1978). For vowel /a/, there was a significant difference in F0 between 13 to 14 age group and 14 to 15 age group (Rashmi, 1985).

Females demonstrated one octave higher F0 than males and F0 was significantly different across the vowels in Kannada. Further, F0 increased as the tongue height increased (Venkatesh, 1995). Fundamental frequency reduced from children to adolescents and further in adults. A significant difference in F0 was noted across males and females. The variability of F0 decreased as a function of age; however, variability was high in adolescent boys due to rapid anatomical variations in larynx (Sreedevi, 2000).

In Malayalam speakers, considerable lowering of fundamental frequencies in males with increase in age was noted and in geriatrics, there was a significant increase in fundamental frequencies in males and decrease in females with increase in age. There was no significant difference in F0 between males and females in younger group (7 to 8 years) whereas older age group (20-25 yrs and 40-45 yrs) showed significant differences (Ampathu, 1998).

Average fundamental frequency of each long vowel was slightly higher than its short vowel counterpart in Malayalam speakers (Jenson & Menon, 1972). Females were found to have higher F0 values for the Malayalam vowels than males in CVCCV context (Riyamol, 2007).

The stressed syllable has the lowest fundamental frequency and maximum range in Telugu. This pattern is not observed in European and Far-Eastern languages. It was also inferred that fundamental frequency and it's range provide good correlates in differentiation stress syllable (Balusu, 2001).

In an effort to recognize the vowels and speakers with the help of acoustic features in Telugu, Pal & Majumder (1977), used Fuzzy sets and decision making approaches. It was reported that accuracy of vowel sound recognition is about 82 % when decision of the machine was based on the highest membership values. Although fundamental frequency F0 and higher formants are more speaker dependent, identification of first three formants only was satisfactory.

Telugu speakers and Hindi speakers differed significantly in the onset-pitch and mid-pitch measures for both the difference and ratio tests. Hindi speakers showed an average decrease of 21.26 mels in onset F0 values, while American English speakers showed an average decrease of 2.6 mels and Telugu speakers, an average increase of 25.73 mels in onset – F0. Mid pitch ratio test of F0 was also significantly different in Telugu speakers (Russell, 2002).

2.6.4 Clinical importance of Fundamental Frequency

Studies on fundamental frequency characteristics in hearing impaired and normal hearing individuals have shown that, normal hearing individuals always used greater mean F0 and variability for oral than spontaneous speech, which the hard-of-hearing subjects did not (Yoshiyuki, 1982b).

Variations in F0 can also be due to deliberate enhancement of speech signal. Studies have revealed that exaggerated effect used in speech resulted in variations of F0 not only in normal individuals but also in disordered population, such as hearing impaired, cochlear implantees (Bush, 1981; Duggirala, 1995; Perkell, Lane, Svirsky & Webster, 1992; Whalen & Levitt, 1994). Various speech tasks such as reading, repeating, counting etc have significant effect on F0 in children and the same tasks can be used to monitor changes in the voice over time in relationship to surgical or behavioral interventions (Baker, Weinrich, Bevington, Schroth & Schroeder, 2008). It's now felt that the influence of task type on F0 values is important for health professionals designing and implementing assessment protocols for children with voice disorders.

Fundamental frequency of vowels has been used as a perceptual cue in hearing and hearing impaired individuals. In a comparative study on normal hearing and listeners with moderate to moderately severe sensorineural hearing loss, it was noted that, normal hearing individuals took benefit of F0 in adverse conditions as compared to hearing impaired. Reduced performance in listeners with hearing loss and reduced F0 benefit was attributed to audibility of vowel sounds and deficits in spectro-temporal processing (Arehart, King & Mclean-Mudgett, 1997).

Fundamental frequency and duration cues were used to study the perception of linguistic stress by individuals with brain damage. There were differences in performance in right hemisphere damage vs left hemisphere damage in using F0 cues. It was hypothesized that differential lateralization happens for specific acoustic parameters (Baum, 1998).

Liu, Wan, Ng, Wang & Lu (2006) in their acoustic analysis of F0 contours in the utterances of /ma/ and /ba/ syllables produced by the esophageal and normal speakers reported that F0 contours of esophageal speakers are similar to normal speakers, but with limited variability.

Fundamental frequency is important to control the suprasegmental features of the sound. In an experiment in English speaking normal subjects, it was noticed that fundamental frequency of the vowel significantly increased under frequency-shifted auditory feedback for long stressed word. It was reported that a negative feedback mechanism controls the fundamental frequency via auditory feedback in speech production (Natke & Kalveram, 2001).

Fundamental frequency can be used to examine the voice onset time of stop consonant. In a study done on 56 young men using six English voiced and voiceless stops in word initial positions, it was noticed that there was no significant effect of F0 for voiced stops but for voiceless stops, higher F0 had significantly shorter voice onset time, than for low or mid (McCrea & Morris, 2005).

In summary, F0 is dependent upon the vowel height, place and quality, physical, linguistic and psychological factors, gender, and rate of speech. Studies on F0 variations are not reported in Telugu as reported in western literature.

2.7 Formant Frequencies

2.7.1 Introduction

The term formant, is a German term, which was first used by Physicist Hermann in the second half of the 19th Century. Singh & Singh (1979) defined a formant frequency as the frequency region that is significantly amplified for the continuous period of time.

A formant is a resonance of the vocal tract. The peaks in the spectrum are not the formants but are the physical properties of the vocal tract. The formants of a speech sound are known as the first formant (F1), second formant (F2), third formant (F3) and so on. The Figure 2.3 depicts the formants for vowel /a:/ in the word /kaaki/ (crow). The formant frequencies of vowels are affected by the length of the pharyngeal-oral tract, the vocal tract constriction and degree of narrowness of the constriction (Pickett, 1996). Bunch (1982) and Denes & Pinson (1963) commented that, the formants correspond to the resonance of the vocal tract and they produce peaks in the speech spectrum. According to them, significant features of vowel spectrum are the frequency and amplitudes of the various formants.

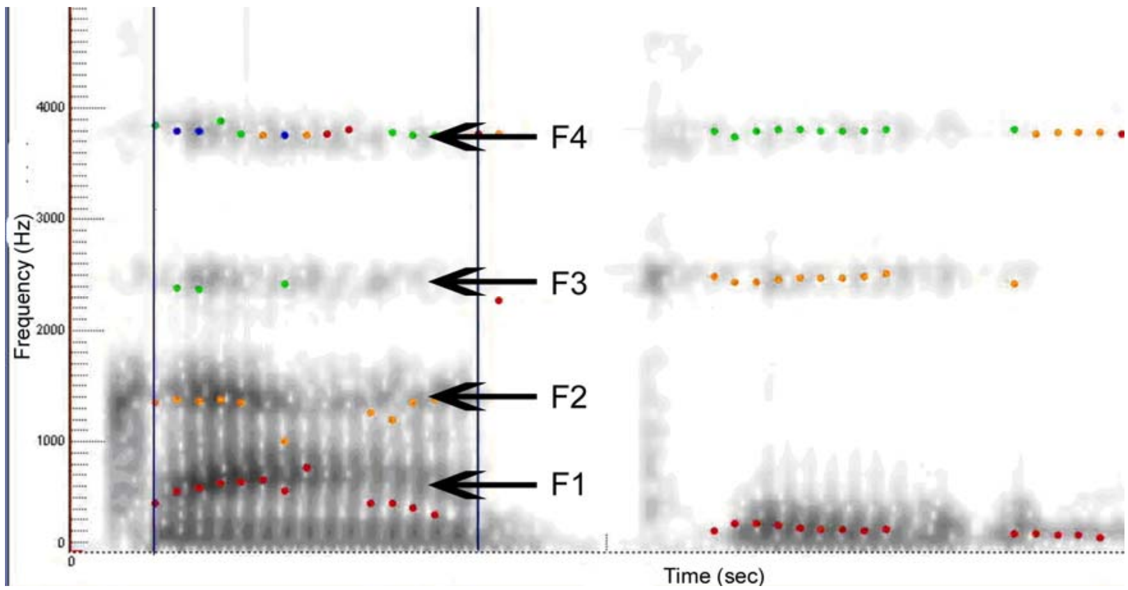


Figure 2.3: Formant for vowel /a:/

Formant is defined as a property of the resonating vocal tract (Fant, 1960). However, Monsen & Engebretson (1983) defined formants as the property of the acoustic signal which has concentration of energy along a frequency scale, defined by the prominence of several harmonics. Formant frequencies are related to the volumes of the cavities in front of (oral cavity) and behind the constriction (pharyngeal cavity) of the vocal tract. In general, larger vocal tract with larger volume will resonate at lower frequencies vs. smaller volumes, which will resonate at higher frequencies.

Formant frequencies are influenced by the vocal tract configuration. It has been presumed from past that the 1st formant corresponds to the back cavity and the 2nd formant corresponds to the front cavity of the mouth (Joos, 1948). Some of the changes reported in the literature are

- As the length of the vocal tract increases, the frequency of all the formants become low.
- As the lip constriction increases, the formant frequencies reduce.
- Elevation of the front of the tongue lowers the 1st formant and raises the second formant.
- Elevation of the posterior part of the tongue tends to reduce the 2nd formant.
- Narrowing of the pharynx raises the frequency of the 1st formant.
- Formant frequencies of nasal vowels are lower than oral vowels.
- Formant frequencies of females are higher than males.
- Constriction in the anterior portion tend to have low F1 and high F2
- Constriction in the posterior portion tend to have low F1 and moderate F2

In the literature, it is proved that, the first two formants, and in some cases, the first three formants are the most important for vowel perception. In addition to the formant frequencies of a vowel, the bandwidths of the formants, the relative levels of the formants, and formant transitions are secondary factors which play some role in the identification of a particular vowel (Monsen & Engebretson, 1983; Carlson & Granström, 1978; Carlson, Granström & Klatt, 1979).

Formant frequencies can be measured using spectrographic analysis or by linear prediction method. In the literature, advantages and disadvantages of each method has been discussed extensively. Monsen and Engebretson (1983) concluded from their study that, formant frequencies can be measured by either technique to the extent of the difference limen as reported by Mermelstein (1978).

Vowels are characterized especially by the first three formants. Each vowel has its characteristic formants. As discussed earlier, the changes in formant frequencies depend on length of vocal resonance tract, location of constriction and degree of constriction. Table 2.4 gives the summary of various formants and their formant frequency range in English speaking adults as described in the literature.

Table: 2.4: Formant frequencies and their place and extent of constriction

Formants	**Due to**	**Location of Constriction**	**Degree of Constriction**	**Frequency Range**
F1	Related to the volume of the pharyngeal cavity	Varies and frequency depends on constriction of vocal tract	Depending upon vowel	270 Hz to 1000 Hz.
F2	Length of the Oral cavity	Varies depending upon the frontness or backness of the highest part of the tongue	Depending upon the vowel	840 Hz to 2500 Hz
F3	Position of lips	Varies depending upon the frontness or backness of the highest part of the tongue	Depending upon the vowel	1690 Hz – 3010 Hz

Pickett (1996) described rules that relate vowel shapes to the formant locations. F1 is influenced by oral and pharyngeal constriction. F2 is dependent upon the tongue constriction in the vocal tract. Formants are also influenced by the lip rounding.

- Oral Constriction /F1 rule: The frequency of F1 is lowered by any constriction in the front half of the oral part of the vocal tract, and the greater the constriction, the more F1 is lowered.
- Pharyngeal Contriction/F1 rule: The frequency of F1 is raised by constriction of the pharynx, and the greater the constriction, the more F1 is raised.
- Back tongue constriction/F2 rule: The frequency of F2 tends to be lowered by a back tongue constriction, and the greater the constriction, the more F2 is lowered.
- Front Tongue constriction/F2 rule: The frequency of F2 is raised by a front tongue constriction, and the greater the constriction, the more F2 is raised.
- Lip rounding rule: The frequencies of all formants are lowered by lip rounding. The more the rounding, the more the constriction, and the more the formants are lowered.

The Length Rule, as described by Pickett (1996), says that "the vowel formants are inversely proportional to the length of the pharyngeal-oral tract". That is, longer the vocal tract, lower are the average formant frequencies. The Length Rule gives information where we may find the approximate formants across the age groups.

Fant (1966) has given a scale factor for calculating the first two formants with the following formula. According to him,

$$1^{st}\text{ Formant, K1} = \frac{\text{F1ofFemale}}{\text{F1ofMale}} - 1 \text{ x } 100$$

$$2^{nd}\text{ Formant, K2} = \frac{\text{F2ofFemale}}{\text{F2ofMale}} - 1 \text{ x } 100$$

The normalization of formant frequencies for the purpose of demonstrating vowel equivalence has several possible complications (Kent & Forner, 1979). However, such data would help in understanding the developmental changes and formant variations across the vowels, genders and dialects. Iso-vowel lines for five English speaking vowels have been developed and widely used to distinguish between normal vs disordered speech (Kent, Weismer & Kent, 1989). It's noticed that, logarithmic transformation of formant frequencies would help in obtaining uniform scale factor; however, this may not yield an exact equivalence of dispersion.

2.7.2 Studies on Formant Frequencies

Studies on fundamental frequency and its variables have been conducted since almost three decades. Black (1939) on studying the effect of consonants on vowels in English has concluded that, although the vowel remains fairly constant when it is present between varying consonants, it differs from word to word. The variability is seen in frequency, intensity, and other intrinsic factors, also within the speech when the vowel is bounded by different consonants.

Peterson & Barney (1952) on their study of formants in different gender group, inferred that the children's formants are highest in frequency, the women's intermediate and the men's, lowest in frequency. Flanagan (1955) found that formant frequencies may be altered by as much as 20 Hz before a difference may be detected.

Peterson & Barney (1952) studied formant frequencies (F1-F3), formant amplitudes and fundamental frequency (F0) in 10 vowels in /hvd/ context spoken by 33 men, 28 women, and 15 children. The results of the study showed a strong relationship between the intended vowel and the formant frequency pattern. However, there was a considerable formant frequency variability from one speaker to the next, and a substantial degree of overlap in the formant frequency pattern among adjacent vowels. Higher F2 values for /a:/ was observed as compared with /e/, although the differences in F1 was not consistent across talker groups.

Stevens & House (1963) studied the formant frequencies of the American English Vowels. Words with 8 common vowels of American English and 14 consonants that appeared both initially and finally were used for the study. The measurement of formant frequencies were performed using a Spectrum – matching procedures. Results showed that in general, the F1 shifts are fairly small. For front vowels, the consonantal environments cause F2 to shift downward and the shift is larger for lax (short vowels) than for tense vowels. Significant differences existed in the vowel formant frequencies from one talker to another when the vowels were in the consonantal environments. They studied effects of consonantal context on the vowel formant frequencies and observed that various consonantal contexts influenced the formant frequencies of vowel and that they differed considerably from one to another. They also observed that, the consonantal context causes systematic shifts in the vowel formant frequencies depending upon the place of articulation of the consonant, its manner of articulation, and it's voicing characteristics.

Eguchi & Hirish (1969) studied formant frequencies (F1 and F2) across the age group using English vowels and reported that,

- First and Second formants decreased from 3 to 5 years of age.
- Second formant decreased greater than First formant.
- First formant is independent of age.
- Front cavity development has greater influence than back cavity development.
- Anatomical and psycho-physiological development influences the variations in the formant frequencies.

Kent (1976) reported that, the formant frequencies of children's vowels are higher than the values obtained for adult females and higher yet than the values obtained for the adult males.

Kallail & Emanuel (1984) in their study reported that, the formant frequencies (F1 through F3) differed from phonated and whispered productions. They also reported the whispered vowel formants to be higher in frequencies than phonation, especially for F1.

Bernstein-Ratner (1985) reported that stress and its secondary manifestations play a role in vowel formant frequencies rather than the duration, thus supporting earlier studies of Delattre (1969) and Liberman (1967). It was also inferred that, most significant shift seen in F2 could be due to stress and ancillary manifestations than duration alone.

Significant differences in F1 and F2 were noted between boys and girls. In English, differences between male and female fundamental frequency and formant frequency patterns begin typically around the age of 11 and become fully established toward the age of 15; however, this is not seen in Hebrew language. The authors suggested future research on the possible cultural differences (Most. et al., 2000).

The frequency of the third formant is affected by the position of the lips. In certain languages such as in French, German the third formant is not predictable. This formant has very little function in distinguishing the vowels (Ladefoged, 2001).

Hillenbrand, Clark & Nearey (2001) investigated the effect of consonant environment on vowel formant patterns. The main purpose of their study was to determine whether a close relationship between vowel identity and spectral change pattern is maintained when the consonant environment is allowed to vary. Formant frequencies, formants F1-F3 were measured and the results showed highly significant effects of phonetic environment, particularly large shifts in formant patterns were seen for rounded vowels in alveolar environments.

In a pilot study on American English speaking population, it was reported that elderly speakers of both genders had lowering of formant frequencies (especially F1) across selected vowel productions as compared to their young cohorts (Xue & Hao, 2003).

Hasegawa-Johnson et.al., (2003) reported that formant frequencies and log area were independent of vowel place. F2 is maximally sensitive to area changes near the vocal tract constriction. F1 is maximally sensitive to area near the glottis, except for vowel /i/.

Cox (2004) in his study on understanding acoustic characteristics of /hVd/ vowels reported that, gender differences in formant values demonstrate non-linear variation. The open vowels when compared to close vowels had clear gender variations.

Watson, Palethorpe & Harrington (2004) in their study on vowels in New Zeland English speakers, have reported that, F1 lowering was seen over the age. Speech of an individual can change over time in accordance with the general population. The authors have attributed the variations to anatomical changes in the vocal tract.

Loakes (2004) in her study to determine if F2 and F3 is speaker specific in monophthongs in Australian English reported that, the front vowels and close-front vowels in particular were most speaker specific. The F2 and F3 of /I/ were most speaker specific parameters between the speakers compared to within speaker. Low vowels showed a higher F1, and F2 showed more frontness in front vowels compared to back vowels (Whalen et al., 2004).

Man (2007), in their study of phonetic analysis of the vowels, diphthongs and triphthongs in Meixian Hakka Chinese language, reported that, the formant patterns for the vowels studied are similar for both male and female speakers. The F1 and F2 formant frequency values for the vowels produced by male speakers were lower than those of female speakers. They also reported that the relative distance between the mid vowels and the high vowels is greater for female speakers than for the male speakers in the vowel ellipses.

The results presented here only suggest a higher stability for vowel /i/ in five languages. /a/ is reputedly a variable vowel, but the acoustic variability found for /u/ might be best understood if we consider it a central articulatory constriction as stated in particular by Vaissière (2007), the stability of the low second formant being mainly due to lips rounding.

2.7.3 Studies on Formant Frequencies in Indian (Dravidian) Languages

There have been studies on formant frequencies in Dravidian languages (Jenson & Menon, 1972; Nagamma Reddy, 1998, 1999; Ampathu, 1998; Sreedevi, 2000; Riyamol, 2007). In the study in Kannada, Sreedevi (2000) reported that male children had significantly higher F1 than females by 3%. Females had higher F1 in adolescents (7%) and adults (11%) compared to males. F2 for females was significantly higher than males across children, adolescent and adults. Linear decrease in F3 was noted from children to adolescents to adults and further marked decrease in adults in both genders. It was also commented that, Formant frequency values produced by children decreased with increase in age not only due to anatomical variations but also due to pharyngeal to oral cavity area.

Ampathu (1998), in his study reported that children showed higher Formant Frequencies and longer word duration than adults in Malayalam. The Formant Frequencies were reduced and word duration was higher in the geriatric population.

Jenson & Menon (1972) in their study of Malayalam language found that formant frequencies (F1 and F2) showed relatively small difference between the short and long vowel pair. Also, they found systematic relation between /u/ versus /u:/ and /a/ versus /a:/ vowel pairs only and not other vowel pairs.

Riyamol (2007) in her study on Malayalam adult speakers reported that female speakers had higher formant frequency pattern than males, confirming the findings of Peterson & Barney (1952) in English speakers. She reported that, low vowels (/a/, /a:/) have high F1 and the high vowels (/i/, /i:/, /u/, /u:/) low F1 frequency. Front vowels have higher F2 compared to low back as well as high back vowels.

Telugu vowels have been reported to be having slightly higher F1 for short vowels, except for /a/, than for long vowels. F3 and F2 formants were considerably higher in long vowels compared to short vowels (Nagamma Reddy, 1998).

Nagamma Reddy (1999) in her study on coarticulation in Telugu, reported that, formant frequencies and quality of same vowel varied depending on the nature of the vowel in the next immediate syllable. The formant frequencies, F1 and F2 for the vowel /a/ decreased when followed by /i/, and even more with /u/ compared to /a/. However, F3 decreased when followed by /i/ and increased when followed by /u/. The differences were dependent upon the vowel height and backness of the first vowel.

2.7.4 Clinical importance of Formant Frequencies

System of iso-vowel lines in F1-F2 and F2-F3 planes developed by Kent & Forner (1979), offers a good solution to compare the data from disordered speakers with normative data (Duggirala, 1983-1984; Kertoy, Guest, Quart & Lieh-Lai, 1999). Duggirala (1983-1984) further quoted that, iso-vowel lines offer a graphic evaluation of formant structure for any given speaker. Each iso-vowel line is an acoustic life line of an average individual's vocal tract, i.e., as a person matures his/her vocal tract lengthens and vowel formants lower in their frequency.

Formant analysis, especially F1 and F2, has been used to understand the emergence of vowel system in Cochlear implantees (Ertmer, 2001), speech intelligibility in cochlear implantees (Poissant et al., 2006) and developmental changes of co-articulation (Gibson & Ohde, 2007).

Sumita, Ozawa, Mukohyama, Ueno, Ohyama & Taniguchi (2002), in their study of characterizing the acoustics of vowel articulation in maxillectomy patients, reported that maxillectomy patients had a significantly lower F2 for all five vowels and a significantly higher F1 for only /i/ vowel. Maxillectomy patients also had a significantly narrower F2 range and this resulted in their poor speech intelligibility. Thus, they inferred that F2 range was effective in evaluating the speech ability of maxillectomy patients.

Estimation of formant frequencies helps in monitoring and understanding the improving vowel production and thus the speech production and speech perception. Langereis, Bosman, Olphen & Smoorenburg (1997) in their study on Dutch cochlear implantees reported variations in F1 and F2 frequencies post implantation.

Murry & Doherty (1980) in his study reported that subjects with an alaryngeal mass had a reduced mean F0, but higher variability due to the influence of the mass on the vocal fold vibratory pattern.

Using iso-vowel lines, F1, F2 were plotted in a myositis case, where all the formant frequencies were much lower than the expected normative data. Vowels /i/ and /u/ were distorted and the investigator emphasized the need for periodic spectrographic analysis of speech to monitor the progress made from medical treatment and speech therapy (Duggirala, 1983-1984).

Children with history of tracheotomy presented varied F2 dimension for /i/ and /u/ and F1 dimension for /æ/ and /i/. Iso-vowel lines were used to map the results and were found to be dispersed. Based on this, it was stated that children undergoing tracheotomy would experience difficulty with tongue extension and retraction (Kertoy et al., 1999). This study highlights the use of iso-vowel lines and formant analysis in describing the speech characteristics in children with history of tracheotomy.

Cervera, Miralles & Álvarez (2001) in their study on Tracheoesophageal speakers, esophageal speakers and normal speakers in Spanish language found that the esophageal and tracheoesophagel speakers had higher F1 and F2 values than in the normal group.

Whitehill, Ciocca, Chan & Samman (2004) analyzed vowel space, formant frequencies (F1 & F2) in glossectomy patients and found that, F1 and its range did not show any significant difference; however, F2 was lower for vowel /i/ and its range was restricted when compared to control speakers. They concluded that, among the parameters studied, F2 range could serve as a sensitive correlate for vowel intelligibility for speakers with partial glossectomy.

In a study to evaluate a formant enhancement algorithm on the perception of speech in noise for normally hearing listeners, Alcantara, Dooley, Blamey & Seligman (1994) using multi talker babble and noise of dynamic filtering with band pass filters centered at the F1 and F2 and reported that it had small effect on perception of vowels.

Kazi et al., (2007) in their study on analysis of formant frequencies in glossectomies reported that formant values, especially F2 and F3 in partial glossectomies were significantly altered when compared with normal subjects. Formant values were also statistically significant with respect to gender and complications and not other factors such as age, site of lesion, treatment methods.

Manwal, Gilbert & Lerman (2001) reported that, the esophageal speaker's intensity and vowel duration data did not contribute much to the perception of meaning as F0 contours did in Cantonese alaryngeal speakers.

Change in F2 intensity would change the perception of vowel and suggests that vowel spectral shape is the most salient cue to vowel identity (Hedrick & Nabelek, 2004). Its' further reported that, in degraded listening conditions, hearing impaired individuals found it very difficult to perceive the vowel with the change in F2 intensity change.

The formant frequencies were centralized and varied little despite changes in fluency, speaking rate and vowel duration in stutterers. Vowel formant frequencies became more centralized as vowel duration decreases (Klich & May, 1982).

Auditory feedback and its influence on human speech production has been evaluated using various experiments, for example, by varying pitch, loudness and gradual manipulation of formants. Purcell & Munhall (2005) in their study manipulated real-time formant tracking and filtering and reported that, both F0 and formants played a role in auditory feedback and auditory perception.

2.8 Formant Bandwidth

2.8.1 Introduction

Formant bandwidth, is the difference in frequency between the points on either side of the peak which have amplitude, that corresponds to 3 dB down from the peak. Damping of the formants was first reported by Fletcher in 1929 and gave a bandwidth of 500 nepers per second, corresponding to 159 cps, for the first formant of natural vowel /a/. Dunn (1961) in his review reported that, there were considerable variations in the band widths obtained by various authors, and this could be due to the method they obtained and the context they used.

Bandwidths were analyzed initially with the help of Fourier analysis using Oscillograms (Dunn, 1961). Researchers using this technique could not get reliable results with the accuracy of findings being questionable. Later, Bogert (Dunn, 1961) introduced Bandwidth analysis using the sound spectrograph with sectioner. Another method used was curve fitting method, where true resonance curves of different widths were calculated and plotted in amplitude and frequency scales of spectrogram. However, its accuracy was questioned based on the calculations used for obtained curves (Dunn, 1961). According to Dunn (1961) the Bandwidths varied from 39 cps to 130 cps for the first formant, 50 to 190 cps for the second formant and 70 to 260 cps for the third formant based on the technique used.

Resonant Frequency Bandwidth estimation is very essential in understanding the quality of spoken vowels and vocal tract acoustics (Yasojima, Takahashi & Tohyama, 2006). Bandwidth of the resonant frequency can be estimated using Clustered Line-Spectrum Modeling (CLSM) (Yosida, Kazama & Toyama, 2001). In this model, the formant frequencies are subjected to analysis where in the bandwidth is calculated by decaying the signal.

2.8.2 Studies on Formant Bandwidth

The bandwidths increased for both male and female speakers as the formant frequencies increased. The bandwidths for females also had greater variation and were wider compared to males (Yasojima et al., 2006).

Formant bandwidth has little effect on the quality or intelligibility of isolated vowels (Klatt, 1982; Rosner & Pickering, 1994); however, it has an effect on the identification of vowels in competition with other vowels (Cheveigne, 1999). The author inferred that at constant root mean square amplitude, identification of a vowel is enhanced by sharpening its formants, or widening those of its competitor. Effects of target and competitor bandwidth are approximately independent, and independent with those of amplitude ratio and $\Delta F0$.

2.8.3 Clinical importance of Formant Bandwidth

John, Marios, Margaret, Timothy & Laura (1997) in a study to understand the effects of bandwidth on identification of synthetic vowels, manipulated the bandwidths of formants F1, F2, F3 and F4 and presented to the cochlear implantees. They found that, broader F1 bandwidths yielded poorer performance than narrower F1 bandwidths however, the same was not true for F2.

2.9 Vowel Space

Vowel space area is a graphical representation constructed using the first (F1) and second (F2) formant frequencies of front, center and back vowel (generally /a/, /i/ and /u/). It is an acoustic measure for indexing the size of the vowel articulatory working space.

Vowel space has been widely used in the study of speech to assess the impact on speech of various disorders such as stuttering (Blomgren, Robb & Chen, 1998; Klich & May, 1982), dysarthria (Duggirala, 1983-1984; Turner, Tjaden & Weismer, 1995), to detect changes in speech perception and production with cochlear implants (Lane et al., 2001), in cross-language comparisons (Bradlow, 1995).

In fluency disorders, studies on vowel space have helped in distinguishing between individuals with fluency disorders and normals. It was observed that, vowel space for vowels /i/, /u/ and /a/ provided significant group differences. Greater vowel centralization in stutterers was noted compared to treated and control groups (Blomgren et al., 1998).

On a comparative study of examining the relation between vowel production characteristics and intelligibility, Neel (2008) observed that, distinctiveness among neighboring vowels is more important in determining vowel intelligibility than vowel space. In confused vowels, acoustic comparisons are more useful than measuring vowel space area while studying the intelligibility of normal and disordered speech. However, vowel space has been used for talker identification (Carrell, 1984).

Significant differences between the vowel spaces are noted in a study of speech sample from speaker at different ages of 50s, 70s and 80s (Watson et al., 2004).

Lindblom (1986) has given The Theory of Adaptive Dispersion (TAD), which makes predictions as to the effect of inventory size on the acoustic distribution of elements of vowel systems. It is reported that, "adaptive dispersion" will occur so as to give sufficient contrast between elements in a vowel inventory. TAD accounts for producing sounds sufficiently contrastive to promote linguistic comprehension by the listener. The theory has thus been extended to account for within speaker variation. For example, Moon & Lindblom (1989) showed that under circumstances that require clear speech, a speaker's vowel space will be expanded relative to his or her casual speech vowel space.

Vowel space expansion is generally associated with increased vowel intelligibility in clear speech; however, the extent of expansion differs from individual to individual within the clear speech. They also noticed in one subject, the smaller vowel space observed in clear speech and vice versa (Ferguson & Kewley-Port, 2007).

In a simulated study, the maximum vowel space in the F1 versus F2 space is larger in both infants and male adults. However, F2 versus F3 acoustic space is reduced in infants compared to adult males (Menard, Jean-Luc & Boe, 2004). It was also commented that for French vowels, vocal tract shape is not a factor contributing for the perception of target sounds.

In dysarthria, researchers have used vowel space calculations to judge the recovery and improvements in perceptual impressions of intelligibility. It has been reported that, there is no relationship found between vowel space and perceptual impressions of intelligibility (Tjaden, Rivera, Wilding & Turner, 2005).

2.10 Summary

The review of the literature discussed hitherto clearly indicates that the acoustic properties of the vowels such as fundamental frequency, amplitude, formant frequencies and duration vary in different age groups, gender, languages, consonant context, speech task, and disordered speech. Extensive research in the west (especially in English language) has been done on the acoustic characteristic of vowels and the factors that influence these acoustic characteristics. Cross linguistic studies in the west, have shown that there are subtle differences in certain acoustic properties (Formant frequencies, vowel duration) between the languages. Literature survey in Indian languages has revealed that, in Kannada and Malayalam languages, findings have been similar to English, with variations in vowel duration, formant frequencies and consonant influences. There is a paucity of studies specifically in Telugu across age, gender and region related aspects on acoustic characteristics of its vowels and their influences.

With the advancement in assessing, diagnosing and rehabilitation of communication disorders, there is a dire need for the clinicians to understand the acoustic properties of the vowels (important speech sounds) of the language they are working in. This information will help in the differential diagnosis and in identifying the factors influencing the deviancies in the normal speech. As Telugu is not having enough information on such factors, and with its speaking population high not only in India but also across the world, the need for understanding its vowel characteristics becomes relevant and greater. Hence, the current study has focused on the acoustic characteristics of vowels in Telugu and has also studied the influence of age, gender, region on their characteristics and the variations among short vs long, front vs central vs back vowels. The outcome of this study, it's felt, would be beneficial to the clinicians of Telugu speaking regions to be more region & dialect appropriate in their management strategies.

3

Method

CHAPTER 3

METHOD

3.1 Introduction

This was an attempt to examine the differences in the temporal and spectral characteristics of vowels in Telugu language across three age groups (children, adolescents and adults), gender, three dialects (Coastal, Rayalaseema and Telengana) and consonant contexts. This chapter provides details on the material, participants, data collection procedures and other relevant aspects of the method.

3.2 Material

A list of 100 meaningful disyllabic words consisting of CVCCV and CVCV syllables were selected from Telugu magazines and dictionary (Sitaramacharyulu, 2005) and given to age appropriate normals across the three different regions (Coastal, Rayalaseema and Telengana) for familiarity rating. They were asked to rate the familiarity of the words on a three point scale (Not at all familiar, Familiar, Most familiar). Only those words that were rated as familiar and most familiar across all the regions and age groups were selected for compilation of the final word list. Thus, the final list of 60 words (Appendix II) consisting of all ten short and long vowels present in Telugu (hence forth called as tokens), in all possible consonant and semivowel context was prepared. Vowels, consonants and their frequency of occurrence in different contexts of the final list are given in Tables 3.1, 3.2 and 3.3 respectively. The target word was embedded in the final position of a carrier sentence "/i: padamu (target word) /" (This word is ______), so as to obtain reasonable uniform stress and intonation patterns (Bennett, 1981; Most, Amir & Tobin, 2000). Power point slides of each word of the list were made. (The pdf version of the power point presentation used is written on to the CD and enclosed).

Table 3.1: List of Telugu vowels included in the study

	Front	Central	Back
High	/i/, /i:/		/u/, /u:/
Mid	/e/, /e:/		/o/, /o:/
Low		/a/, /a:/	

Table 3.2: List of Telugu consonants included in the study

Consonant	Description
/k/	Voiceless unaspirated velar plosive
/g/	Voiced unaspirated velar plosive
/tʃ/	Voiceless aspirated alveopalatal affricate
/dʒ/	Voiced unaspirated alveopalatal affricate
/tˌ/	Voiceless retroflex stop
/dˌ/	Voiced unaspirated retroflex
/t/	Voiceless dental unaspirated plosive
/d/	Voiced dental aspirated plosive
/p/	Voiceless bilabial plosive
/b/	Voiced bilabial plosive
/m/	Bilabial nasal
/n/	Alveolar nasal
/r/	Alveolar trill
/l/	Alveolar lateral
/s/	Voiceless alveolar fricative
/ʃ/	Voiceless alveopalatal fricative
/w/	Bilabial semi-vowel
/y/	Palatal semi-vowel

Table 3.3: Frequency of occurrence of vowels in different contexts

Vowels	**Consonants**																		**Total**
	/p/	**/b/**	**/t/**	**/d/**	**/t̪/**	**/d̪/**	**/k/**	**/g/**	**/ch/**	**/j/**	**/m/**	**/n/**	**/s/**	**/ʃ/**	**/l/**	**/r/**	**/w/**	**/y/**	
i	1			1								1							3
i:	1							1	1			1							4
e	1				1				1		1				1	1	1		7
e:	1			1			1	1	1		1								6
a		1					1	1				1	1		1		1	1	8
a:	1	1	1	1			1	1	1		1	1		1					10
o	1	1	1								1	1							5
o:	1		1			1			1										4
u	1	1	1	1			1		1	1			1			1			9
u:	1			1							1	1							4
																		Total	**60**

A total of 4320 tokens of vowels from 72 participants served as the initial sample size. 21 tokens were eliminated owing to poor acoustic features, bringing down the final sample size to 4299. In few of the participants, in certain vowel contexts (/u/ and /o/ both short and long), higher formants were not reliably identified. In such tokens, only the lower formants were measured. Consequently, the total number of measurements for the higher formants was smaller by about 20% than that of the total number for the lower formants. Nevertheless, it needs to be noted that all measurements were based on a large corpus of data. Further division of the occurrences for each subgroup is given in Appendix III and Appendix IV.

3.3 Participants

A total of 72 Telugu speaking normals from three different regions (Coastal, Rayalaseema and Telengana) in three different age groups (Group I: 06 to 09 years; Group II: 13 – 15 years; Group III: 20 – 30 years) with equal gender ratio participated in the study. Selection of age criteria for Group I was to avoid the effect of pubertal changes among the participants. Both genders were included in this group, as children below this age group generally don't demonstrate any significant differences in their vocal characteristics (Most, Amir & Tobin, 2000). The sample size for the study was calculated based on the formula,

$$N = \frac{2\,(Z\alpha + Z\beta)^2\,\sigma^2}{d^2}$$

Where,

$Z\alpha = 1.96$

$Z\beta = 0.8 = 0.84$ or $0.9 = 1.282$

Based on the reported (Sreedevi, 2000) standard deviation of 10 to 20 across participants between the groups and 100 to 250 between parameters and using the above formula and with d values at 95 % level of significance and power of .9 on chi test, the number of participants and number of tokens were calculated. The values are tabulated in Table 3.4 and Table 3.5 respectively.

Table 3.4: Number of participants calculated with standard deviation of 10 and 20 at 95% level of significance and power of 0.9 on Chi-square test

	10 (σ)	**20 (σ)**
10 (d)	**21**	84
20 (d)	5	21

Table 3.5: Number of tokens calculated with standard deviation of 100 and 250 at 95% level of significance and power of 0.9 on Chi-square test

	100 (σ)	**250 (σ)**
10 (d)	2102	13138
20 (d)	526	**3286**

Considering the values obtained at 95 % level of significance and with the power of 0.9 on Chi-square test, a sample size of 24 participants per each age group and 4230 tokens (Appendix III and IV) were arrived upon. The mean age across each group that participated in the study is represented in table 3.6. Each age group was further divided into equal number of males and females. Further, three subgroups were made based on each region (Coastal, Rayalaseema and Telengana) of the language usage. Thus, each regional group consisted of 4 participants; each gender, 16 participants and each age group, 24 participants. A total of 18 subgroups were formed. A flow chart of all the subgroups and the number of participants is given in Appendix V. All the participants were born in Andhra Pradesh and were native Telugu speakers. A qualified Audiologist and Speech-Language Pathologist evaluated and certified their speech, language, and hearing, as being normal at the time of data collection.

Table 3.6: Mean age of the participants for each group

Group	Minimum Age (in years)	Maximum Age (in years)	Mean	Standard Deviation
Group I	7	10	8.5	0.96
Group II	11	15	13.42	1.15
Group III	20	30	23.42	2.84
Overall	7	30	15.03	6.42

3.4 Procedure

After an informed consent (Appendix IX), the randomly selected participants from the respective groups were comfortably seated (Figure 3.1) in a sound treated chamber of the Speech and Hearing department and in a quite room while recording samples at schools. With the condenser microphone (Appendix VI) to mouth distance kept constant at 2 centimeters, the recording was done on to the hard disk of a personal laptop computer (IBM ThinkPad, with Genuine Inter(R) CPU, T2300 @ 1.66GHz, 504 MB of RAM and with a built-in audio interface card) installed with the Wave Surfer recording software (Appendix VI). The speech sample was recorded at a sampling rate of 22,050 kHz and bit rate of 256 kbps.

The tokens were presented on the computer screen to the participant one at a time. The participant was instructed to read the target embedded sentence twice as it appeared on the screen. All recordings were done by the researcher and stored in Microsoft Windows wave format (*.wav) for future retrieval and analysis.

From the two thus recorded sentences, the perceptually correct target word was extracted using Adobe Audition (Appendix VI) software. The extracted sound was saved in *.wav format. The target words were presented to one Telugu speaking adult Speech Language Pathologist to perceptually judge the correct pronunciation of the target word. The words that were judged to be incorrect were deleted and re-recorded by the same speaker.

Figure 3.1: Seating and presentation setup of the study

Computerized Speech Lab (CSL) 4500 (Appendix VI) was used for temporal and spectral analysis of the target vowel present in the target word. An anti-aliasing filter with a 10 kHz cutoff frequency was used before A/D conversion and a pre-emphasis factor of 0.8 was applied. Following steps were carried out while analyzing the temporal and spectral parameters of vowels.

1. The target word file was loaded by selecting file, open command.
2. The target word was loaded into window A of the CSL.
3. Each word was displayed as a broad band spectrogram with a pre emphasis factor of 0.80. The analysis bandwidth was set to 100 points (234.38 Hz) for Group I,

male and female samples and Group III female sample, 125 points (187.50 Hz) for Group II males and females and 200 points (117.19 Hz) for Group III male samples. A Hamming window was used.

4. Spectrograms were displayed in monochrome (black and white) and the grid size used was 8 x 8 pixels with a linear vertical axis.
5. A macro was created to generate spectrogram of the displayed data and mark the formant frequencies. Another macro was created to emphasize by a factor of 2 for the weaker waveform prior to generating the spectrogram.
6. The first vowel in CVC/CVCCV was considered for the analysis.
7. Vowel duration (Appendix VII) was marked from the spectrogram in window B of the CSL. While selecting the start and end points, wave form of the signal in window A was also considered to extract most accurate duration. This was done by synchronizing both windows.
8. The starting and end points were recorded in an Microsoft Excel sheet to further calculate the difference between the two points to get the vowel duration.
9. Fundamental frequency of the target vowel was analyzed using SIGVIEW version 1.91 acoustical software (Appendix VI). It is a real-time signal analysis software package with wide range of powerful FFT spectral analysis tools. Sample screen for extracting fundamental frequency are given in Appendix VII.
10. Formants F1, F2, F3 and F4 (Appendix VII) were identified visually and recorded. Using analysis, formant history, mark formant history for all data, the position and values were reconfirmed. Only clearly visible formants were considered. Values were obtained in three different positions in the steady state of the vowel and were recorded in the Microsoft Excel sheet. The average of these three values was considered as the frequency of the target formant.
11. Bandwidth was recorded from the displayed numerical results by using command "Alt + N". At the same three different Formant frequency positions, the Bandwidth of the respective formants was recorded (Appendix VII).
12. A resource disk was developed to facilitate clinicians (Appendix X).

3.5 Inter and Intra judge reliability

The researcher re-measured 10% of the tokens (random selection) after 6 months of the first measure for intra-judge reliability. Results from the paired *t*-test suggest that the two measures are highly reliable ($t_{(431)}$ = 1.026, p = 0.309). An experienced speech pathologist, unaware of the purpose of the study, measured temporal and spectral characteristics of 10% of the tokens (random selection) for inter-judge reliability. Results from the paired *t*-test suggest that the two measures are highly reliable ($t_{(431)}$ = 0.10, p = 0.920).

3.6 Statistical Analysis

Descriptive analysis of the data was performed using SPSS 16 (Appendix VI). To evaluate the effect of age, gender and region on the response variables (vowel duration, fundamental frequency, formant frequencies and bandwidths), a multilevel approach (Quene & Bergh, 2004) was used in MlWin 1.1. A three-level model was constructed with individuals as first level, consonants context as second level and vowels as third level. The pictorial representation of the model is depicted in Figure 3.2. Significance levels were determined with Wald test. Definitions of terms used in the multilevel approach, models used in the study are described in Appendix VII.

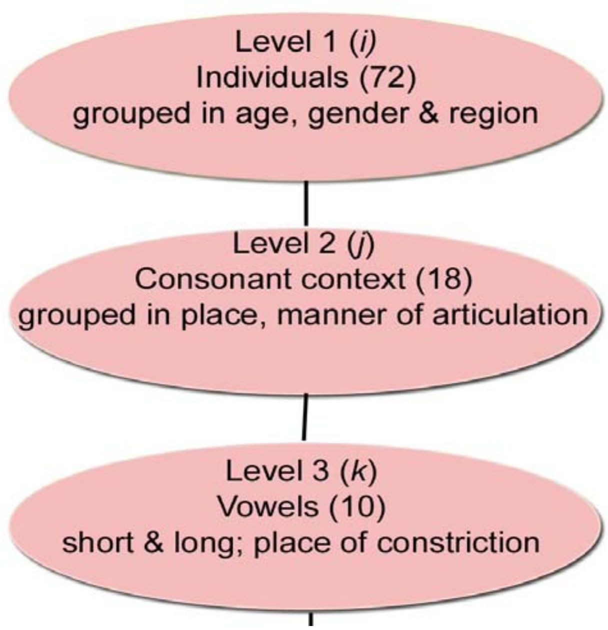


Figure 3.2: Multilevel framework considered in the study

Further to estimate the significant mean difference of each vowel between the age, region and gender groups for each response variables, one way ANOVA with Tukey HSD post hoc test and Student's *t*-test were used respectively using SPSS 16. The details pertaining to analysis of the results and their interpretation is discussed in the following chapters titled, "Results and Discussion".

4

Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Temporal characteristics of Telugu vowels

4.1.1 Vowel duration (VD)

Scrutiny of the vowel duration data revealed that the mid high vowel /e/ and low mid vowel /a:/ were the longest and the high front vowels /i/ and /i:/ were the shortest. Central vowels were longer followed by front and back vowels. It was also observed that, the mean vowel duration of the short vowel was shorter followed by long vowel. The mean and 1 standard deviation (1 SD) bars of all vowels' vowel duration are depicted in Figure 4.1.1. The means, standard deviation (SD) and 95% confidence interval for mean of all the vowels; for central, front and back vowels and short and long vowel ratios across the age groups are given in Appendix VIII a (Tables 4.1.1, 4.1.2 & 4.1.3 respectively).

It was observed that the ratio of short vs long vowels increased from children to adults with children having a ratio of approximately 1:2, while adolescents and adults, 1:2.2 and 1:2.4 respectively.

Children had longer mean vowel duration followed by adolescents and adults for all short vowels, except for /i/ and /u/, where adults exhibited longer vowel duration as compared to adolescents. The mean vowel duration was also longer in children followed by adults and adolescents in all long vowels. The means with 1 SD bars of vowel duration across the age groups are depicted in Figure 4.1.2. The means, SD, and 95% confidence interval for mean for all the three age groups are given in Appendix VIII a (Table 4.1.4).

It was also observed that gender wise, females had longer mean vowel duration for all short and long vowels as compared to males. The high mid vowel /e/ had the longest vowel duration while high front vowel /i/, the shortest vowel duration in both females and males. The low mid long vowel /a:/ had longer while high front long vowel /i:/, the shortest duration in both genders. The means with 1 SD bars of vowel duration across gender groups are given in Figure 4.1.3. The means, standard deviation and 95% confidence interval for mean of short and long vowels for both genders are given in Appendix VIII a (Table 4.1.5).

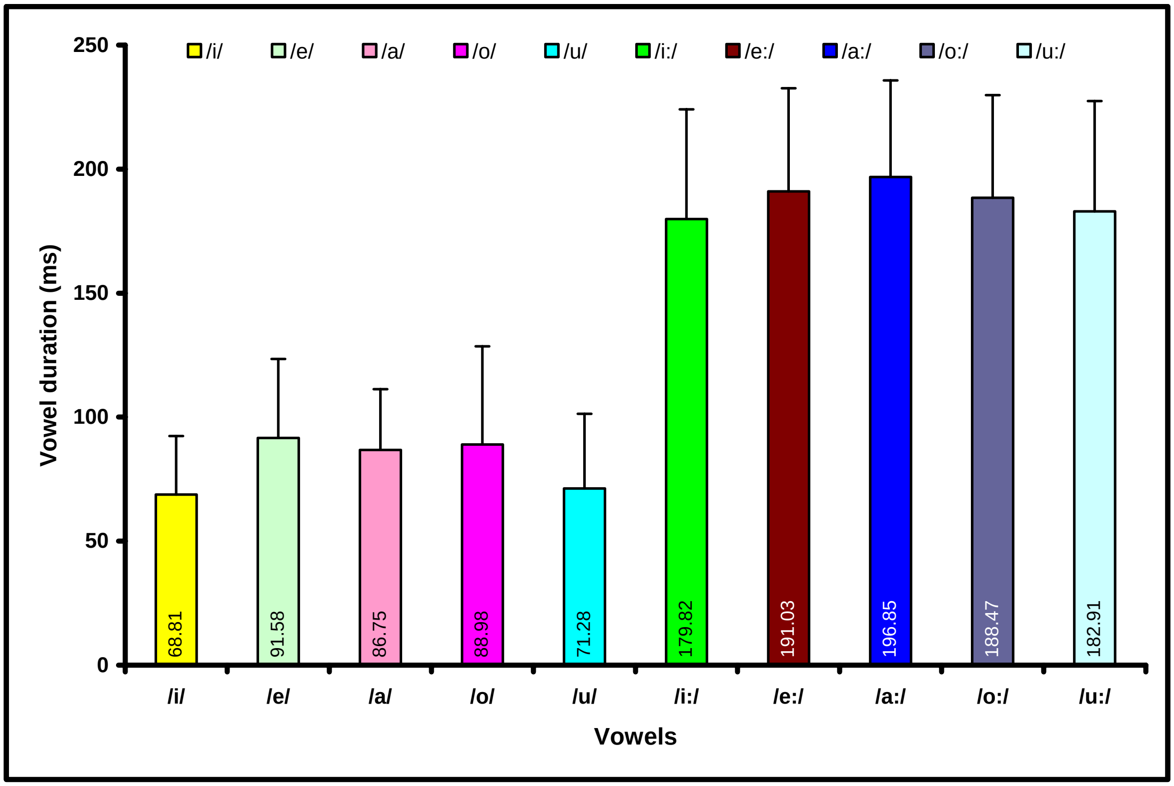


Figure 4.1.1: Mean vowel duration (ms) and 1 SD bars of all vowels

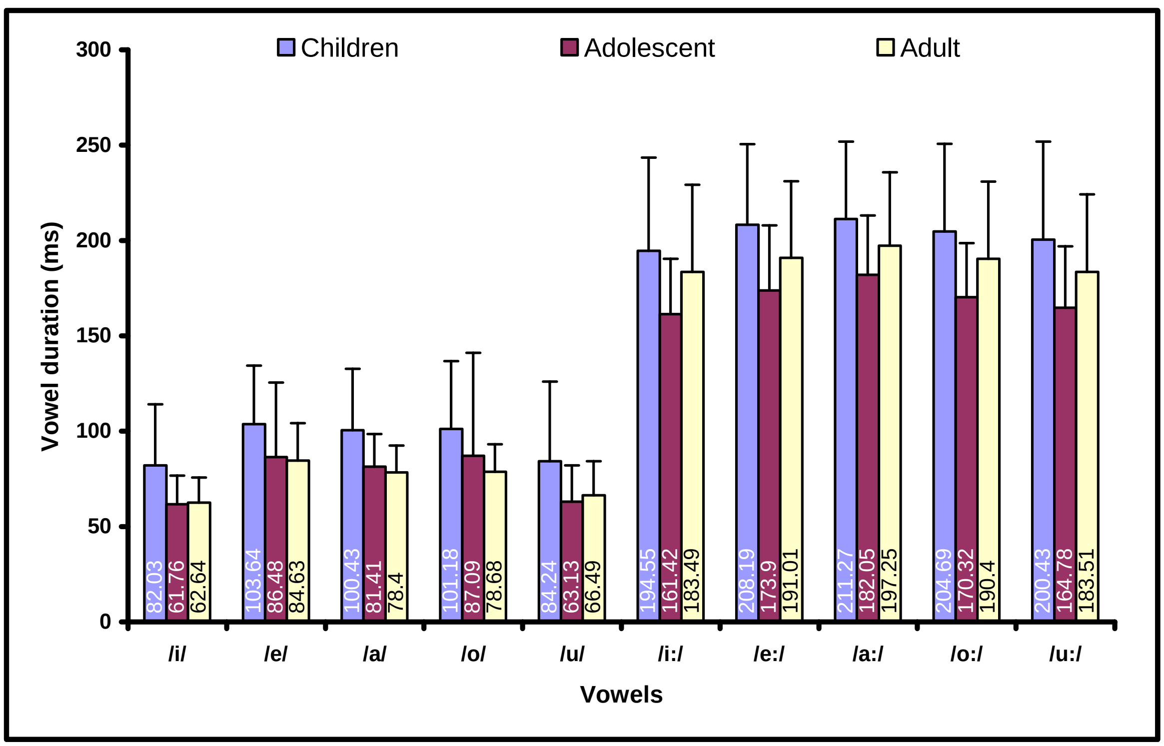


Figure 4.1.2: Mean vowel duration (ms) and 1 SD bars across age groups

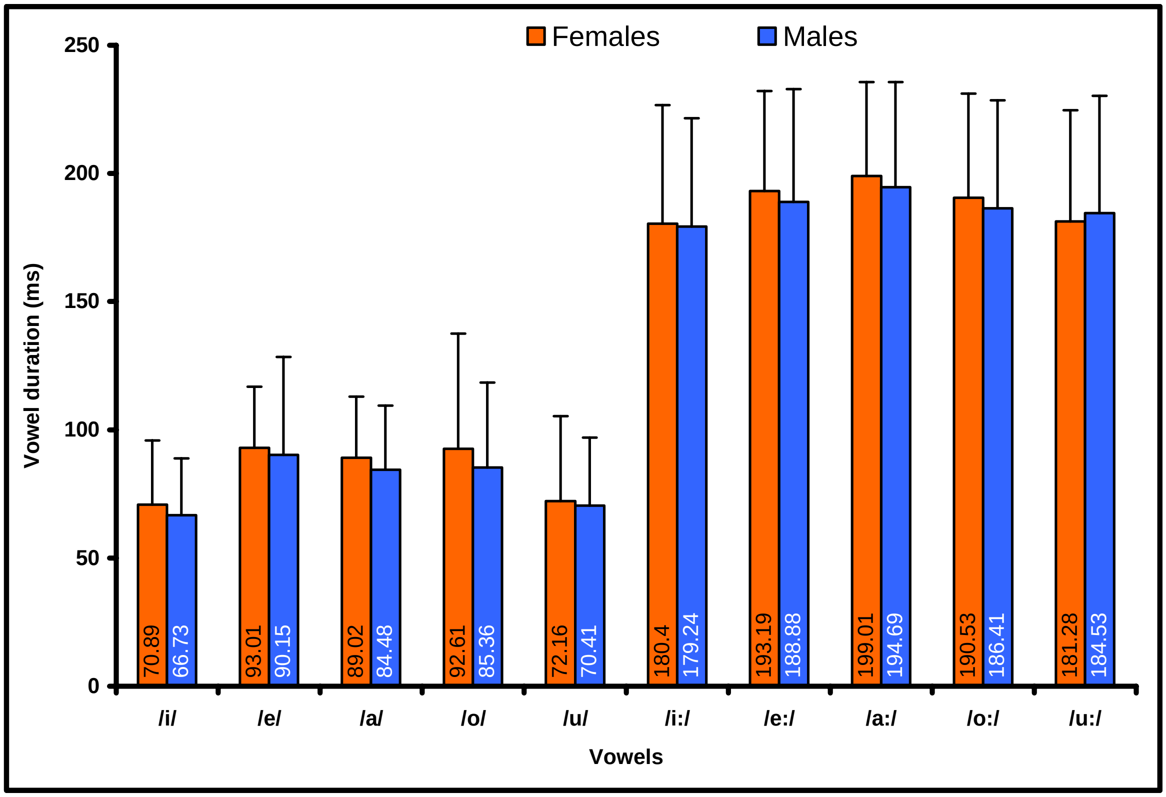


Figure 4.1.3: Mean vowel duration (ms) and 1 SD bars across gender groups

Region wise, speakers from Rayalaseema region had longer mean vowel duration for all short and long vowels followed by Telengana and Coastal speakers. Among short vowels, front mid vowel /e/ had the longest mean vowel duration for Coastal, Rayalaseema and Telengana speakers. Short front high vowel /i/ had the shortest mean vowel duration for Coastal, Rayalaseema and Telengana speakers. Among long vowels, low mid vowel /a:/ had the longest mean vowel duration in Coastal, Rayalaseema and Telengana speakers respectively. Long vowel /i:/ had the shortest vowel duration for Coastal, Rayalaseema and Telengana speakers respectively. The means with 1 SD bars of vowels duration across region groups are given in Figure 4.1.4. The means, standard deviation and 95% confidence interval for the mean values of vowel duration for Coastal, Rayalaseema and Telengana are given in Appendix VIII a (Table 4.1.6).

Preceding consonant context wise, front short vowel /e/ had longer mean vowel duration when preceded by stop consonants while back high short vowel /u/ had shorter mean vowel duration. Mid long vowel /a:/ had longer mean vowel duration followed by

/e:/, /o:/, /u:/ and /i:/. Front vowel /e/ had longer mean vowel duration than back vowel /u/ when preceded by affricate consonants. Back vowel /o/ had longer mean vowel duration followed by /e/, /a/ and /i/ when preceded by nasal consonants. Front high vowel /e/ had longer mean vowel duration followed by /a/ and /u/ when preceded by fricative consonants. Front vowel /e/ had longer mean vowel duration compared to mid vowel /a/ when preceded by lateral consonants. Front vowel /e/ had longer mean vowel duration compared to back vowel /u/ when preceded by trill consonants. The mean values with 1 SD bars of vowel duration across different manner of articulation of the preceding consonant context for short and long vowels are given in Figures 4.1.5a & 4.1.5b respectively and the values are given in Appendix VIII a (Table 4.1.7).

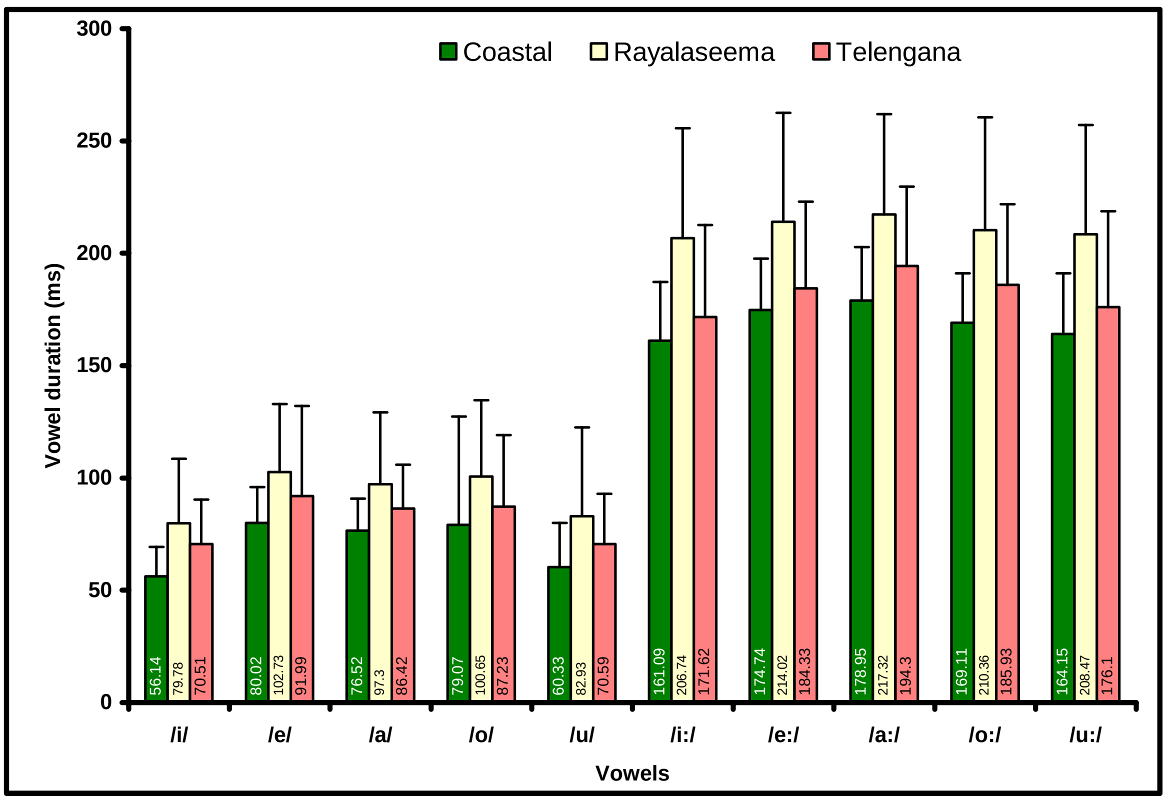


Figure 4.1.4: Mean vowel duration (ms) and 1 SD bars across region groups

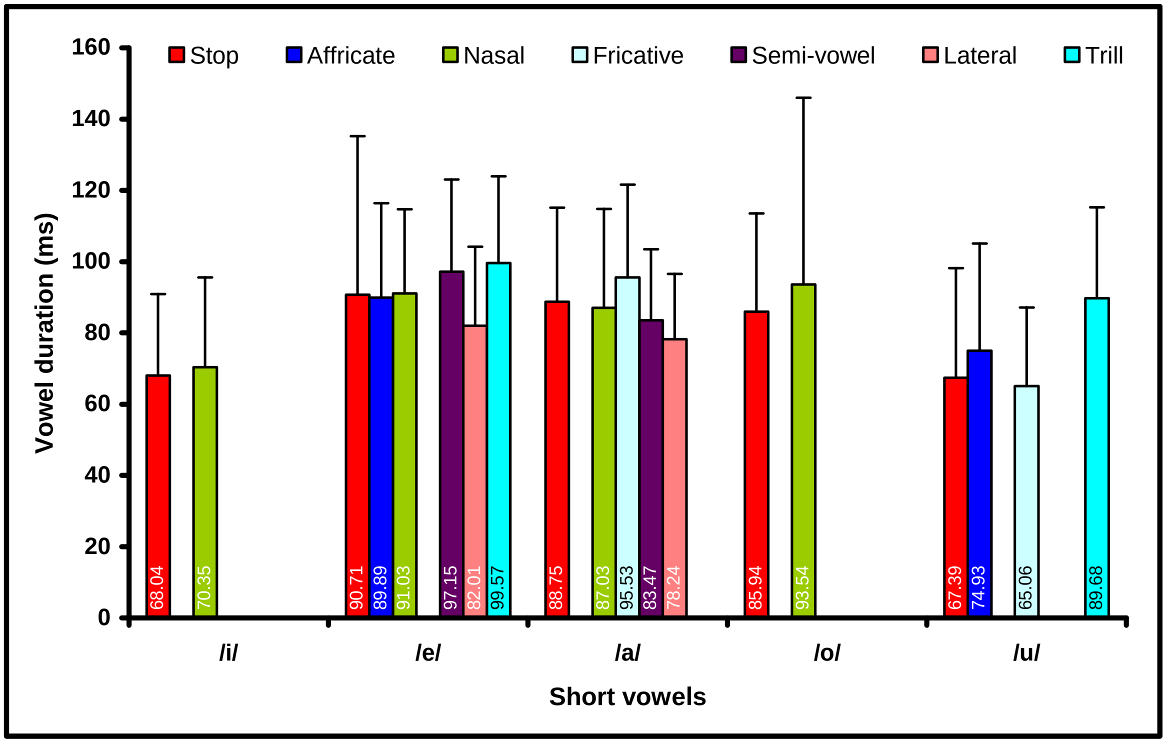


Figure 4.1.5a: Mean vowel duration (ms) and 1 SD bars of short vowels across manner of articulation of the preceding consonant

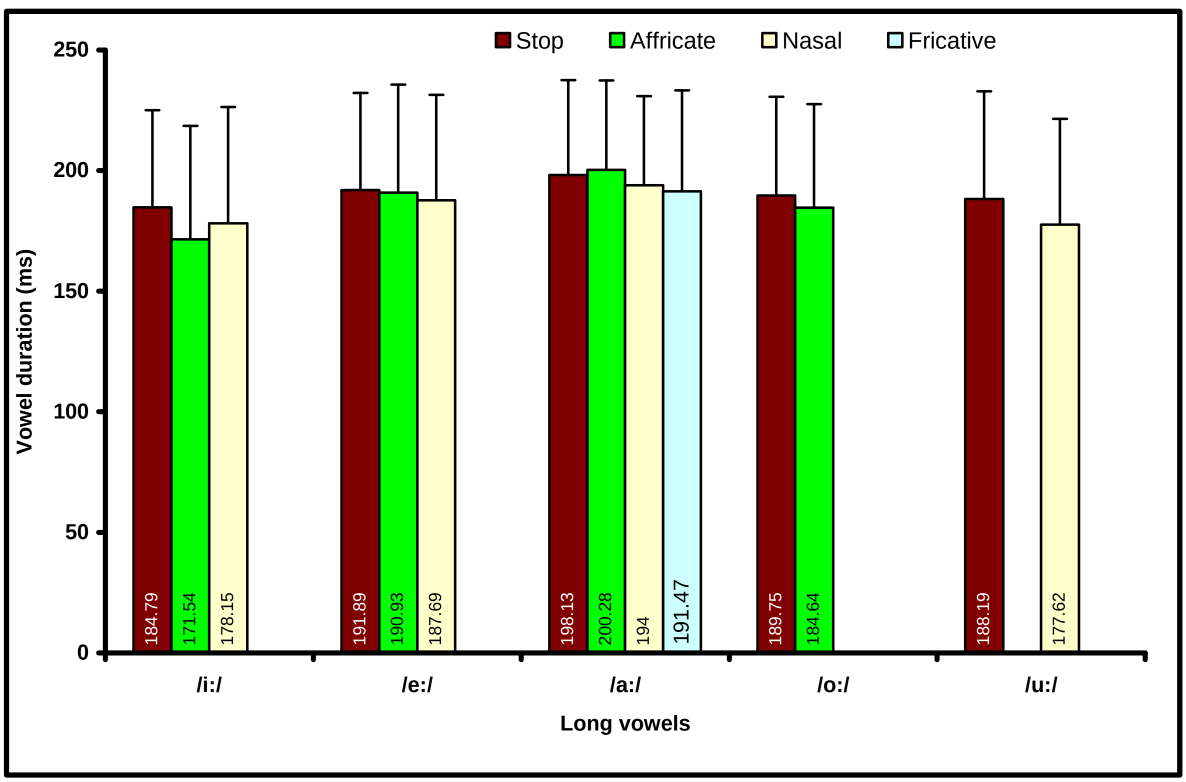


Figure 4.1.5b: Mean vowel duration (ms) and 1 SD bars of long vowels across manner of articulation of the preceding consonant

It was evident from the data that, place of articulation of the preceding consonant had an effect on the vowel duration. Front high short vowel /i/ had longer mean vowel duration when preceded by dental consonants followed by alveopalatal and bilabial consonants; however, long vowel /i:/ had longer mean vowel duration when preceded by velar consonants followed by alveopalatal and bilabial consonants. Front mid vowel /e/ had longer mean vowel duration when preceded by retroflex consonants followed by alveopalatal and bilabial consonants while its counterpart long vowel /e:/ had longer mean vowel duration when preceded by velar consonants followed by alveopalatal, dental and bilabial consonants. Mid low vowel /a/ had longer mean vowel duration when preceded by velar consonants followed by alveopalatal and bilabial consonants but long vowel /a:/ had longer mean vowel duration when preceded by dental consonants followed by velar, bilabial and alveopalatal. Back mid vowel /o/ had longer mean vowel duration when preceded by alveopalatal consonants followed by bilabial and dental consonants but its counterpart long vowel /e:/ had longer mean vowel duration when preceded by retroflex consonants followed by dental, bilabial and alveopalatal consonants. Back high vowel /u/ had longer mean vowel duration when preceded by alveopalatal consonants followed by dental, bilabial and velar consonants and long vowel /u:/ had longer mean vowel duration when preceded by dental followed by bilabial and alveopalatal consonants. The mean values with 1 SD bars of vowel duration across different place of articulation of the preceding consonants for short and long vowels are graphically represented in Figures 4.1.6a & 4.1.6b respectively and the values are given in Appendix VIII a (Table 4.1.8).

It was observed that all vowels followed by voiced consonants had longer mean vowel duration compared to voiceless consonants except for back high long vowel /u:/. The mean values with 1 SD bars of vowel duration across voicing feature of the preceding consonant are graphically represented in Figure 4.1.7 and the values are given in Appendix VIII a (Table 4.1.9).

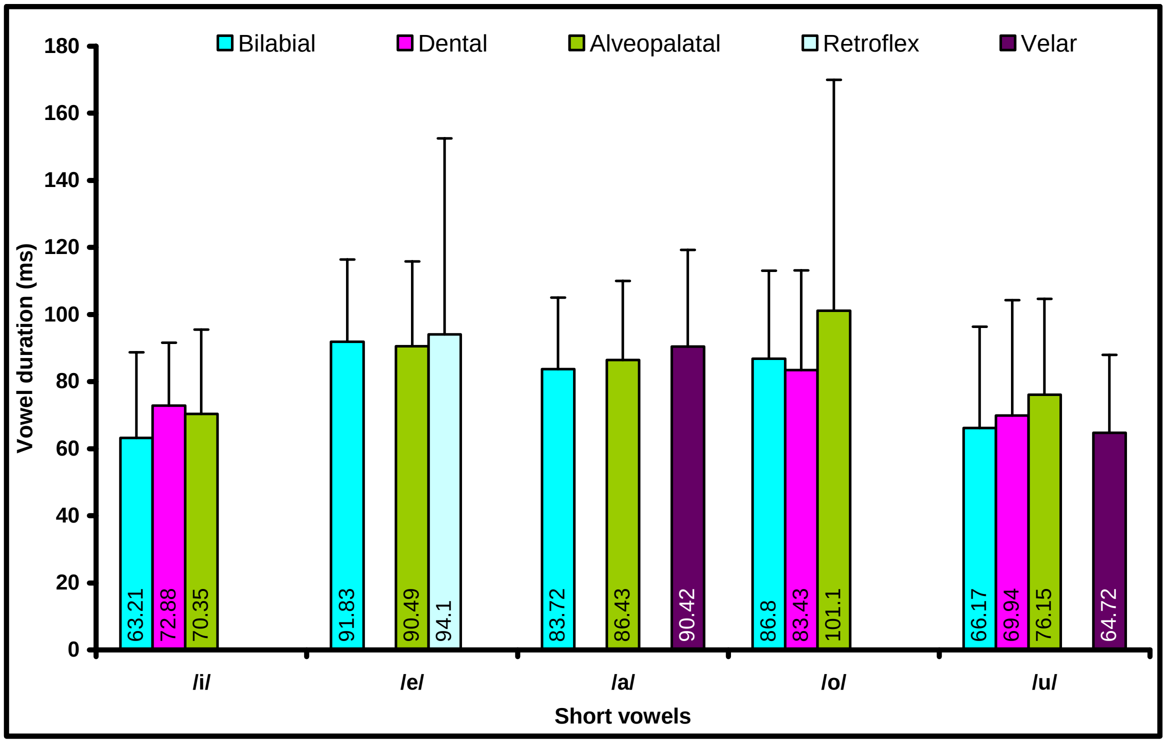


Figure 4.1.6a: Mean vowel duration (ms) and 1 SD bars of short vowels across place of articulation of the preceding consonant

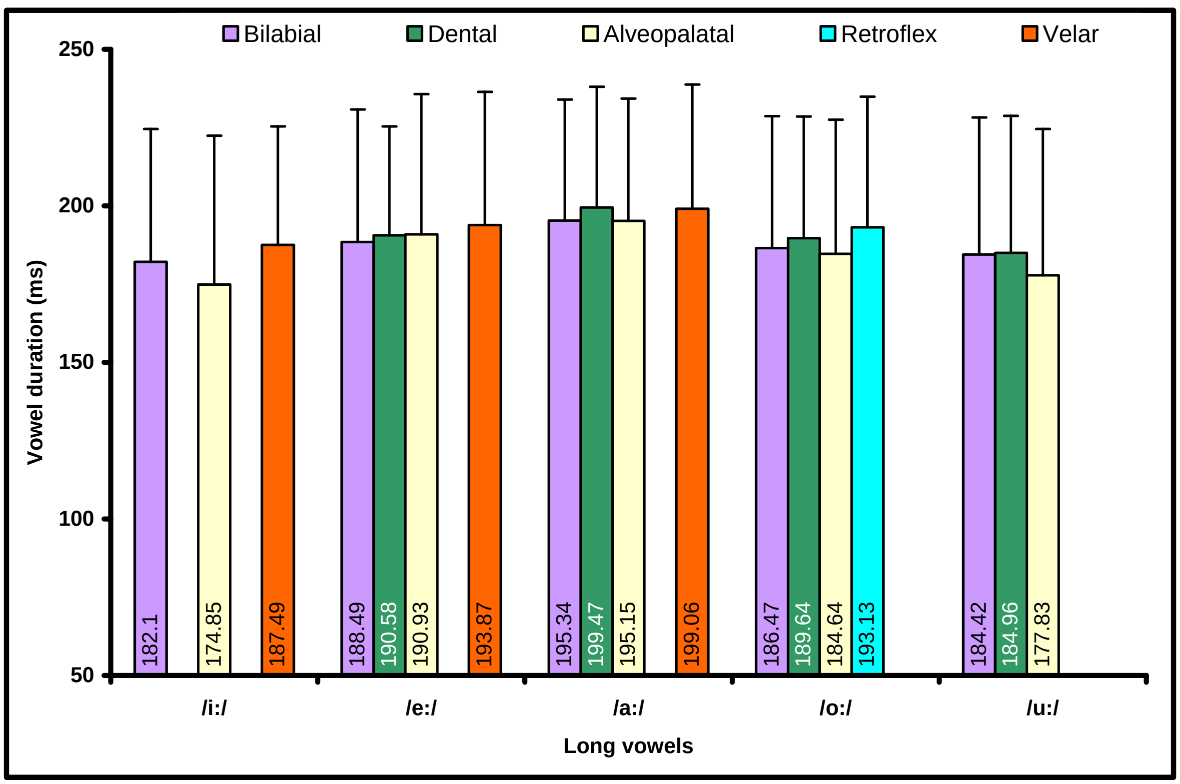


Figure 4.1.6b: Mean vowel duration (ms) and 1 SD bars of long vowels across place of articulation of the preceding consonant

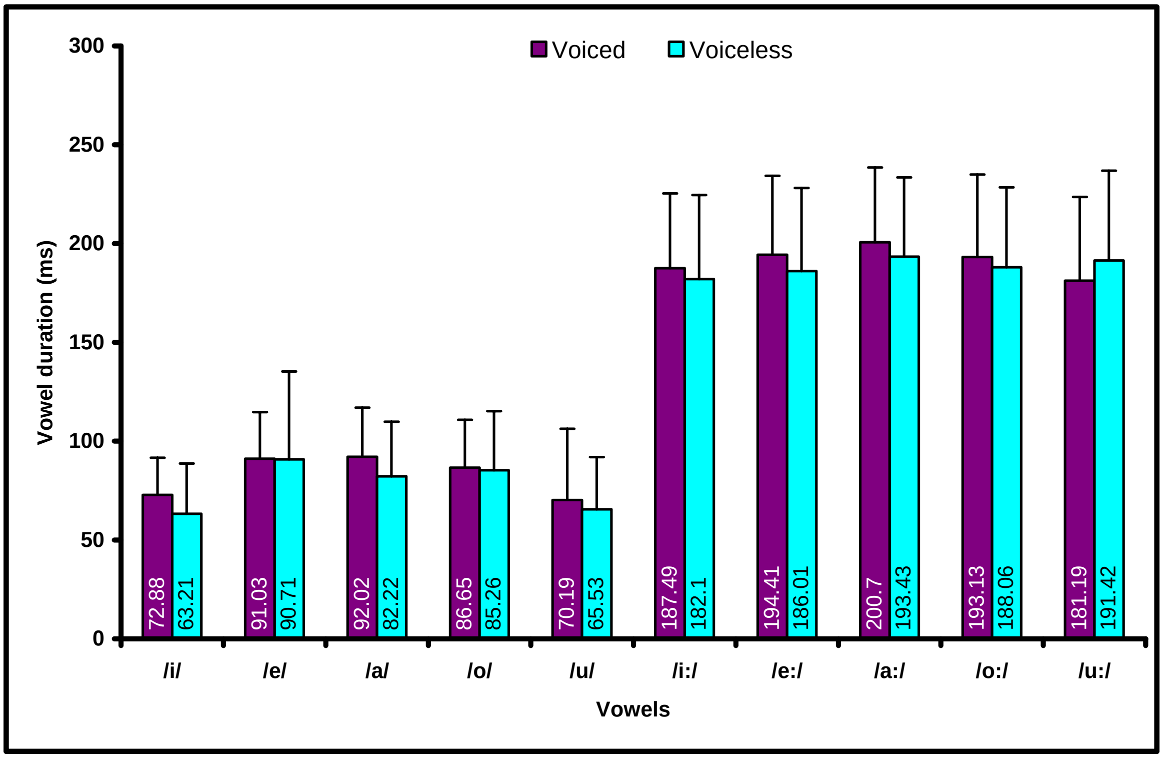


Figure 4.1.7: Mean vowel duration (ms) and 1 SD bars of vowels across voicing feature of the preceding consonant

Following questions were addressed to further understand the variations in the mean vowel duration as observed in the analysis. (1) Do age, gender and region have any association with vowel duration and if so, what kind of an association? (2) Which of the vowels studied have significant difference in vowel duration among the age, gender and region groups? In order to answer these questions, random intercept model 3 was used (as described in the method) to determine if there was any association between vowel duration and age, gender and region groups. The results are given in Table 4.1.a.

From Table 4.1.a it is observed that, there is a significant association of vowel duration with age, gender and region with, age and gender having negative association.

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was done and the results suggested that vowel duration of all short vowels (/i/, /e/, /a/, /o/ and /u/) did not show statistically significant difference between adolescents and adults and for /i:/ between children and adults (Table 4.1.b). Within the region groups, vowel duration of vowels /o/, /i:/, /e:/ and /u:/ did not show statistically significant difference between Coastal speakers and Telengana speakers (Table 4.1.c). Student's *t*-test was done to determine as to which of the vowels significantly differed with the gender groups and the results are depicted in Table 4.1.d.

Table 4.1.a: Statistical analysis using random intercept model for VD

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	137.08	9.58	14.31	< 0.01
Age (β_{1ijk})	-0.82	0.08	-10.25	< 0.01
Gender (β_{2ijk})	-2.57	1.07	-2.40	0.01
Region (β_{3ijk})	5.69	0.65	8.75	< 0.01
Variance components				
Random Error:	1207.54			
Consonant Level:	42.28			
Individual level:	2970.79			
Total variation:	4220.6			
*-2*loglikelihood(IGLS) = 43190.59*				

**significant at 0.05 level*

Model: Vowel Duration = 137.08 – 0.82age – 2.57gender + 5.69region.

Table 4.1.b: Post hoc results for each vowel between age groups for VD

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	20.26(*)	< 0.01
	Children	Adult	19.39(*)	< 0.01
	Adolescent	Adult	-.88	0.968
/e/	Children	Adolescent	17.16(*)	< 0.01
	Children	Adult	19.01(*)	< 0.01
	Adolescent	Adult	1.85	0.847
/a/	Children	Adolescent	19.02(*)	< 0.01
	Children	Adult	22.03(*)	< 0.01
	Adolescent	Adult	3.01	0.392
/o/	Children	Adolescent	14.08(*)	0.014
	Children	Adult	22.49(*)	< 0.01
	Adolescent	Adult	8.41	0.211
/u/	Children	Adolescent	21.11(*)	< 0.01
	Children	Adult	17.75(*)	< 0.01
	Adolescent	Adult	-3.36	0.443
/i:/	Children	Adolescent	33.14(*)	< 0.01
	Children	Adult	11.06	0.166
	Adolescent	Adult	-22.07(*)	0.001
/e:/	Children	Adolescent	34.28(*)	< 0.01
	Children	Adult	17.18(*)	0.001
	Adolescent	Adult	-17.10(*)	0.001
/a:/	Children	Adolescent	29.22(*)	< 0.01
	Children	Adult	14.02(*)	< 0.01
	Adolescent	Adult	-15.20(*)	< 0.01
/o:/	Children	Adolescent	34.36(*)	< 0.01
	Children	Adult	14.29(*)	0.031
	Adolescent	Adult	-20.07(*)	0.001
/u:/	Children	Adolescent	35.65(*)	< 0.01
	Children	Adult	16.92(*)	0.016
	Adolescent	Adult	-18.73(*)	0.006

*significant at 0.05 level

Table 4.1.c: Post hoc results for each vowel between region groups for VD

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig
/i/	Coastal	Rayalaseema	-23.64(*)	< 0.01
	Coastal	Telengana	-14.38(*)	< 0.01
	Rayalaseema	Telengana	9.26(*)	0.029
/e/	Coastal	Rayalaseema	-22.71(*)	< 0.01
	Coastal	Telengana	-11.96(*)	0.001
	Rayalaseema	Telengana	10.74(*)	0.004
/a/	Coastal	Rayalaseema	-20.78(*)	< 0.01
	Coastal	Telengana	-9.90(*)	< 0.01
	Rayalaseema	Telengana	10.88(*)	< 0.01
/o/	Coastal	Rayalaseema	-21.58(*)	< 0.01
	Coastal	Telengana	-8.17	0.232
	Rayalaseema	Telengana	13.42(*)	0.021
/u/	Coastal	Rayalaseema	-22.60(*)	< 0.01
	Coastal	Telengana	-10.25(*)	0.001
	Rayalaseema	Telengana	12.34(*)	< 0.01
/i:/	Coastal	Rayalaseema	-45.65(*)	< 0.01
	Coastal	Telengana	-10.53	0.161
	Rayalaseema	Telengana	35.11(*)	< 0.01
/e:/	Coastal	Rayalaseema	-39.28(*)	< 0.01
	Coastal	Telengana	-9.59	0.084
	Rayalaseema	Telengana	29.69(*)	< 0.01
/a:/	Coastal	Rayalaseema	-38.38(*)	< 0.01
	Coastal	Telengana	-15.35(*)	< 0.01
	Rayalaseema	Telengana	23.03(*)	< 0.01
/o:/	Coastal	Rayalaseema	-41.25(*)	< 0.01
	Coastal	Telengana	-16.81(*)	0.006
	Rayalaseema	Telengana	24.44(*)	< 0.01
/u:/	Coastal	Rayalaseema	-44.32(*)	< 0.01
	Coastal	Telengana	-11.96	0.103
	Rayalaseema	Telengana	32.36(*)	< 0.01

*significant at 0.05 level

Table 4.1.d: Student's *t*-test results for all vowels between two gender groups for VD

N=4320

Vowel	Mean Difference	df	t
/i/	4.16	214	1.297
/e/	2.86	420	1.007
/a/	4.55	574	2.229*
/o/	7.24	358	1.741
/u/	1.75	646	0.739
/i:/	1.15	286	0.221
/e:/	4.31	430	1.077
/a:/	4.32	709	1.489
/o:/	4.12	286	0.844
/u:/	-3.24	286	-0.618

*significant at 0.05 level

From Table 4.1.d, it's observed that, only vowel /a/ had statistically significant difference in vowel duration between females and males.

From the results, it is inferred that there is a significant association between age, gender and region with respect to vowel duration. As age increased, there was a significant decrease in vowel duration. It may also be noted that, individual analysis of the vowels among the genders was not significant; however, it was significant when the influence of other level (consonant and individuals) variations were considered. From the analysis it is inferred that, vowel duration is influenced more by the individual variations as compared to preceding consonants.

The finding of reduced vowel duration for vowel /i/ in this study is similar to the findings of Nagamma Reddy (1998) and Prabhavathi Devi (1990) in Telugu and Sreedevi (2000), Venkatesh (1995) in Kannada. Similar findings have also been reported in English by Lisker (1974). The findings of the present study further support the report of Maddieson (1993) that vowel duration depends on the height of the tongue.

Central vowels having longer vowel duration followed by front and back vowels have been reported in most of the languages *viz.,* English (Clopper, Pisoni & de Jong, 2005; Hunyady, 2006), Hebrew (Most, Amir & Tobin, 2000), Greek (Daver, 1980), Telugu (Girija & Sridevi, 1995; Prabhavathi, 1990; Sreenivasa Rao, Suryakanth, Gangashetty & Yegnanarayana, 2001), and other Indian languages (Riyamol, 2007; Savithri, 1984; Venkatesh, 1995). Based on the aforesaid studies, it may be appropriate to conclude that vowel duration due to place of constriction is an universal phenomenon irrespective of language. This could probably be attributed to the anatomical and physiological aspects of the articulators involved in the production of these vowels.

Small and long vowel ratio observed in the current study have been reported earlier on children (Prabhavathi Devi, 1990) and adults (Girija & Sridevi, 1995; Nagamma Reddy, 1998). Minimal changes in the observed values of the current study could be due to the probable variables of the influence of preceding and following consonant and the sample studied by earlier authors. The increase in the ratio corresponding to age could be due to clear distinctions made by adults in the production of short and long vowels as compared to adolescents and children.

It can thus be concluded from the current study that, as the age increases, vowel duration reduces. The reduction in vowel duration as the age progresses is reported in English (Eguchi & Hirish, 1969; Kent & Burkhard, 1981; Kent & Forner, 1979; Krause, 1982; Smith, 1978), Hebrew (Most et.al., 2000) and in all Indian languages studied (Rashmi, 1985; Samuel, 1973; Sreedevi, 2000; Usha, 1978) excepting in Malayalam (Ampathu, 1998). Such a reduction in vowel duration could be attributed to neuromuscular changes that occur over the age (Eguchi & Hirish, 1969; Kent & Burkhard, 1981) and as an index of deterioration of vowel precision in various adult speakers (Strom, Thomson, Boutsen & Pentz, 2005).

The results of the present study also indicate that gender has an effect on the vowel duration in Telugu vowels. Studies in Australian English, American English, Indian languages (Kannada, Malayalam and Sanskrit) also report significant differences between females and males with females having longer duration (Cox, 2004; Hillenbrand, Getty, Clark & Wheeler, 1995). Among the Indian studies, the study of only Venkatesh (1995) in Kannada reported no gender variations for short vowels whereas all other studies reported of females having significantly longer vowel duration than males (Rashmi, 1985; Riyamol, 2007; Sashidharan, 1995; Savithri, 1989; Sreedevi, 2000). Similar are the findings in the current study.

Regional variations or dialectal variations in vowel duration as observed in the present study for Telugu have also been reported for American English (Clopper, Pisoni & de Jong, 2005; Gendrot & Adda-Decker, 2007).

Changes in vowel duration with different preceding consonants have been observed and reported in English and other languages (Duggirala, 2005; Krause, 1982; Nagamma Reddy, 1999; Peterson & Lehiste, 1960; Sreenivasa Rao, Suryakanth, Gangashetty, & Yegnanarayana, 2001; Crystal & House, 1982). Vowels when preceded by stop consonants had the longest vowel duration followed by nasal and fricative consonants and have been reported in English and Malayalam (House, 1961; House & Fairbanks, 1953; Riyamol, 2007). Increase in vowel duration when preceded by bilabial consonants compared to velar sounds has been observed in English, Sanskrit (House & Fairbanks, 1953; Savithri, 1984). Vowels when followed by voiced consonants having longer vowel duration compared to voiceless consonants, as observed in the current study, have been reported in English and Telugu (Smith, 1978; Halle & Stevens, 1967; Girija & Sridevi, 1995).

4.1.2 Summary of VD

From the current study, it can be concluded that, in Telugu:

- Vowels /e/ and /a:/ have longest vowel duration.
- Short and long vowels /i/ have shortest vowel duration.
- Children have longer vowel duration as compared to adolescents or adults.
- Females have longer vowel duration than males.
- Regional influences are seen on vowel duration. Rayalaseema speakers have longer vowel duration as compared to Coastal or Telengana speakers.
- Central vowels when preceded by stop consonants have longest vowel duration followed by nasal and fricative consonants.

- Back vowels when preceded by nasal consonants have longest vowel duration followed by stop and fricative consonants.
- Central and Back vowels have longer vowel duration when preceded by dental followed by bilabial and velar consonants.
- The short and long vowel ratios observed in children are approximately 1:2, while it is 1:2.2 in adolescents and 1:2.4 in adults.
- Central vowels have longer vowel duration followed by front and back vowels.

4.2 Spectral characteristics of Telugu vowels

4.2.1.1 Fundamental Frequency (F0)

In the current study, short vowels had maximum mean fundamental frequency as compared to the long vowels. Maximum mean fundamental frequency was observed for high back vowel /u/ and for front high vowel /i:/. Minimum mean F0 was observed for low mid vowels /a/ and /a:/. Back vowels had higher mean F0 followed by front and central vowels. The means and 1 SD bars of F0 for all vowels are depicted in Figure 4.2.1.1. The means, SD and 95% confidence interval for mean of all the vowels and for central, front and back vowels across the age groups are given in Appendix VIII b (Tables 4.2.1.1 and 4.2.1.2 respectively).

The mean F0 was highest in children followed by adolescents and adults for all vowels. Children and adults had higher mean fundamental frequency for high back vowel /u/. High front vowel /i:/ had higher mean fundamental frequency in children, adolescents and adults. The low mid vowel /a/ and /a:/ had lowest mean fundamental frequency in children, adolescents and adults. The means and 1 SD bars all vowels' F0 across age groups are depicted in Figure 4.2.1.2. The means, SD and 95% confidence interval for mean of all the vowels for three age groups are given in Appendix VIII b (Table 4.2.1.3).

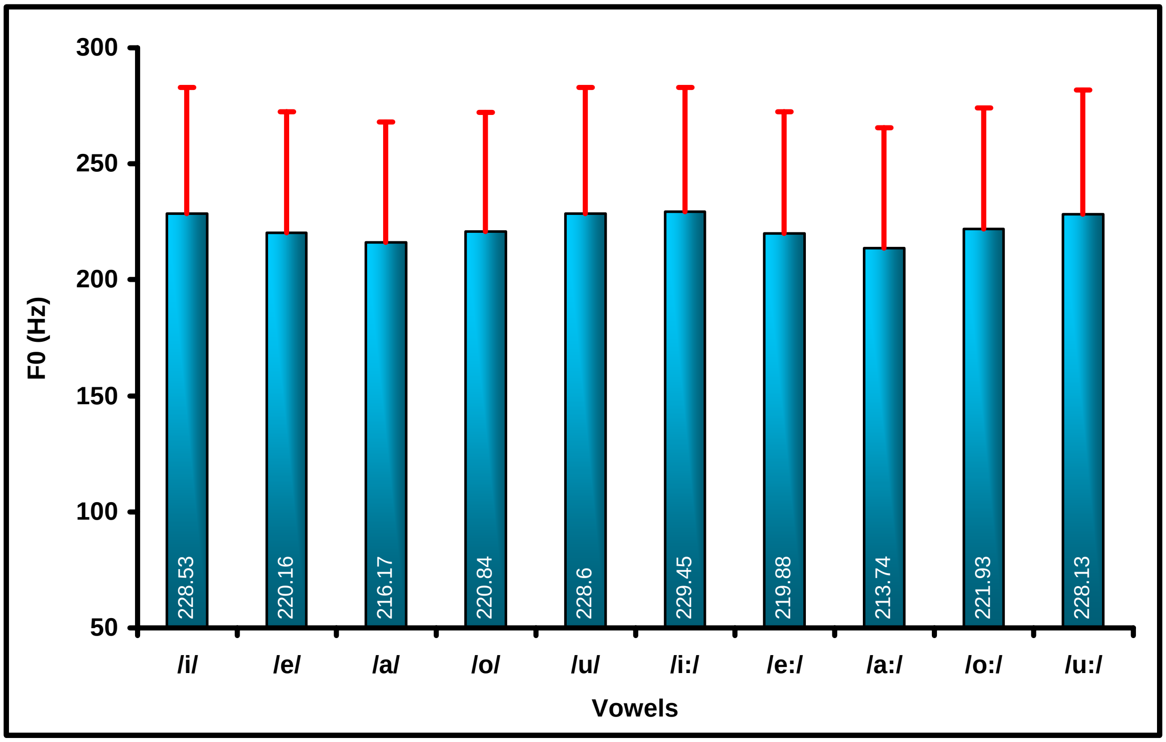


Figure 4.2.1.1: Mean F0 (Hz) and 1 SD bars of all vowels

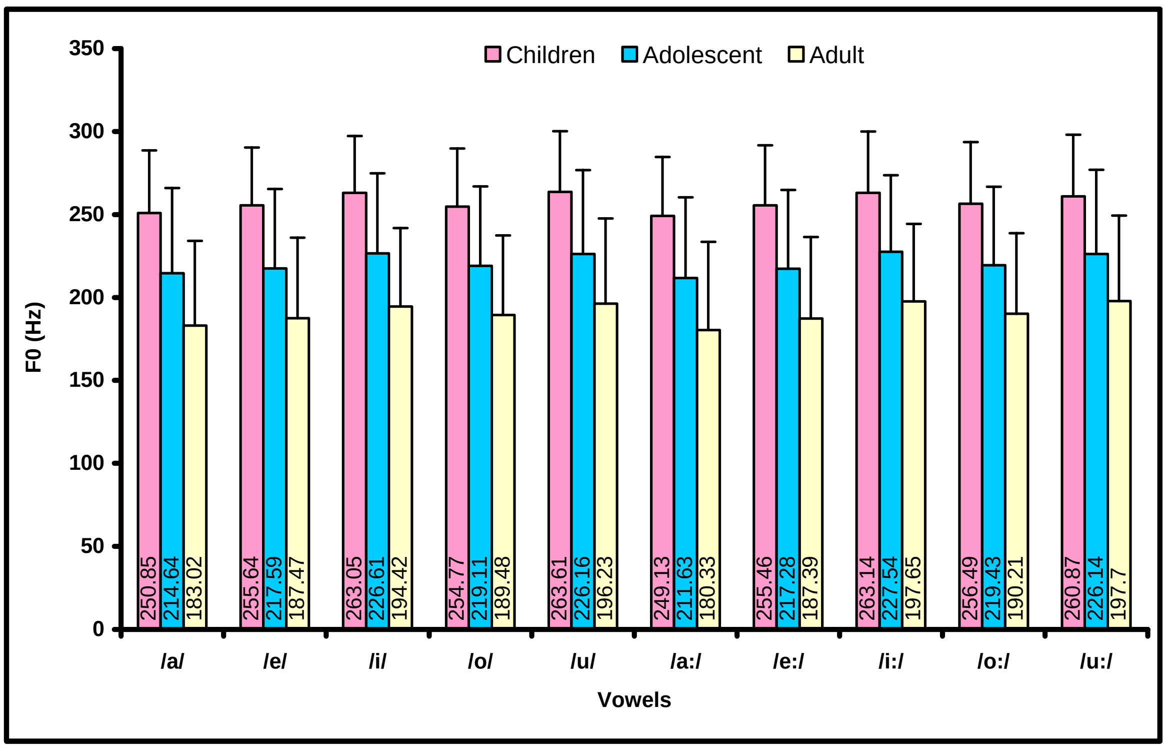


Figure 4.2.1.2: Mean F0 (Hz) and 1 SD bars across age groups

Females had higher mean F0 for all vowels as compared to males. The high back vowel /u/ had the highest mean F0 in females and the high front vowel /i/, the highest in males. High front vowel /i:/ had highest fundamental frequency in both females and males. Low mid vowel /a/ and /a:/ had lowest fundamental frequency in females and males respectively. The means and 1 SD bars of all vowels' F0 across gender groups are depicted in Figure 4.2.1.3. The means, SD and 95% confidence interval for mean of all the vowels across the two gender groups are given in Appendix VIII b (Table 4.2.1.4).

Regionally, Rayalaseema speakers had higher F0 for all short and long vowels followed by Telengana and Coastal speakers. Among the short vowels, /u/ had the highest fundamental frequency in Coastal and Telengana speakers while /i/ in Rayalaseema speakers. Long vowel /i:/ had the highest fundamental frequency in Coastal, Rayalaseema and Telengana. Short and long vowels /a/ and /a:/ had lowest fundamental frequency in Coastal, Rayalaseema and Telengana speakers. The means and 1 SD bars of all vowels' F0 across regional groups are depicted in Figure 4.2.1.4. The means, SD and 95% confidence interval for mean of all the vowels across the three region groups are given in Appendix VIII b (Table 4.2.1.5).

Scrutiny of data on preceding consonant context revealed that front high vowels /i/ and /i:/ had higher mean F0 when preceded by nasal consonants as compared to stop consonants; front mid vowels /e/ and /e:/ had higher mean F0 when preceded by affricates as compared to stop consonants; low mid vowels /a/ and /a:/ had higher F0 when preceded by fricatives and nasals as compared to stop consonants; back mid vowel /o/ had higher F0 when preceded by stop consonant while for /o:/, it was when preceded by affricate consonants; back high vowel /u/ had higher F0 when preceded by fricative consonants while for /u:/, it was when preceded by stop consonants. Generally, vowels following affricates had higher F0 followed by nasal, fricative, stop, trill, lateral and semi vowel consonants. The means and 1 SD bars of all vowels' F0 across different preceding manner of articulation for short and long vowels are depicted in Figures 4.2.1.5a and 4.2.1.5b respectively and the values are given Appendix VIII b (Table 4.2.1.6).

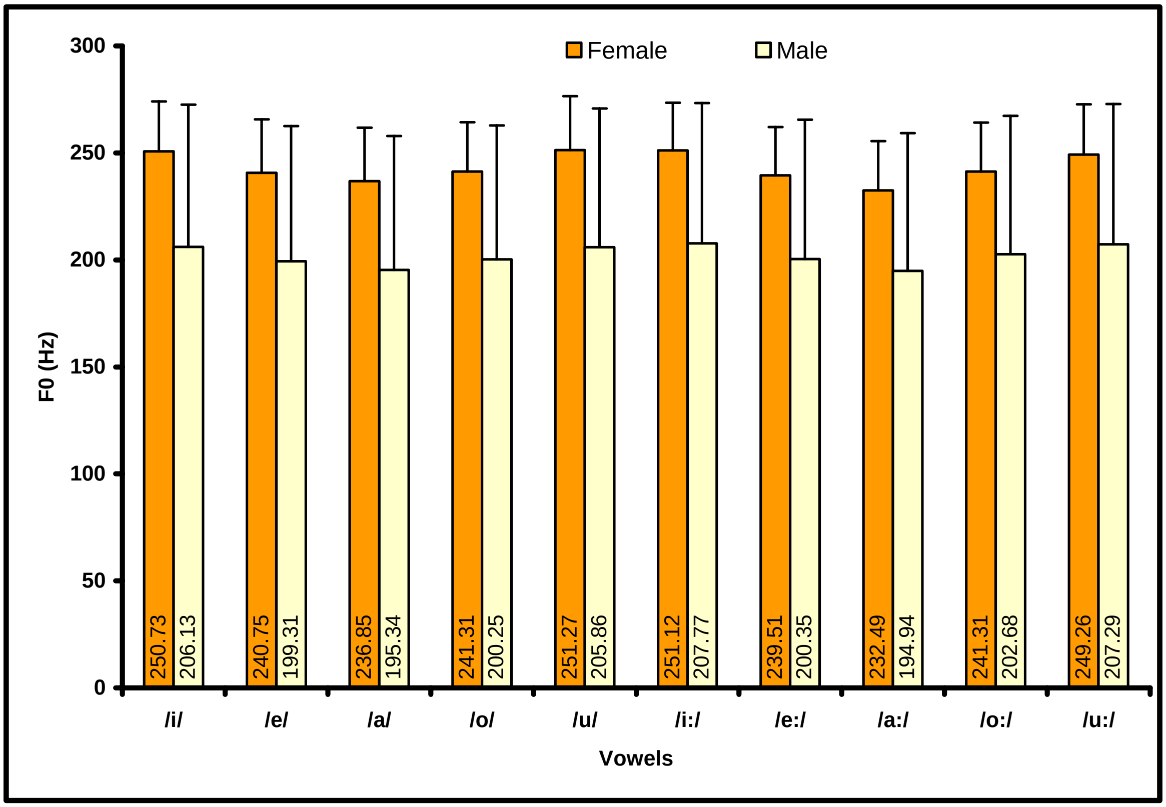


Figure 4.2.1.3: Mean F0 (Hz) and 1 SD bars across gender groups

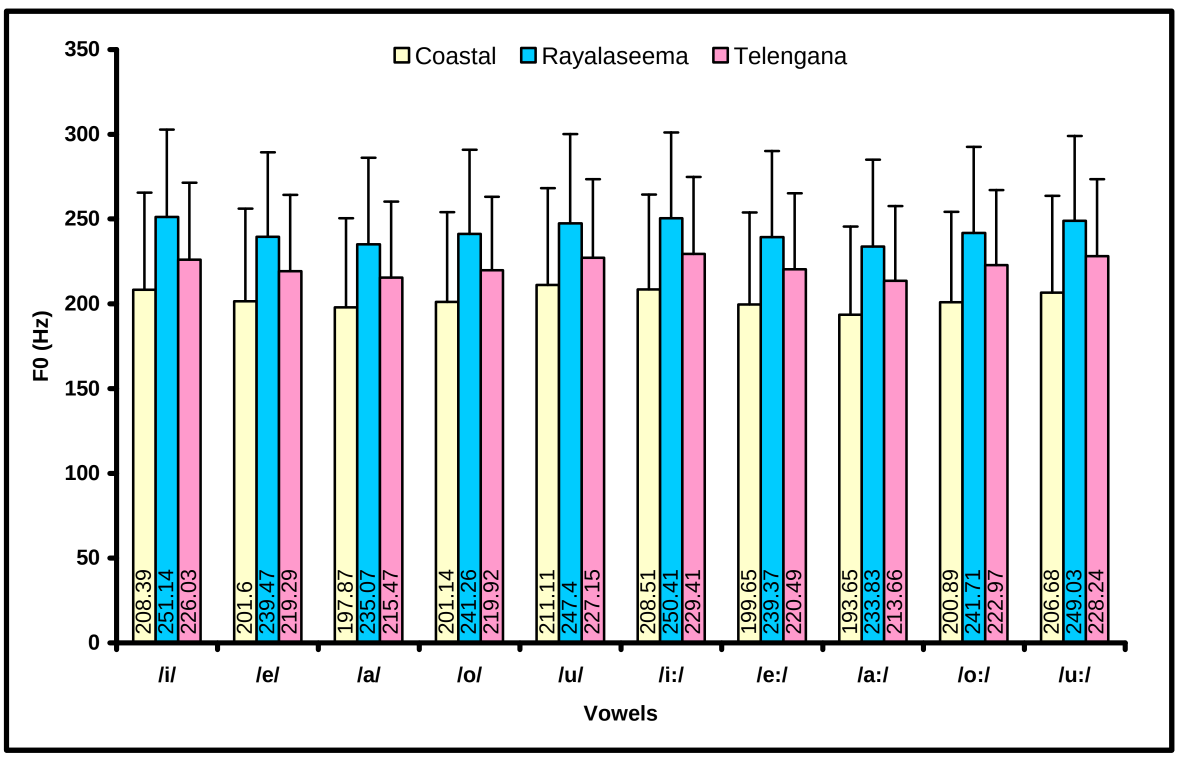


Figure 4.2.1.4: Mean F0 (Hz) and 1 SD bars across region groups

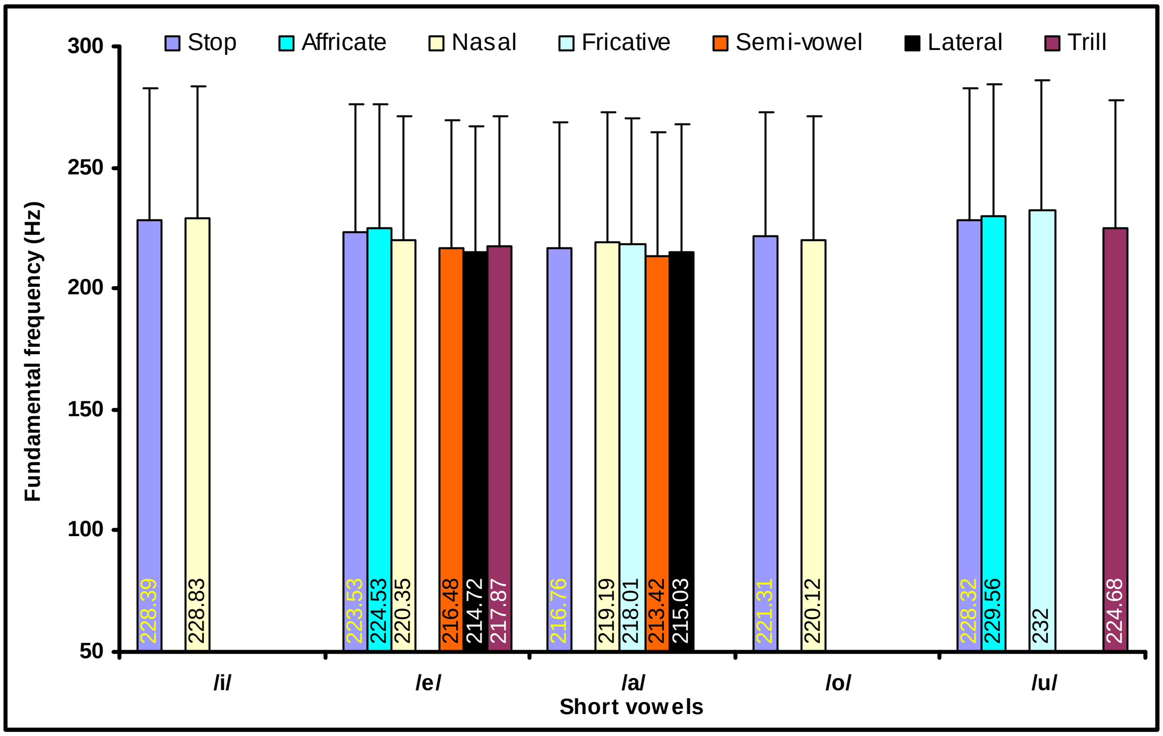


Figure 4.2.1.5a: Mean F0 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

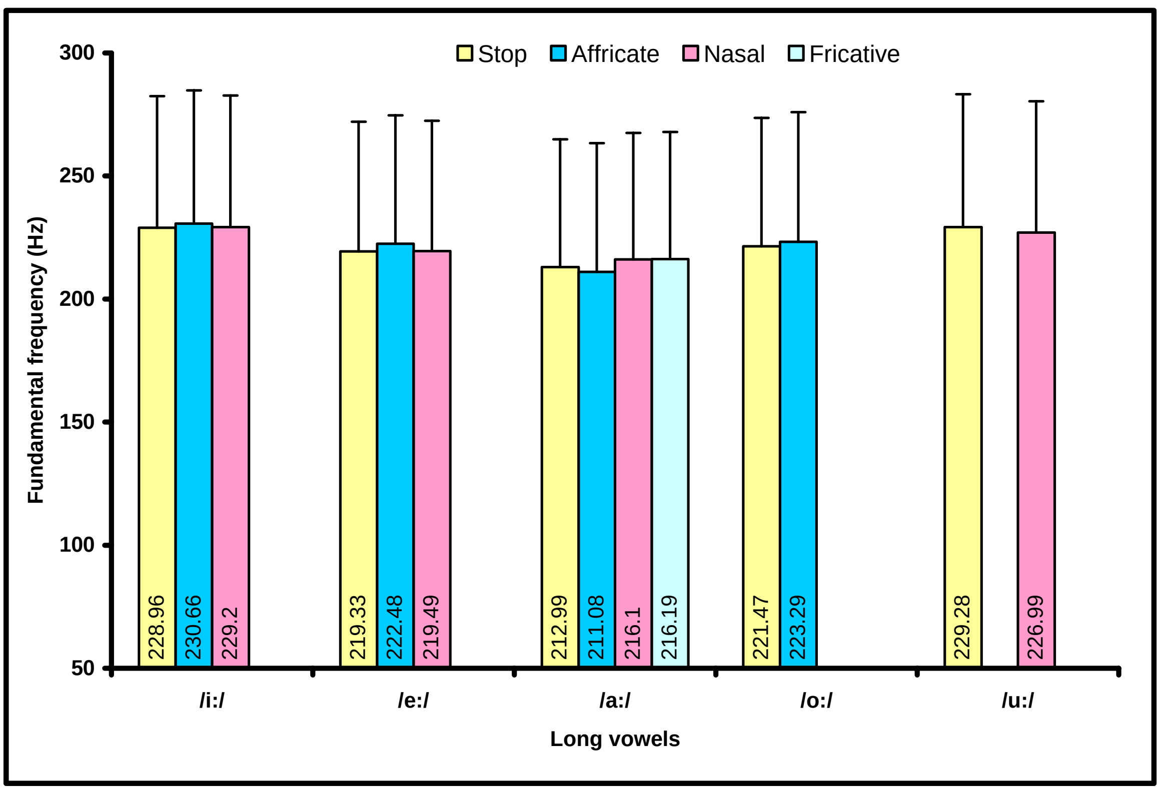


Figure 4.2.1.5b: Mean F0 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

Place of articulation of the preceding consonant also has an effect on F0 in Telugu vowels. Vowels /i/, /i:/, /a:/ and /u:/ had higher mean F0 when preceded by bilabials; /o/ and /u/ when preceded by dentals; /e:/ and /o:/ when preceded by alveopalatals; /a/ when preceded by velars and /e/ when preceded by retroflex. The means and 1 SD bars of all vowels' F0 across different preceding place of articulation consonant for short and long vowels are depicted in Figures 4.2.1.6a and 4.2.1.6b respectively and the values are given in Appendix VIII b (Table 4.2.1.7).

Vowels when preceded by voiced consonants had lower F0 than when followed by voiceless consonants. The means and 1 SD bars of all vowels' F0 across voicing feature of the preceding consonant are depicted in Figure 4.2.1.7 and the values are given in Appendix VIII b (Table 4.2.1.8).

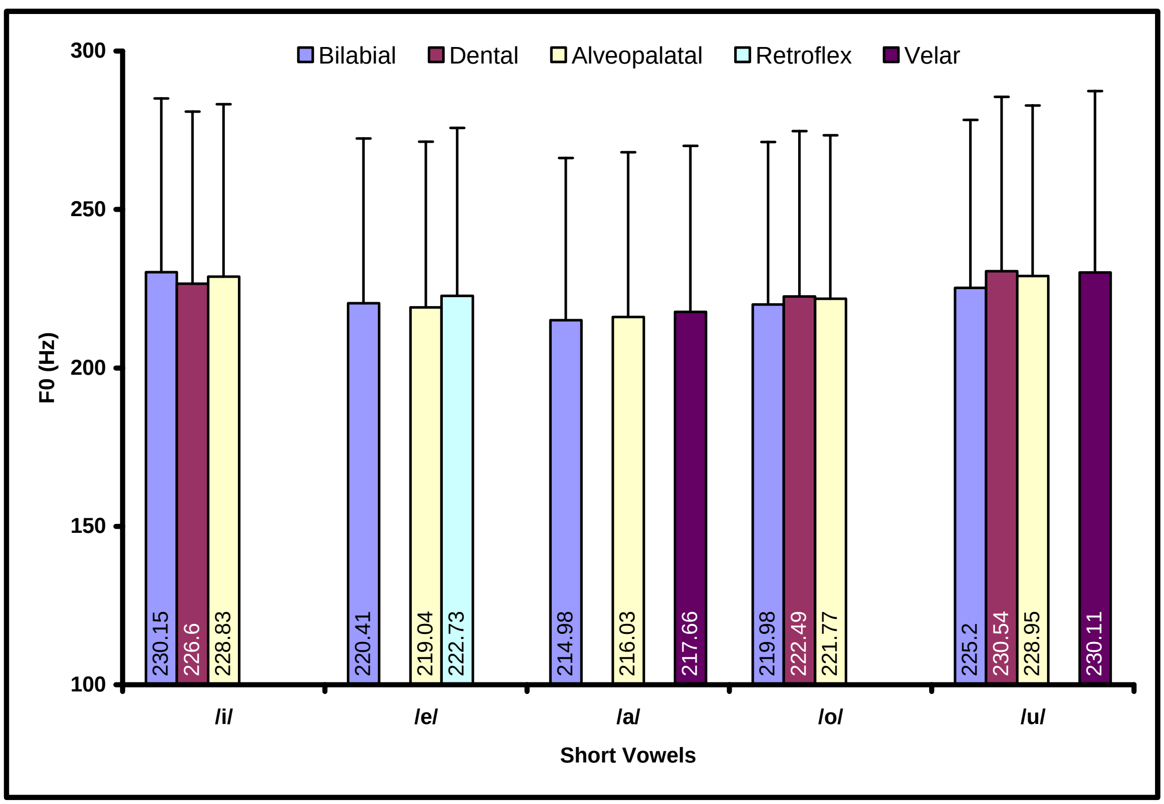


Figure 4.2.1.6a: Mean F0 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

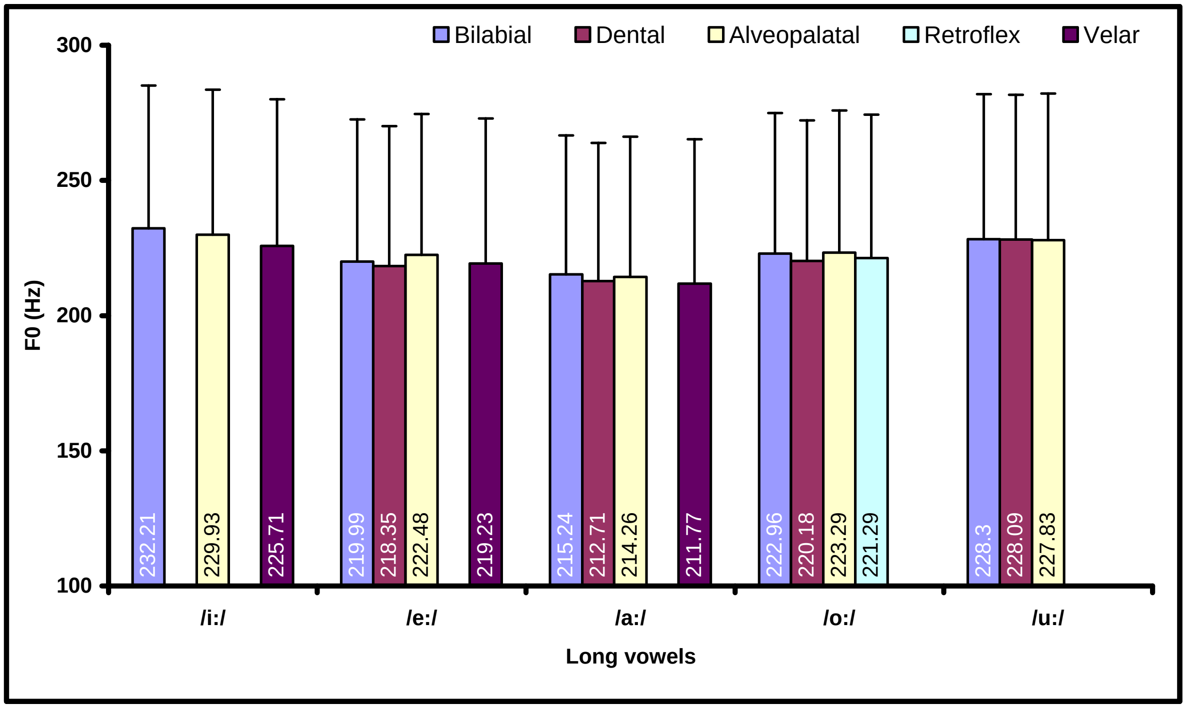


Figure 4.2.1.6b: Mean F0 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

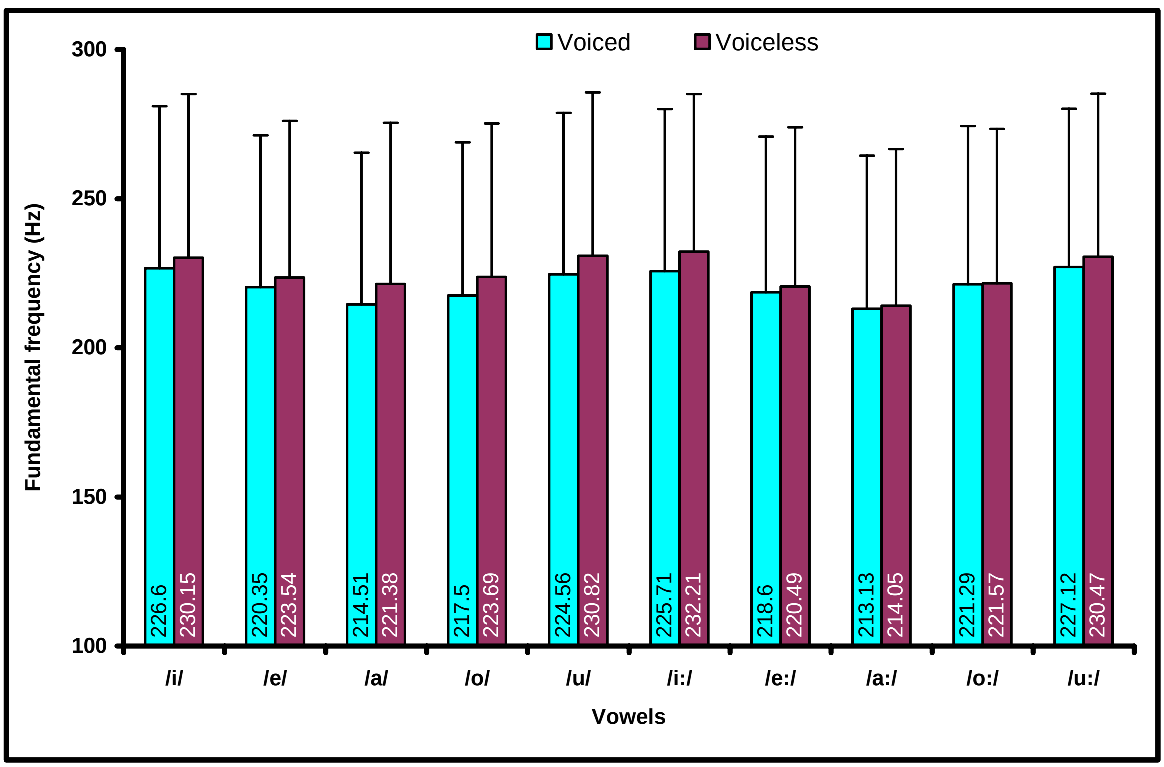


Figure 4.2.1.7: Mean F0 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

Questions that cropped up to further understand the variations in the fundamental frequency observed in the analysis were (1) Do age, gender and region have any association with fundamental frequency and if so what kind of association? (2) Which of the vowels studied have significant difference in fundamental frequency among the age, gender and region groups? Random intercept model 3 was used (as described in the method) to understand if there was any association between F0 and age, gender and region groups. The results are given in Table 4.2.1.a.

Table 4.2.1.a: Statistical analysis using random intercept model for F0

N=4320

Covariates	Estimate	Std. Error	Wald ratio	P value*
Constant (β_{0ij})	326.59	2.87	113.79	< 0.01
Age (β_{1ijk})	-4.33	0.09	-48.11	< 0.01
Gender (β_{2ijk})	-37.56	1.19	-31.56	< 0.01
Region (β_{3ijk})	8.58	0.73	11.75	< 0.01
Variance components				
Random Error:	1499.40			
Consonant Level:	23.18			
Individual level:	16.49			
Total variation:	1539.07			
*-2*loglikelihood(IGLS) = 43714.23*				

**significant at 0.05 level*

Model: Fundamental frequency (F0) = 326.59 – 4.33age – 37.56gender + 8.58region.

From Table 4.2.1.a, it’s observed that, there is a significant association between F0 and age, gender and region with age and gender having negative association with F0.

Further to study as to which of the vowels differed significantly among the age and region groups, Tukey HSD was done and the results suggested that F0 of all vowels showed statistically significant difference between children, adolescents and adults (Table 4.2.1.b). Within the region groups, all vowels had statistically significant difference in F0 between Coastal, Rayalaseema and Telengana speakers, except for front vowel /i/ between

Coastal and Telengana speakers (Table 4.2.1.c). Student's *t*-test to study as to which of the vowels significantly differed with the gender groups are depicted in Table 4.2.1.d.

Table 4.2.1.b: Post hoc results for each vowel between age groups for F0

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	36.4494(*)	< 0.01
	Children	Adult	66.6316(*)	< 0.01
	Adolescent	Adult	30.1822(*)	< 0.01
/e/	Children	Adolescent	38.0486(*)	< 0.01
	Children	Adult	68.1694(*)	< 0.01
	Adolescent	Adult	30.1208(*)	< 0.01
/a/	Children	Adolescent	36.2208(*)	< 0.01
	Children	Adult	67.8446(*)	< 0.01
	Adolescent	Adult	31.6238(*)	< 0.01
/o/	Children	Adolescent	35.6672(*)	< 0.01
	Children	Adult	65.2933(*)	< 0.01
	Adolescent	Adult	29.6261(*)	< 0.01
/u/	Children	Adolescent	37.4517(*)	< 0.01
	Children	Adult	67.3779(*)	< 0.01
	Adolescent	Adult	29.9262(*)	< 0.01
/i:/	Children	Adolescent	35.6026(*)	< 0.01
	Children	Adult	65.4922(*)	< 0.01
	Adolescent	Adult	29.8896(*)	< 0.01
/e:/	Children	Adolescent	38.1725(*)	< 0.01
	Children	Adult	68.0679(*)	< 0.01
	Adolescent	Adult	29.8954(*)	< 0.01
/a:/	Children	Adolescent	37.5033(*)	< 0.01
	Children	Adult	68.8038(*)	< 0.01
	Adolescent	Adult	31.3005(*)	< 0.01
/o:/	Children	Adolescent	37.0622(*)	< 0.01
	Children	Adult	66.2840(*)	< 0.01
	Adolescent	Adult	29.2218(*)	< 0.01
/u:/	Children	Adolescent	34.7340(*)	< 0.01
	Children	Adult	63.1691(*)	< 0.01
	Adolescent	Adult	28.4351(*)	< 0.01

*significant at 0.05 level

Table 4.2.1.c: Post hoc results for each vowel between region groups for F0

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-42.7419(*)	< 0.01
	Coastal	Telengana	-17.6331	0.105
	Rayalaseema	Telengana	25.1089	0.011
/e/	Coastal	Rayalaseema	-37.8736(*)	< 0.01
	Coastal	Telengana	-17.6829(*)	0.004
	Rayalaseema	Telengana	20.1908(*)	0.001
/a/	Coastal	Rayalaseema	-37.1982(*)	< 0.01
	Coastal	Telengana	-17.5957(*)	0.002
	Rayalaseema	Telengana	19.6025(*)	< 0.01
/o/	Coastal	Rayalaseema	-40.1170(*)	< 0.01
	Coastal	Telengana	-18.7864(*)	0.009
	Rayalaseema	Telengana	21.3306(*)	0.002
/u/	Coastal	Rayalaseema	-36.3025(*)	< 0.01
	Coastal	Telengana	-16.0484(*)	0.004
	Rayalaseema	Telengana	20.2540(*)	< 0.01
/i:/	Coastal	Rayalaseema	-41.8978(*)	< 0.01
	Coastal	Telengana	-20.9027	0.013
	Rayalaseema	Telengana	20.9951	0.013
/e:/	Coastal	Rayalaseema	-39.7149(*)	< 0.01
	Coastal	Telengana	-20.8319(*)	0.001
	Rayalaseema	Telengana	18.8830(*)	0.004
/a:/	Coastal	Rayalaseema	-40.1844(*)	< 0.01
	Coastal	Telengana	-20.0118(*)	< 0.01
	Rayalaseema	Telengana	20.1725(*)	< 0.01
/o:/	Coastal	Rayalaseema	-40.8191(*)	< 0.01
	Coastal	Telengana	-22.0791(*)	0.006
	Rayalaseema	Telengana	18.7400	0.025
/u:/	Coastal	Rayalaseema	-42.3416(*)	< 0.01
	Coastal	Telengana	-21.5518	0.011
	Rayalaseema	Telengana	20.7898	0.014

*significant at 0.05 level

Table 4.2.1.d: Student's *t*-test results for all vowels between two gender groups.

N=4320

Vowel	Mean Difference	df	t
/i/	44.5927	213	6.590*
/e/	41.4408	321.992	9.634*
/a/	41.5095	372.688	10.440*
/o/	41.0531	223.901	8.207*
/u/	45.4130	414.841	11.676*
/i:/	43.3594	175.625	7.516*
/e:/	39.1510	264.994	8.327*
/a:/	37.5414	447.992	10.417*
/o:/	38.6287	178.234	6.765*
/u:/	41.9717	179.405	7.229*

*significant at 0.05 level

From the Table 4.2.1.d, it's observed that, all vowels had statistically significant differences in F0 between females and males.

From the results, it is inferred that there is a significant association between age, gender and region with F0. As age increased, there was a significant variation in F0. Except for the vowel /i/ between Coastal and Telengana speakers, all other vowels in all age, gender groups had significant differences in F0. It is also observed that, consonants contribute more for the variations of F0 of vowels along with individual variations.

The findings of the current study although supporting the theory proposed by Mohr (1971) that build of air pressure behind the vowel constriction is the causative factor for variations in the F0, do not support the fact that back vowels have low F0.

In the current study, high vowels /i/ and /u/ had higher F0 and low vowel /a/ and /a:/, low F0. Similar findings are noted in the literature for English (Lehiste & Peterson, 1961; O'Shaughnessy, 1976; Peterson & Barney, 1952; Whalen & Levitt, 1995; Yoshiyuki, 1982a), Hebrew (Most et.al., 2000) and Kannada (Venkatesh, 1995). The current findings support the theories proposed by Taylor (1933), Ladefoged (1964) and Lehiste (1970) that high vowels have high F0 due to mechanical pull of the tongue and transference of muscle tension.

In the current study, it was observed that as the age increases, F0 reduces. The reduction in F0 as the age progresses depicts the developmental trend as reported in English (Crelin, 1987; Eguchi & Hirish, 1969; Kent, 1976; Pickett, 1996; Robb & Saxman, 1985), Kannada (Rashmi, 1985; Samuel, 1973; Sreedevi, 2000; Usha, 1978), and in Malayalam (Ampathu, 1998). The changes in F0 can be attributed to the anatomical and physiological changes that occur in vocal folds (Crelin, 1987; Pickett, 1996).

In English, Kent & Read (1995) commented that F0 varies with reference to gender and in Hebrew, Most et.al., (2000) reported of significant gender variations. In Indian languages, Venkatesh (1995) and Sreedevi (2000) in Kannada; Ampathu (1998) and Riyamol (2007) in Malayalam reported of females having higher F0 than males. The current study endorses the findings of the above mentioned studies.

It is noted in the current study that, regions have an effect on the fundamental frequency of vowels. Venkateswara Sastry (1990-91) reported of stress and linguistic variations among the regions which could be considered as the contributing factors for the variations in F0 among the regions of this study and lending support to the reports of Umeda (1981) and Vorperian et.al., (2009) that anatomical variations could also be a contributing factor. It's hence felt that understanding of the linguistic aspects of the language and anatomical variations between the regions could help in a better understanding of this aspect.

Vowels having higher F0 when preceded by voiced stops have been reported by Dyhr (1990); Honda & Fujimura (1991); House & Fairbanks (1953) and Lehiste & Peterson (1961). However, Umeda (1981) reported that voiceless stops had higher F0 than voiceless fricatives. In the current study, although variations in F0 are observed with different preceding consonants, these findings are not same as is English. It is observed that most of the vowels had higher F0 when preceded by fricatives, affricates and nasals than stop consonants. Only detailed analysis using specific context will strengthen the findings and evolve clarity on this issue. As the following consonant and vowel influences are not controlled in the current study, inferring or generalizing the findings may not be appropriate and should be done with caution.

4.2.1.2 Summary of F0

From the current study, it can be concluded that, in Telugu:

- High vowels, /i/ and /u/ have higher F0 and low vowel /a/ and /a:/, low F0.
- Short vowels have higher F0 than long vowels.
- Back vowels have higher F0 followed by front and central vowels.
- F0 was highest in children followed by adolescent and adults for all short and long vowels.
- Children and adults have highest F0 for short vowel /u/. Long vowel /i:/, highest F0 in all age groups.
- Short and long vowel /a/ and /a:/ have lowest F0 in all age, gender and region groups.
- Females have higher F0 for all short and long vowels as compared to males.
- Among the short vowel /u/ has the highest F0 in females and /i/ in males.
- Long vowel /i:/ has highest F0 in both genders.
- Rayalaseema speakers have higher F0 for all short and long vowels followed by Telengana and Coastal speakers.
- Short vowel /u/ has highest fundamental frequency in Coastal and Telengana speakers while /i/ in Rayalaseema speakers.
- Long vowel /i:/ has highest fundamental frequency in Coastal, Rayalaseema and Telengana.
- Vowels when preceded by voiced consonants have lower F0 than when followed by voiceless consonants.
- Vowels following affricates have higher F0 followed by nasal, fricatives, stops, trill, lateral and semi vowel.
- Vowels followed by dental consonants have higher F0 followed by alveopalatal, retroflex, bilabial and velar consonants.
- Central vowels when preceded by nasal and fricatives consonants have highest fundamental frequency and lowest when preceded by stops.

- Back vowels when preceded by fricatives have highest F0 and lowest when preceded by nasals.
- Back vowels have highest fundamental frequency when preceded by velar and lowest when preceded by bilabial consonants.

4.2.2.1 First Formant Frequency (F1)

Scrutiny of the F1 data revealed that low mid vowel /a/ and /a:/ had the highest mean F1 and back high vowel /u/ and /u:/, the lowest mean F1. Except for vowel /a/, mean F1 decreased with increase in phonetic length of the vowel. Central vowels had higher mean F1 followed by front and back vowels. The mean F1 and 1 SD bars of all vowels are depicted in Figure 4.2.2.1. The means, SD and 95% confidence interval for mean of all the vowels and for central, front and back vowels across the age groups are given in Appendix VIII c (Tables 4.2.2.1 and 4.2.2.2 respectively).

In the current study, it was observed that as age increases, mean F1 decreased. Children had higher mean F1 followed by adolescents and adults for all vowels. It was also observed that, the low mid vowel /a/ and /a:/ had higher mean F1 values and high back vowels /u/ and /u:/, lower mean F1 values. Except for vowel /a/, mean F1 decreased with increase in phonetic length of the vowel in all age groups. The mean F1 and 1 SD bars of all vowels across age groups are depicted in Figure 4.2.2.2. The means, SD and 95% confidence interval for mean of all the vowels across the three age groups are given in Appendix VIII c (Table 4.2.2.3).

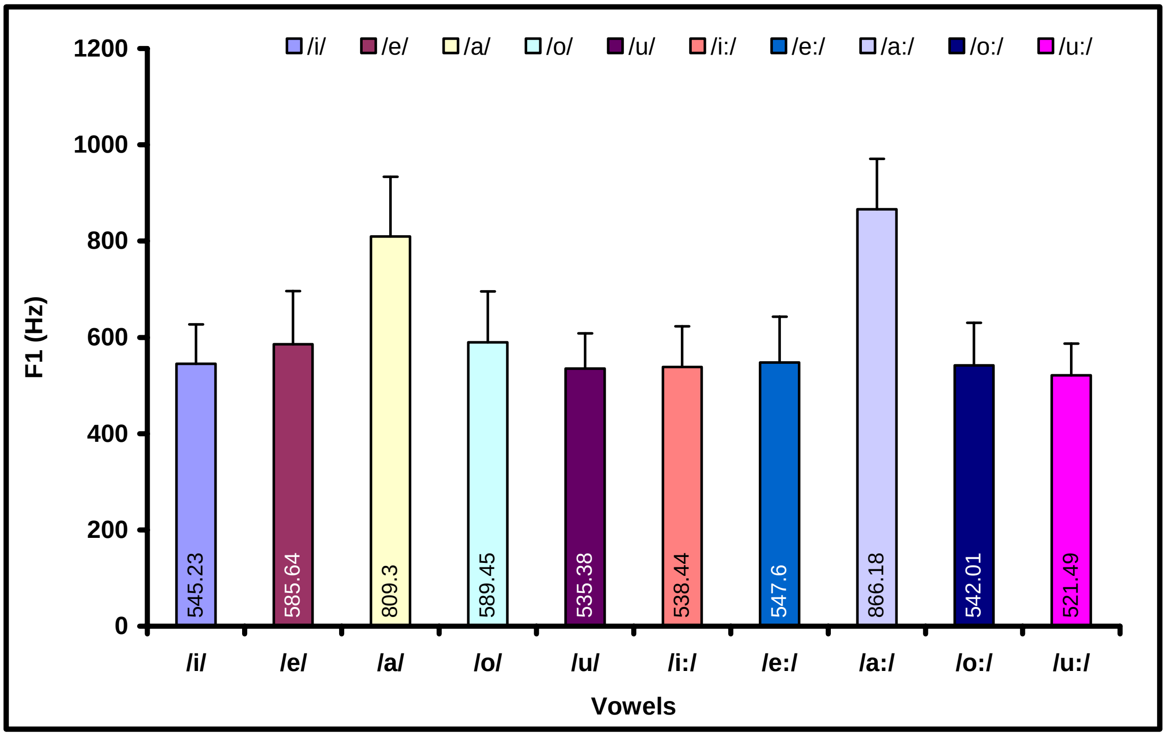


Figure 4.2.2.1: Mean F1 (Hz) and 1 SD bars of all vowels

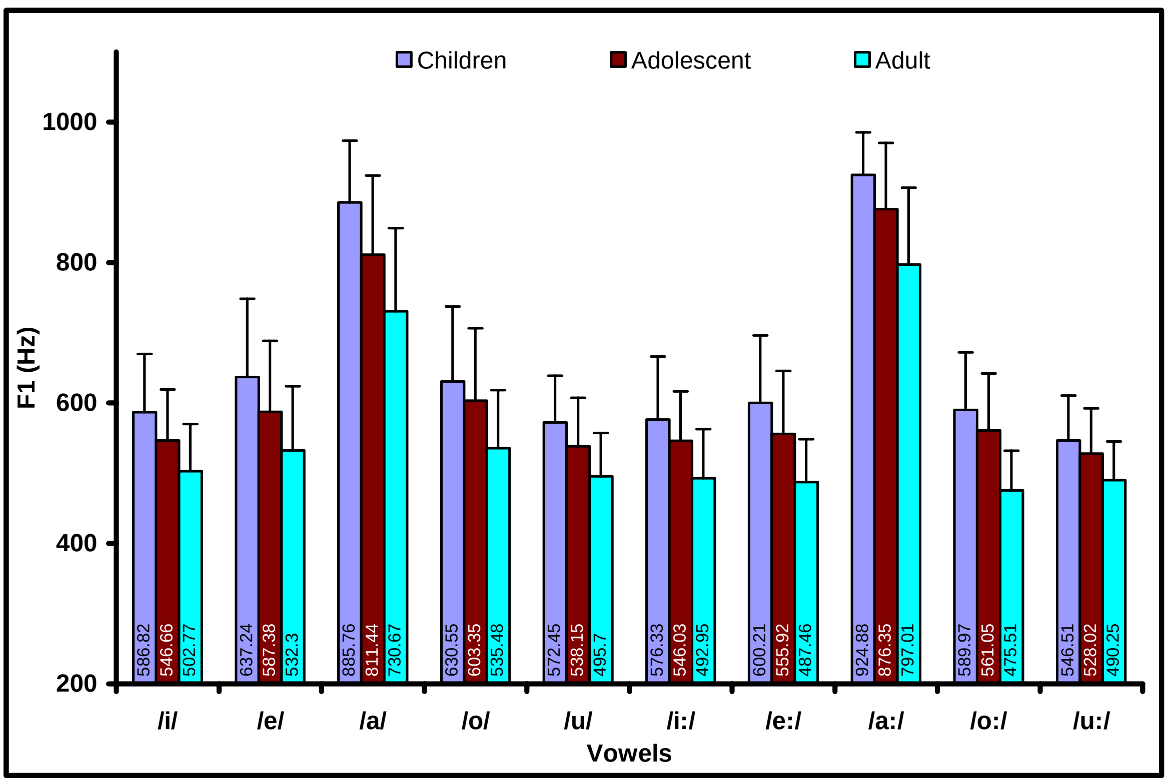


Figure 4.2.2.2: Mean F1 (Hz) and 1 SD bars across age groups

Females had higher mean F1 values when compared to males for all vowels. Low mid vowels /a/ and /a/: had higher F1 while back high vowels /u/ and /u:/ had lower mean F1 in both genders. Except for vowel /a/, mean F1 decreased with increase in phonetic length of the vowel in all age groups. Central vowel /a/ had higher mean F1 followed by front vowel /i/ and back vowel /u/. The mean F1 and 1 SD bars of all vowels across gender groups are depicted in Figure 4.2.2.3. The means, SD and 95% confidence interval for mean of all the vowels across the gender groups are given in Appendix VIII c (Table 4.2.2.4).

It has been observed in this study that, dialect has an effect on the first formant. Accordingly, it was observed that, for vowels /o/, /i:/, /a:/, /o:/, and /u:/, Telengana speakers had higher mean F1 followed by Rayalaseema and Coastal speakers; for vowel /e:/, speakers from Coastal region had higher mean F1 followed by Rayalaseema and Telengana and for /a/, speakers from Telengana had higher mean F1 followed by Coastal and Rayalaseema speakers. Low mid vowel /a/ had higher F1 and back high vowel /u:/ had lower F1 across the regions except for Telengana, where /e:/ had lower F1. Across all regions, F1 reduced with increase in phonetic length except for vowel /a/. The mean F1 and 1 SD bars of all vowels across regional groups are depicted in Figure 4.2.2.4. The means, SD and 95% confidence interval for mean of all the vowels across the three region groups are given in Appendix VIII c (Table 4.2.2.5).

Front vowels /i/, /i:/, /e/,/e:/, mid vowel /a/ and back vowels /o/ and /u:/, had higher mean F1 when preceded by nasal consonants than stops. Vowels /u/ and /a:/ had higher mean F1 when preceded by affricates than stop consonants. Only back long vowel /o:/ had higher mean F1 when preceded by stop consonants. Mid vowel /a/ had higher mean F1 when preceded by lateral followed by nasal, stop, semivowel and fricative consonants. The mean F1 and 1 SD bars of short and long vowels across different manner of articulation of preceding consonant are depicted in Figures 4.2.2.5a and 4.2.2.5b respectively. The means and SD of all the vowels across the different manner of articulation consonants are given in Appendix VIII c (Table 4.2.2.6).

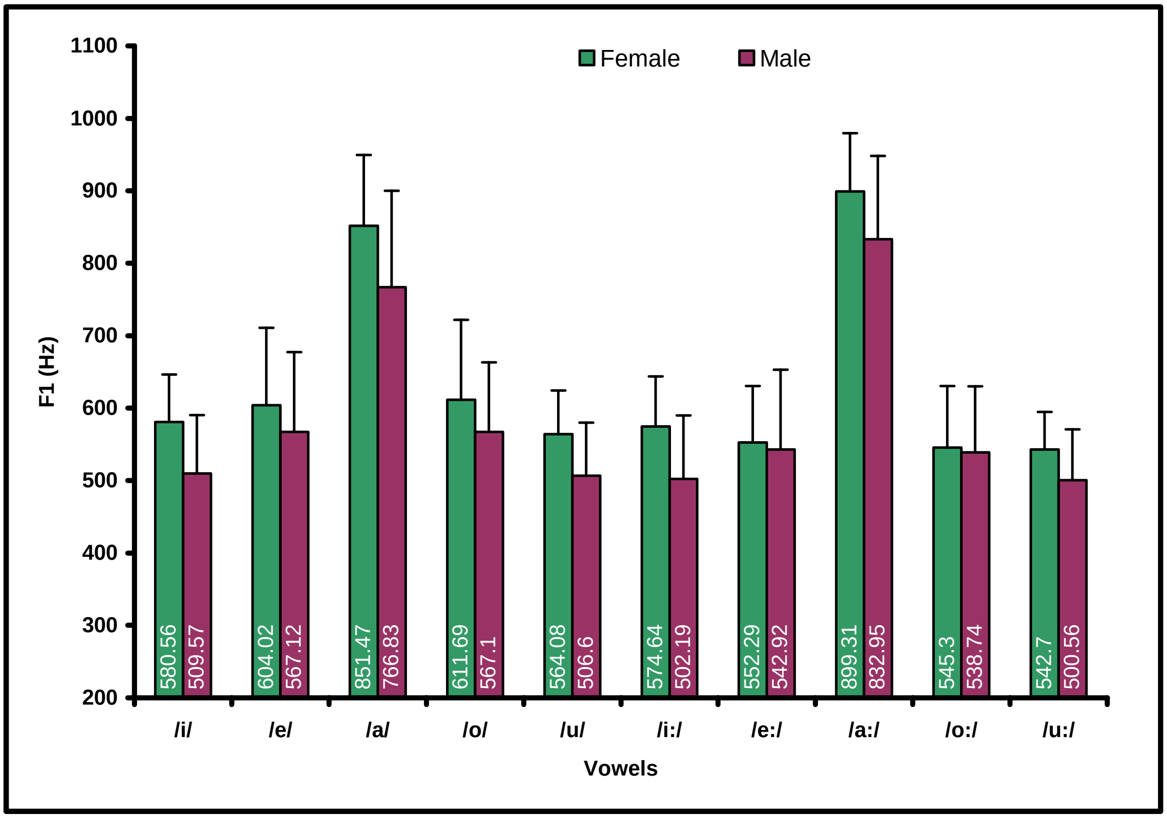


Figure 4.2.2.3: Mean F1 (Hz) and 1 SD bars across gender groups

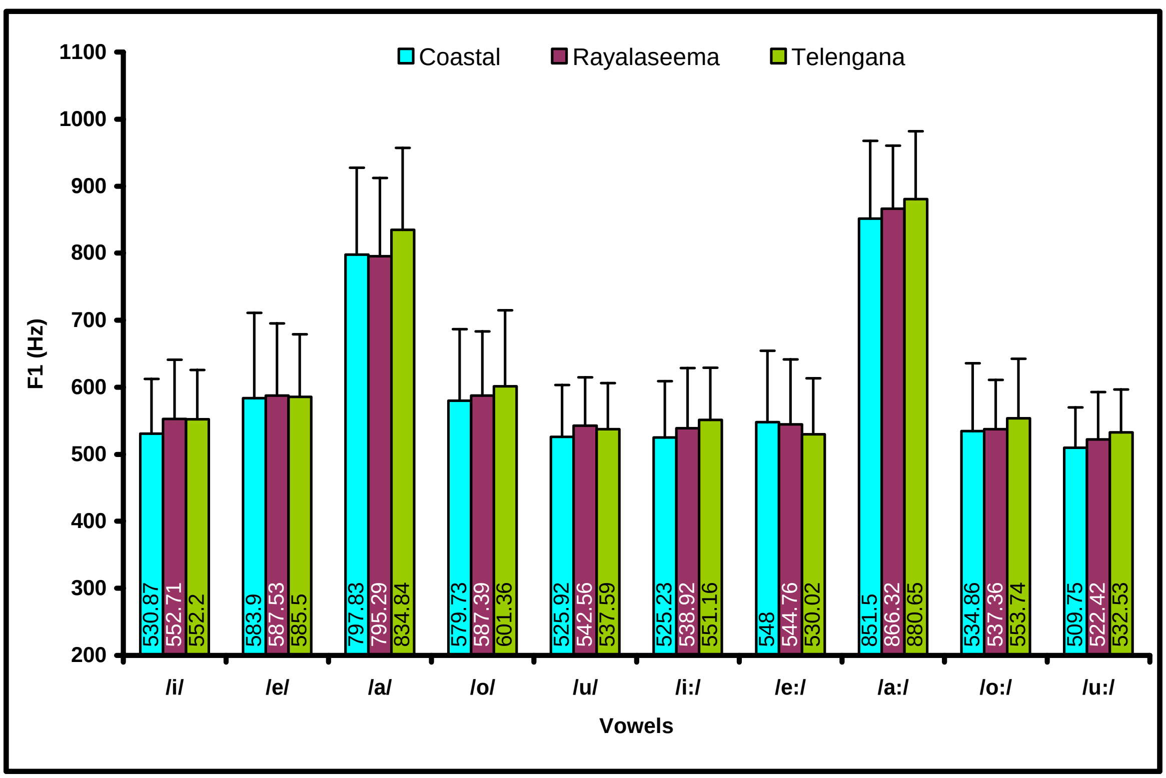


Figure 4.2.2.4: Mean F1 (Hz) and 1 SD bars across region groups

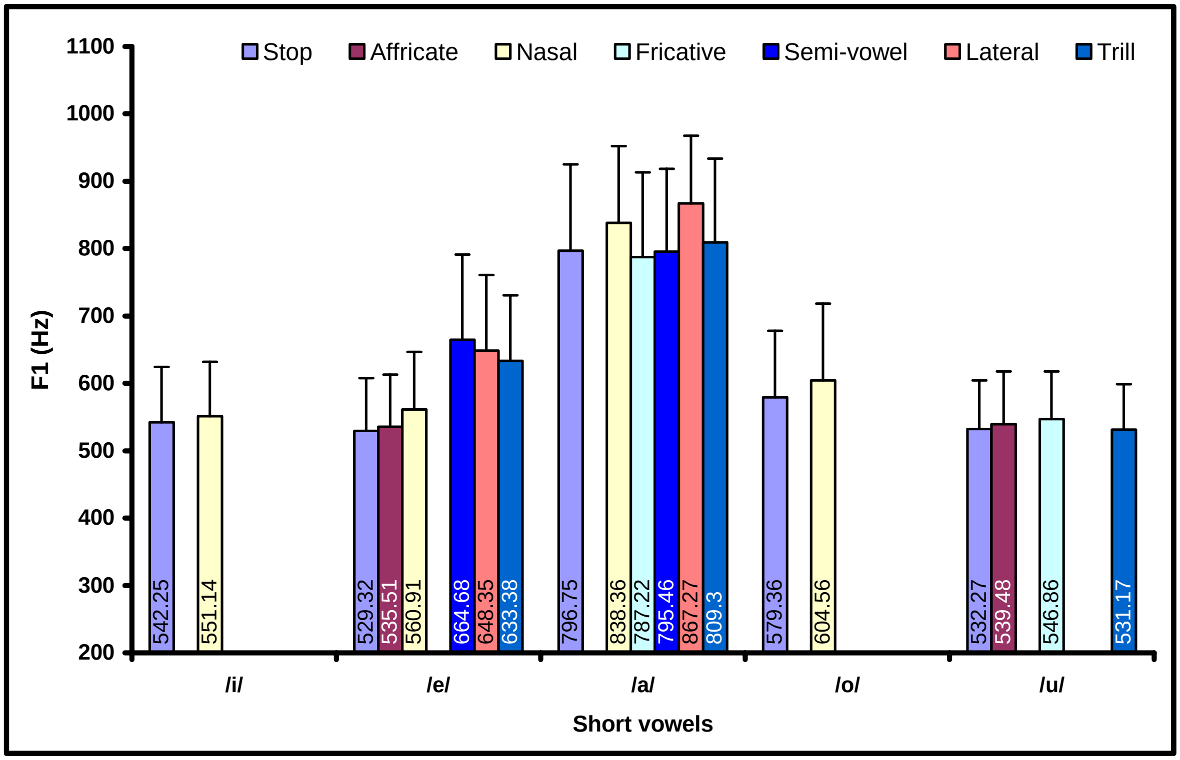


Figure 4.2.2.5a: Mean F1 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

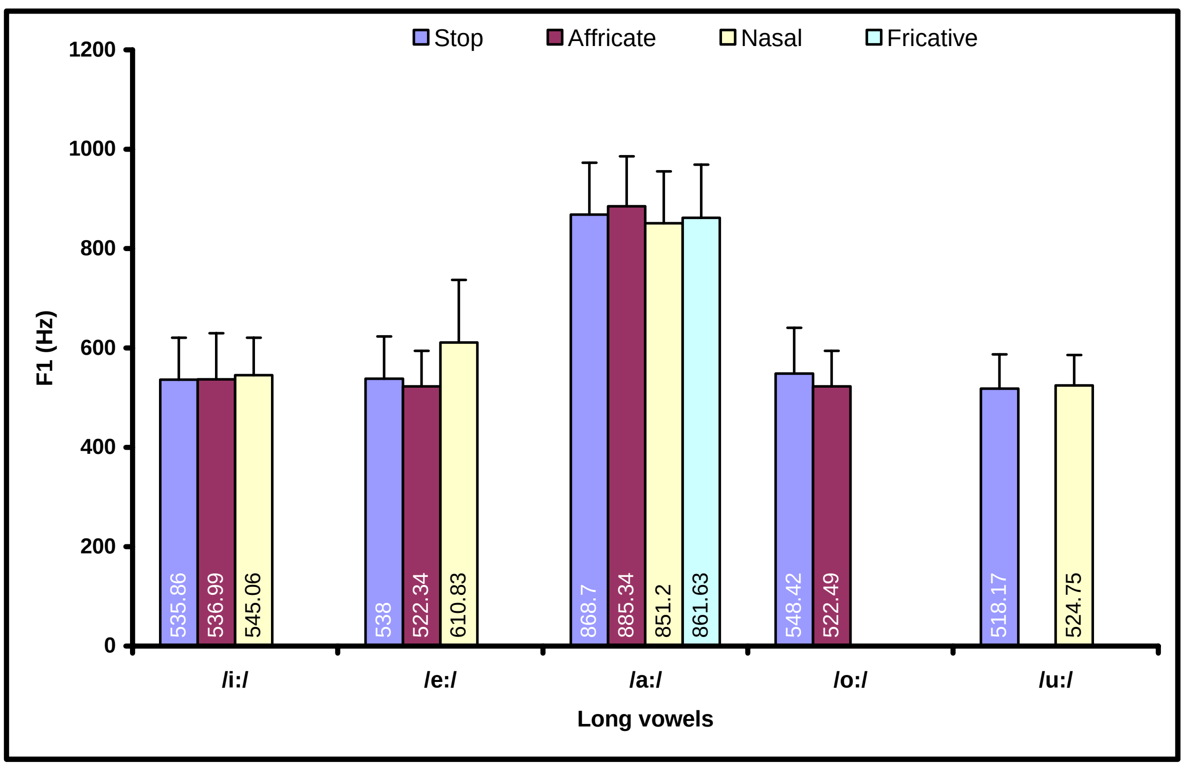


Figure 4.2.2.5b: Mean F1 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

It's to be noted that, place of articulation of the preceding consonants also had an effect on F1 of the vowel. All vowels had higher mean F1 when preceded by alveopalatal consonants as compared to bilabials except for mid vowels /e:/ and /o:/. Short and long vowels /o/, /u/; long vowel /a:/ had higher mean F1 when preceded by dental consonants as compared to bilabial consonants; however, /i/ and /e:/ had higher mean F1 when preceded by bilabial consonants as compared to dental consonants. The mean F1 and 1 SD bars of short and long vowels across different place of articulation of preceding consonant are depicted in Figures 4.2.2.6a and 4.2.2.6b respectively. The means and SD of all the vowels across the different places of articulation consonants are given in Appendix VIII c (Table 4.2.2.7).

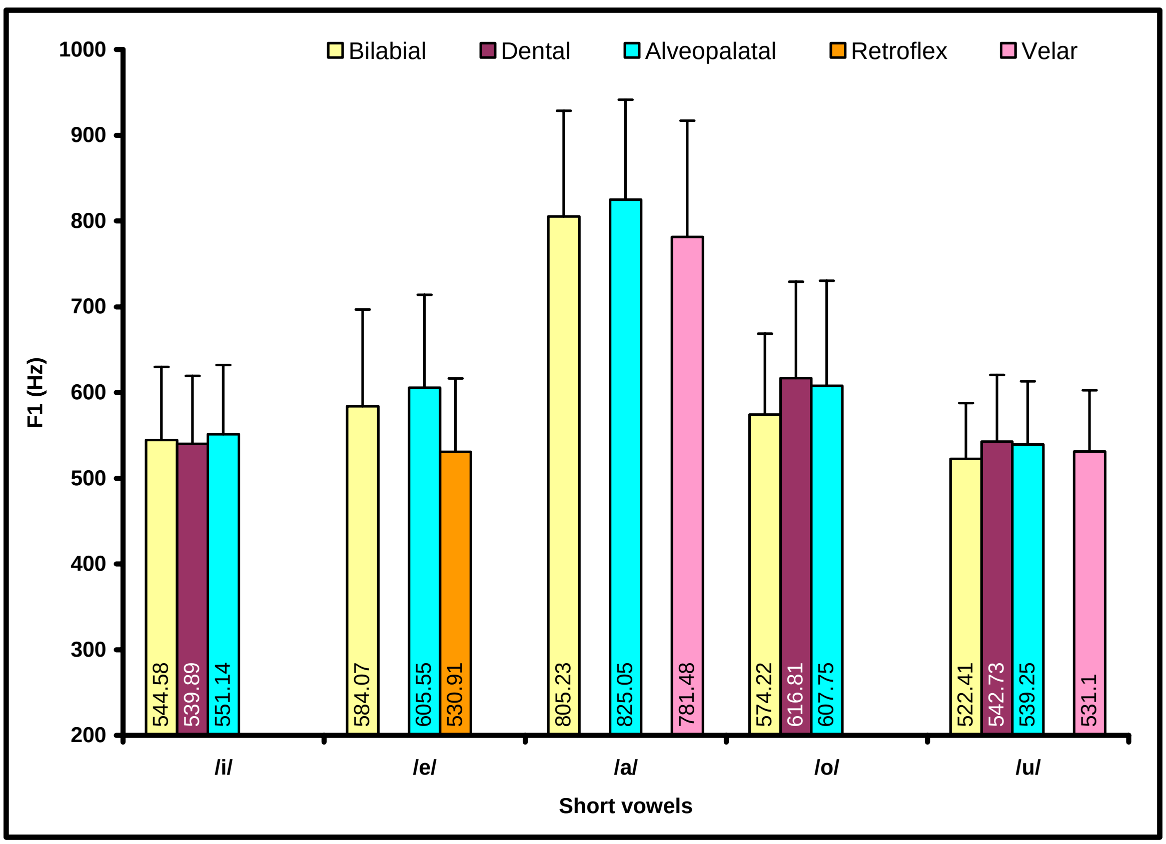


Figure 4.2.2.6a: Mean F1 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants.

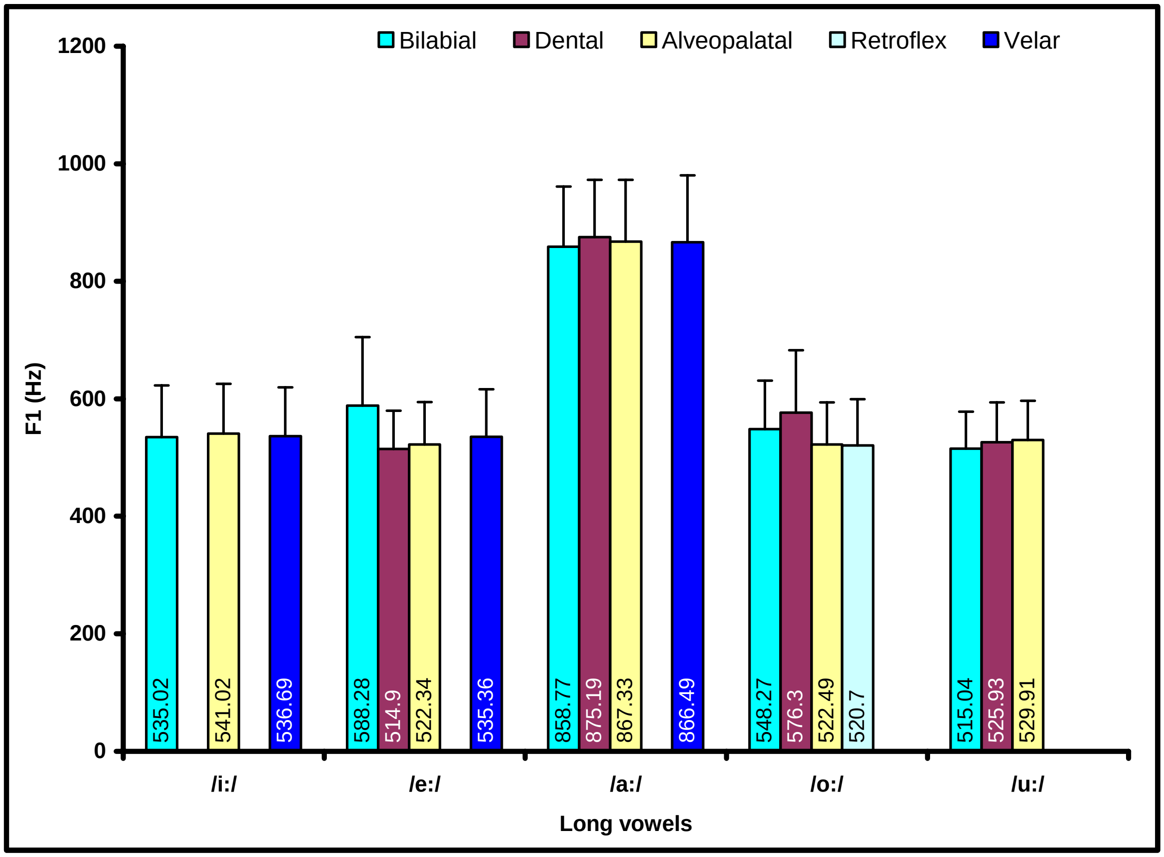


Figure 4.2.2.6b: Mean F1 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

Among the short vowels, mid and low vowels (/e/, /a/ and /u/) had higher mean F1 when preceded by voiced consonants, while high vowels (/i/ and /u/) had higher mean F1 when preceded by voiceless consonants. The reverse was observed in long vowels, i.e., mid and low vowels (/e:/, /a:/ and /u:/) had higher mean F1 when preceded by voiceless consonants while for high vowels (/i:/ and /u:/), it was when preceded by voiced consonants. The mean F1 and 1 SD bars of all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.2.7. The means and SD of all the vowels across the different voiced and voiceless consonants are given in Appendix VIII c (Table 4.2.2.8).

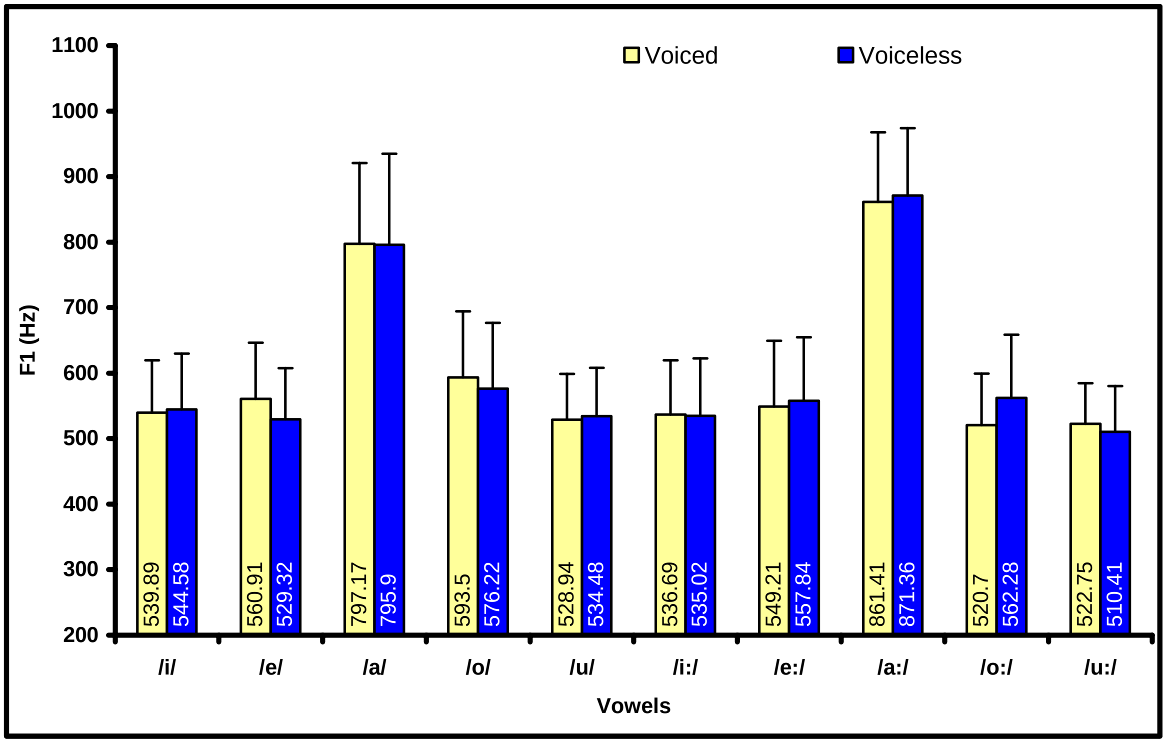


Figure 4.2.2.7: Mean F1 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants.

The following questions were attempted to further understand the variations in the F1 observed in the analysis. (1) Do age, gender and region have any association with F1, if so what kind of association? (2) Which of the vowels studied have significant difference in F1 among the age, gender and region groups? Random intercept model 3 was used (as described in the method) to understand if there was any association between F1 and age, gender and region groups. The results are given in Table 4.2.2.a. It is observed that, there is a significant association between F1 and age, gender and region. Further, age and gender have negative association with F1.

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was done and the results suggested that mean F1 of all vowels showed statistically significant difference between children, adolescents and adults (Table 4.2.2.b) except for back vowels /o/ and /u:/ between children and adolescents. Within the region groups, all vowels had statistically no significant difference in F1 between Coastal, Rayalaseema and Telengana speakers, except for mid vowel /a/ and /a:/ between Coastal – Telengana, Rayalaseema – Telengana and Coastal – Telengana speakers respectively

(Table 4.2.2.c). Student's *t*-test was done to study which of the vowels significantly differed with the gender groups. The results are given in Table 4.2.2.d.

Table 4.2.2.a: Statistical analysis using random intercept model for F1

N=4320

Covariates	Estimate	Std. Error	Wald ratio	P value*
Constant (β_{0ij})	775.26	22.74	34.09	< 0.01
Age (β_{1ijk})	-6.65	0.19	-35	< 0.01
Gender (β_{2ijk})	-45.11	2.5	-18.04	< 0.01
Region (β_{3ijk})	8.13	1.53	5.31	< 0.01
Variance components				
Random Error:	6080.89			
Consonant Level:	1247.05			
Individual level:	16021.15			
Total variation:	23349.09			
*-2*log likelihood(IGLS) = 50286.04*				

**significant at 0.05 level*

Model: First formant frequency (F1) = 775.26 – 6.65age – 45.11gender + 8.13region.

Table 4.2.2.b: Post hoc results for each vowel between age groups for F1

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	40.16(*)	0.004
	Children	Adult	84.05(*)	< 0.01
	Adolescent	Adult	43.89(*)	0.001
/e/	Children	Adolescent	49.86(*)	< 0.01
	Children	Adult	104.94(*)	< 0.01
	Adolescent	Adult	55.08(*)	< 0.01
/a/	Children	Adolescent	74.32(*)	< 0.01
	Children	Adult	155.09(*)	< 0.01
	Adolescent	Adult	80.77(*)	< 0.01
/o/	Children	Adolescent	27.20	0.085
	Children	Adult	95.07(*)	< 0.01
	Adolescent	Adult	67.87(*)	< 0.01
/u/	Children	Adolescent	34.30(*)	< 0.01
	Children	Adult	76.74(*)	< 0.01
	Adolescent	Adult	42.45(*)	< 0.01
/i:/	Children	Adolescent	30.30	0.019
	Children	Adult	83.38(*)	< 0.01
	Adolescent	Adult	53.08(*)	< 0.01
/e:/	Children	Adolescent	44.29(*)	< 0.01
	Children	Adult	112.75(*)	< 0.01
	Adolescent	Adult	68.46(*)	< 0.01
/a:/	Children	Adolescent	48.53(*)	< 0.01
	Children	Adult	127.87(*)	< 0.01
	Adolescent	Adult	79.34(*)	< 0.01
/o:/	Children	Adolescent	28.92	0.020
	Children	Adult	114.46(*)	< 0.01
	Adolescent	Adult	85.55(*)	< 0.01
/u:/	Children	Adolescent	18.48	0.095
	Children	Adult	56.26(*)	< 0.01
	Adolescent	Adult	37.77(*)	< 0.01

*significant at 0.05 level

Table 4.2.2.c: Post hoc results for each vowel between region groups for F1

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-21.85	0.244
	Coastal	Telengana	-21.33	0.263
	Rayalaseema	Telengana	0.52	0.999
/e/	Coastal	Rayalaseema	-3.63	0.951
	Coastal	Telengana	-1.60	0.990
	Rayalaseema	Telengana	2.03	0.984
/a/	Coastal	Rayalaseema	2.54	0.978
	Coastal	Telengana	-37.01(*)	0.010
	Rayalaseema	Telengana	-39.55(*)	0.005
/o/	Coastal	Rayalaseema	-7.66	0.841
	Coastal	Telengana	-21.63	0.257
	Rayalaseema	Telengana	-13.97	0.565
/u/	Coastal	Rayalaseema	-16.64	0.047
	Coastal	Telengana	-11.67	0.221
	Rayalaseema	Telengana	4.97	0.758
/i:/	Coastal	Rayalaseema	-13.69	0.496
	Coastal	Telengana	-25.93	0.084
	Rayalaseema	Telengana	-12.24	0.571
/e:/	Coastal	Rayalaseema	3.25	0.956
	Coastal	Telengana	-2.01	0.983
	Rayalaseema	Telengana	-5.26	0.887
/a:/	Coastal	Rayalaseema	-14.81	0.265
	Coastal	Telengana	-29.15(*)	0.006
	Rayalaseema	Telengana	-14.33	0.287
/o:/	Coastal	Rayalaseema	-2.50	0.979
	Coastal	Telengana	-18.88	0.303
	Rayalaseema	Telengana	-16.38	0.405
/u:/	Coastal	Rayalaseema	-13.18	0.342
	Coastal	Telengana	-23.28	0.037
	Rayalaseema	Telengana	-10.11	0.527

*significant at 0.05 level

Table 4.2.2.d: Student's *t*-test results for all vowels between two gender groups for F1

Vowel	Mean Difference	df	t
/i/	70.99	204	7.06*
/e/	36.89	500	3.81*
/a/	84.64	523	8.66*
/o/	44.59	349	4.07*
/u/	57.47	617	10.88*
/i:/	72.51	286	8.07*
/e:/	9.37	386	1.02
/a:/	66.35	638	8.96*
/o:/	6.56	285	0.63
/u:/	42.14	264	5.77*

*significant at 0.05 level

From Table 4.2.2.d, its' observed that, all vowels had statistically significant differences in F1 between females and males except for /e:/ and /o:/.

From the results, it is inferred that, there is a significant association between age, gender and region for F1. As age increased, there was a significant decrease in F1 and also significant variations among the regions and gender groups. From the statistical analysis, it could also be inferred that, individual level variations contribute much to F1 as compared to consonant contexts.

The current study reveals that F1 varied depending upon the elevation of the tongue, the volume and constriction of the vocal tract. Higher the elevation of the tongue in the vocal tract, the lower the first formant. Similar results have been reported in the literature (Fant, 1960; Joos, 1948; Whalen et.al., 2004). Front vowels having lower F1 as compared to central vowels support the rules given by Pickett (1996); however, it does not support the case of back vowels having lower F1. It appears that, elevation of the tongue plays a major role in the F1 variations as observed in the current study. Tongue position appears to be higher for the production of vowel /i/ as compared to vowel /u/; however, almost same tongue height is maintained for the production of mid vowels /e/ and /o/ with variation in place of constriction. The findings did not differ much between the production of short and long vowels. The results of the current study support the findings of Nagamma Reddy (1999) that short vowels in Telugu have higher F1 than long vowels, excepting vowel /a/ and the findings of Jenson & Menon (1972) in Malayalam. The observed variations between the short and long vowels could be due to lesser time taken by the tongue to reach the appropriate position before the production of the next consonant for the production of short vowels.

The findings that as age progresses, F1 decreases has been reported in English (Peterson & Barney, 1952; Eguchi & Hirish, 1969; Kent, 1976), Hebrew (Most et.al., 2000), New Zealand English (Watson, Palethorpe & Harrington, 2004) and Indian languages (Sreedevi, 2000; Ampathu, 1998). It may be inferred that F1 also varied on the length and resonance of the vocal tract, which changes over the age. (Monsen & Engerbretson, 1983; Watson et.al., 2004). Most et.al., (2000) recommended cultural, language specific analysis for formants as differences could exist. F1 variations were observed from children to adult, for most of the vowels; however, this was observed in Hebrew only till adolescence. (Most et.al., 2000).

It is observed from the analysis of the current study that regional variations were observed across the speakers for F1. Most et.al., (2000) had commented that regional, cultural variations for formants can exist. The variations in F1 can further be attributed to the anatomical and dialectal differences in the different regions as stated in the literature (Venkateswara Sastry, 1990-91). Further research to understand these differences is warranted.

The variability of F1 in different consonant contexts has been studied and reported in English (Black, 1939; Stevens & House, 1963; Hillenbrand et.al., 1995), and Telugu (Nagamma Reddy, 1999). Similar to English (Stevens & House, 1963), F1 of vowels varied when preceded by different place of articulation, manner of articulation and voicing characteristics in Telugu also.

4.2.2.2 Summary of F1

From the current study, it can be concluded that, in Telugu:

- Low mid vowels had the highest F1 and back high vowels had the lowest F1.
- First formant increased with increase in phonetic length of the vowel except for vowel /a/.
- Central vowels had higher F1 followed by front and back.
- Children had higher F1 followed by adolescents and adults.
- The low mid vowels had higher F1 and high back vowels, lower F1 values across age groups.
- Females had higher F1 values when compared to males for all vowels.
- Low mid vowels had higher F1 while back high vowels had lower F1 in both genders.
- Telengana speakers had higher F1 followed by Rayalaseema and Coastal speakers for vowels /o/, /i:/, /a:/, /o:/, and /u:/.
- Short vowels had higher F1 when preceded by voiced consonants, except /i/ and /u/.
- Long vowels had higher F1 when preceded by voiceless consonants, except /i:/ and /u:/.
- Vowels following lateral consonants had higher F1 followed by semivowels, fricatives, nasals, stops, affricatives and trills.
- Vowels when preceded by velar consonants had higher F1 followed by alveopalatal, bilabial, dental and retroflex consonants.
- Central vowels had higher F1 compared to back vowels when preceded by stop, nasal and fricative consonants.
- Central vowels when preceded by nasal consonants had higher F1 followed by stop and fricative consonants.
- Back vowels had higher F1 when preceded by fricative consonants followed by stop and nasal consonants.
- Central and back vowels had higher F1 values when preceded by dental consonants followed by bilabial and velar consonants.

4.2.3.1 Second Formant Frequency (F2)

Current study revealed that long vowels had higher mean F2 as compared to short vowels. High front vowel /i/ and /i:/ had the highest mean F2 and back high vowel /u/ and /u:/, the lowest. The mean F2 decreased as the tongue constriction varied from front to back. Front vowels had higher F2 followed by central and back. The mean F2 and 1 SD bars of all vowels are depicted in Figure 4.2.3.1. The means, SD and 95% confidence interval for mean of all the vowels and for central, front and back vowels across the age groups are given in Appendix VIII d (Tables 4.2.3.1 and 4.2.3.2 respectively).

It was observed that, as age increases, F2 decreased. Children had higher F2 followed by adolescents and adults. Front high vowel /i/ and /i:/ have higher mean F2 values and high back vowel /u/ and /u:/, lower mean F2 values across the age groups. Vowels /e/, /a/, /o/, /u/, /a:/, /o:/, /u:/ had reduced mean F2 from children to adults. Vowels /i/, /i:/ and /e:/ in children had lower mean F2 values as compared to adolescents. On comparing the data between the short and long vowels it was found that, for vowels /e/, /o/ and /u/, the mean F2 values increased with increase in phonetic length in children and adolescents groups; however, the mean F2 values decreased for vowels /a/, /o/ and /u/ in adults as phonetic length increased. Only vowel /e/ had consistently increased mean F2 values as phonetic length increased in all age groups. The mean F2 and 1 SD bars of all vowels across different age groups are depicted in Figure 4.2.3.2. The means, SD and 95% confidence interval for mean of all the vowels for all three age groups are given in Appendix VIII d (Table 4.2.3.3).

Gender wise, females had higher mean F2 values when compared to males for all vowels. The high front vowel /i/ and /i:/ had higher mean F2 while back high vowel /u/ and /u:/ had lower F2 in both the genders. On scrutiny of the data between the short and long vowels, it was observed that, for vowels /i/, /a/ and /o/, F2 decreased with increase in phonetic length in females, while in males, it was observed for only vowels /i/ and /e/. Only front vowels /i/ & /i:/ and back vowels /u/ & /u:/ followed a consistent pattern with increase in phonetic length in both genders. The mean F2 and 1 SD bars of all vowels across gender groups are depicted in Figure 4.2.3.3. The means, SD and 95% confidence interval for mean of all the vowels for two gender groups are given in Appendix VIII d (Table 4.2.3.4).

Regional variations of second formant were observed more in short vowels than long vowels. From the data, it was observed that, for vowels /i/, /e/ and /a/, Rayalaseema speakers had higher mean F2 while for vowel /o/ and /u/, Telengana speakers had higher mean F2. Telengana speakers had consistently higher mean F2 for long vowels /e:/, /a:/, /o:/ and /u:/ except for /i:/, Coastal speakers had higher mean F2. Across the regions, it was observed that, high front vowel /i/ had higher mean F2 and back high vowel had lower mean F2 in both short and long vowels. Further, only long vowels /e:/ and /u:/ had consistently higher mean F2 values as compared to their counterparts across all regions. The mean F2 and 1 SD bars of all vowels across different regional groups are depicted in Figure 4.2.3.4. The means, SD and 95% confidence interval for mean of all the vowels for all three region groups are given in Appendix VIII d (Table 4.2.3.5).

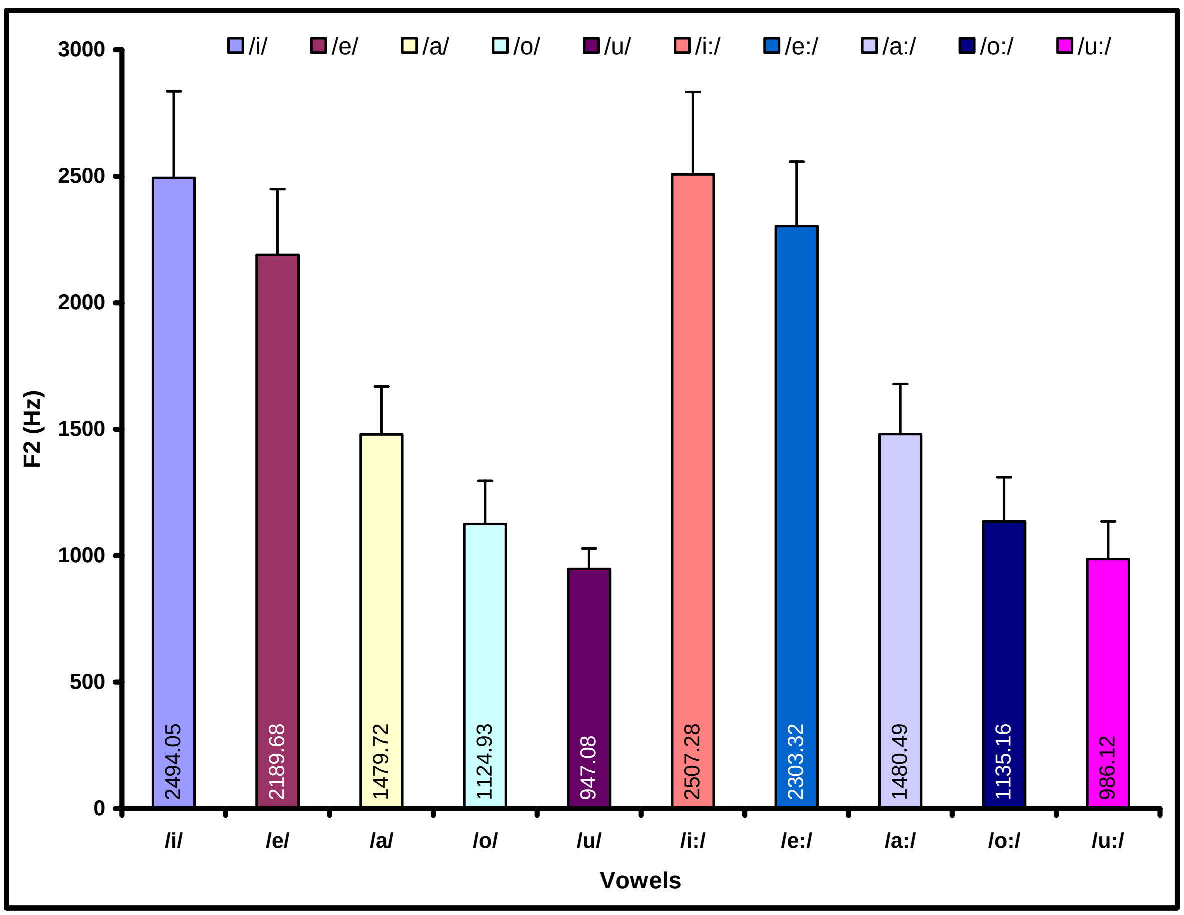


Figure 4.2.3.1: Mean F2 (Hz) and 1 SD bars of all vowels

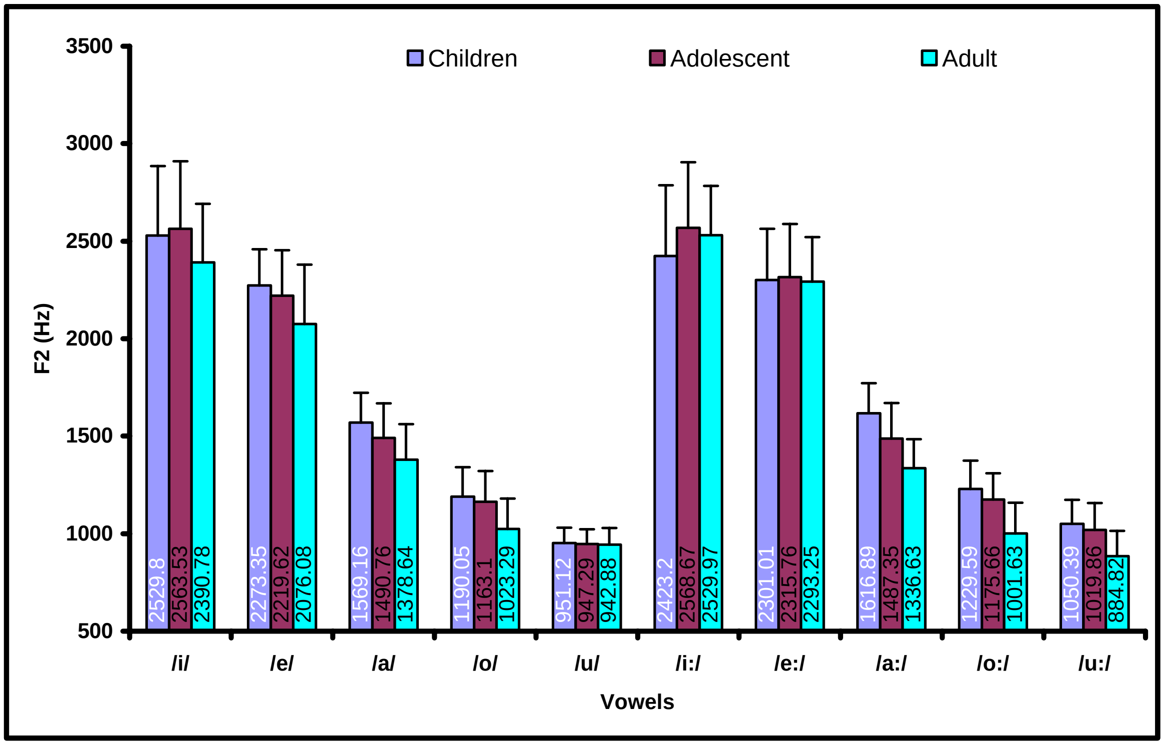


Figure 4.2.3.2: Mean F2 (Hz) and 1 SD bars across age groups

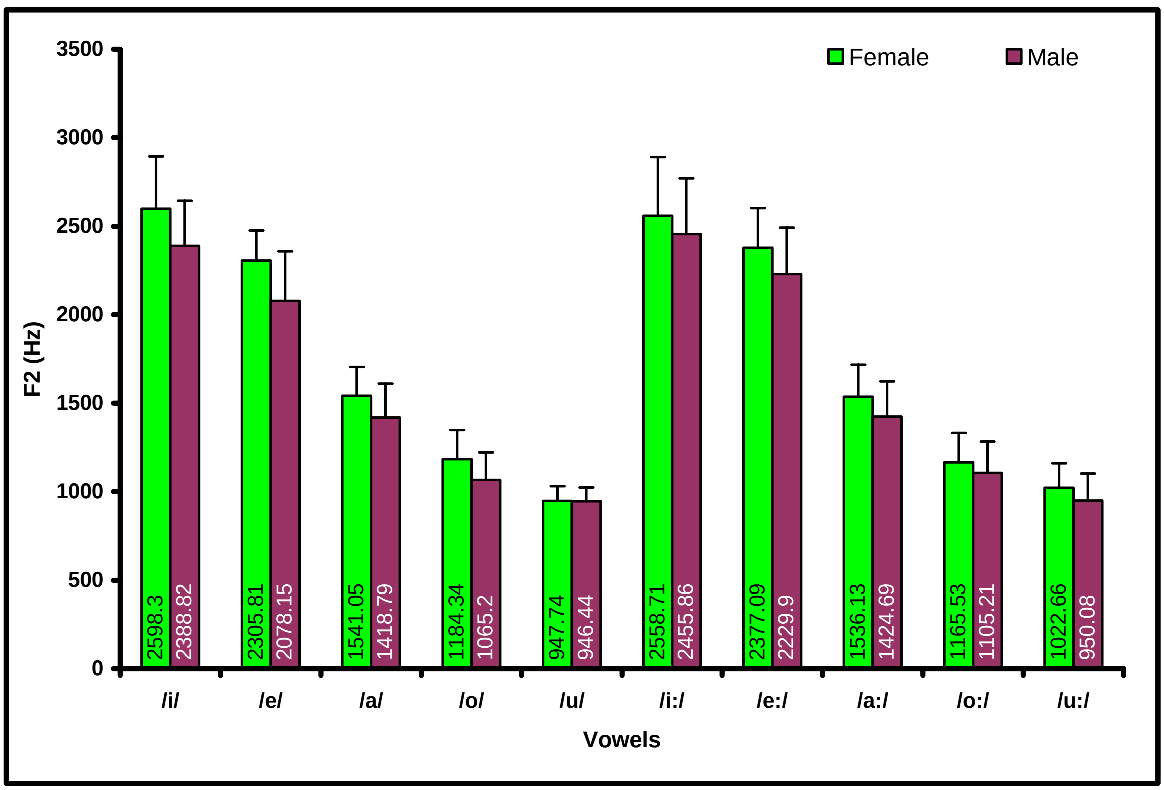


Figure 4.2.3.3: Mean F2 (Hz) and 1 SD bars across gender groups

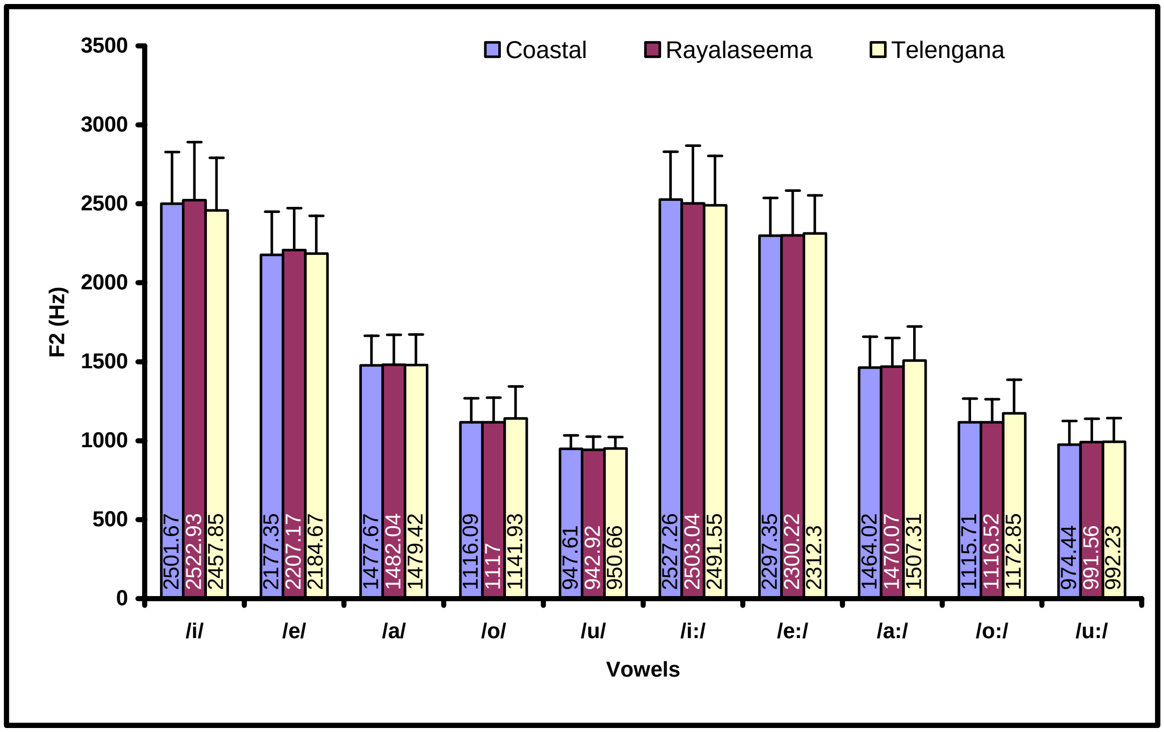


Figure 4.2.3.4: Mean F2 (Hz) and 1 SD bars across region groups

Manner of articulation of the preceding consonant had an effect on F2 of the following vowel in Telugu. In the current study, it was observed that front short vowels /i/ and /e/ had higher mean F2 when preceded by nasal consonants as compared to stop consonants, while the opposite was noticed for their counterpart (long vowels). All long vowels had higher mean F2 values when preceded by affricates as compared to stops except for vowel /u:/. On further inspection of the data, it was observed that, central vowels when preceded by stop consonants had higher mean F2 followed by fricative and nasal consonants; however, back vowels had higher the F2 when preceded by nasal consonants followed by stop and fricative consonants. The mean F2 and 1 SD bars of short and long vowels across different manner of articulation of the preceding consonant are depicted in Figures 4.2.3.5a and 4.2.3.5b respectively. The means and SD of all the vowels for different preceding manner of articulation of the consonants are given in Appendix VIII d (Table 4.2.3.6).

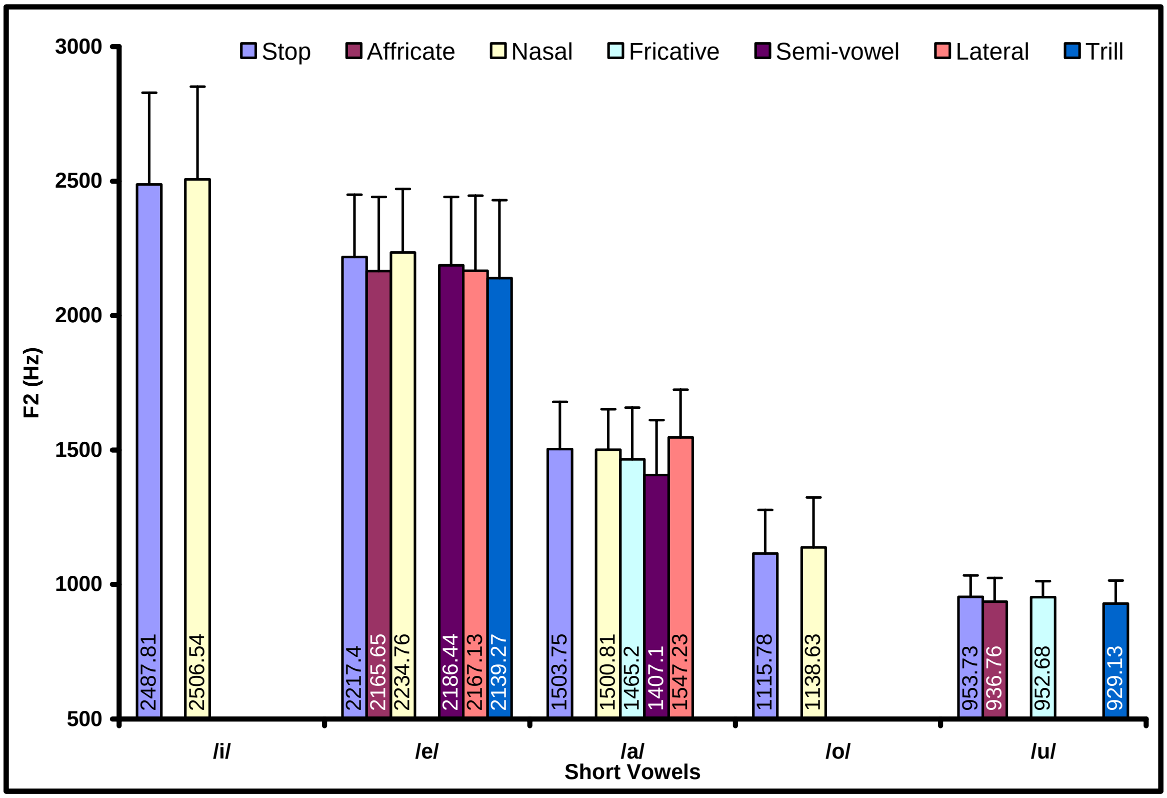


Figure 4.2.3.5a: Mean F2 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

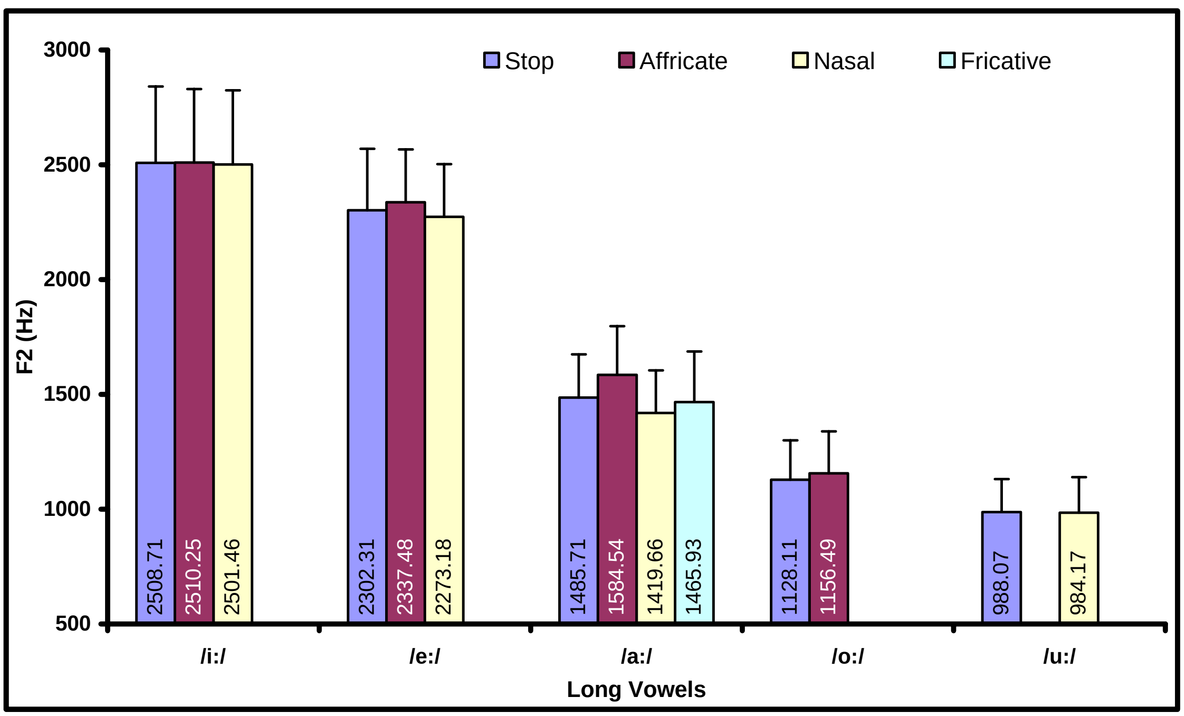


Figure 4.2.3.5b: Mean F2 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants.

Place of articulation of the preceding consonant also had an influence on the F2 of the following vowel in Telugu. Vowels /i/, /e/ /u/ and /i:/ had higher mean F2 when preceded by bilabials as compared to alveopalatals. Vowels /o/, /u/, /e:/, /a:/. /o:/ and /u:/ had higher mean F2 when preceded by dentals as compared to bilabials. Central vowels had higher mean F2 when preceded by velar consonants followed by dental and bilabial consonants, but back vowels had higher mean F2 when preceded by dental consonants followed by bilabial and velar consonants. Short and long vowels /i/ had higher mean F2 when preceded by bilabials as compared to alveopalatals. Short and long mid vowels /a/ and /a:/ had higher mean F2 when preceded by velars as compared to bilabials. Short and long back vowels /o/, /o:/. /u/ and /u:/ had higher mean F2 when preceded by dentals as compared to bilabials. The mean F2 and 1 SD bars of short and long vowels across different place of articulation of the preceding consonant are depicted in Figures 4.2.3.6a and 4.2.3.6b. The means and SD of all the vowels for different preceding place of articulation consonants are given in Appendix VIII d (Table 4.2.3.7).

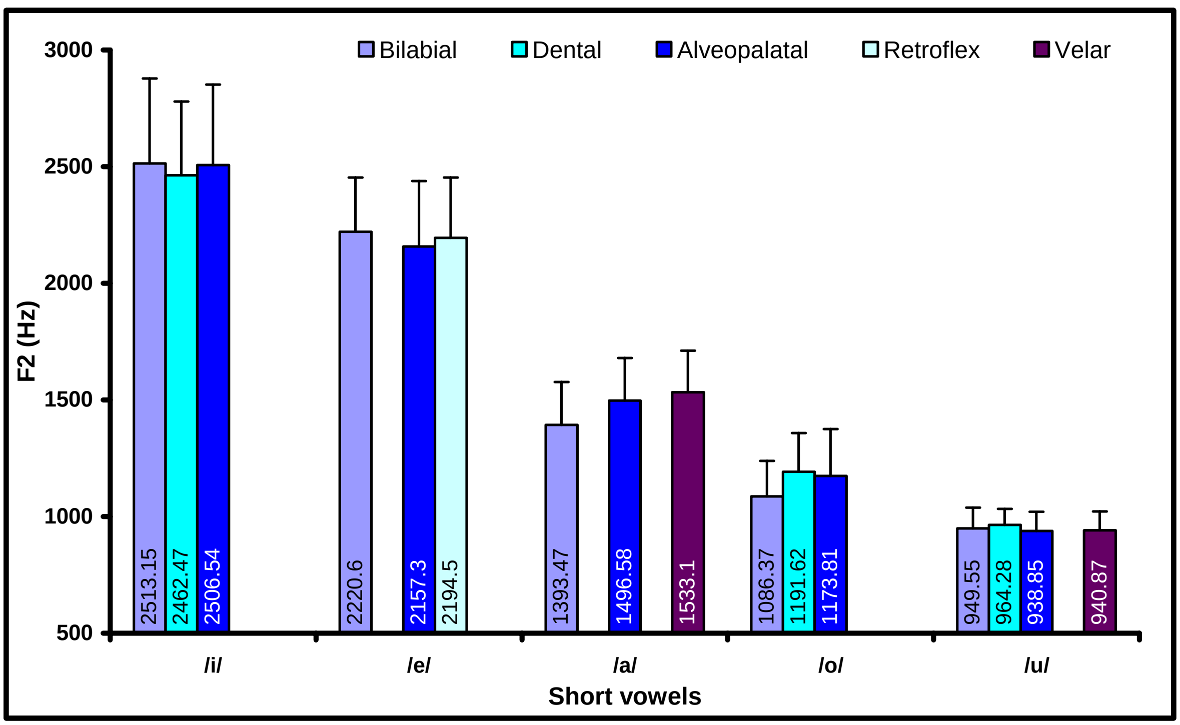


Figure 4.2.3.6a: Mean F2 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

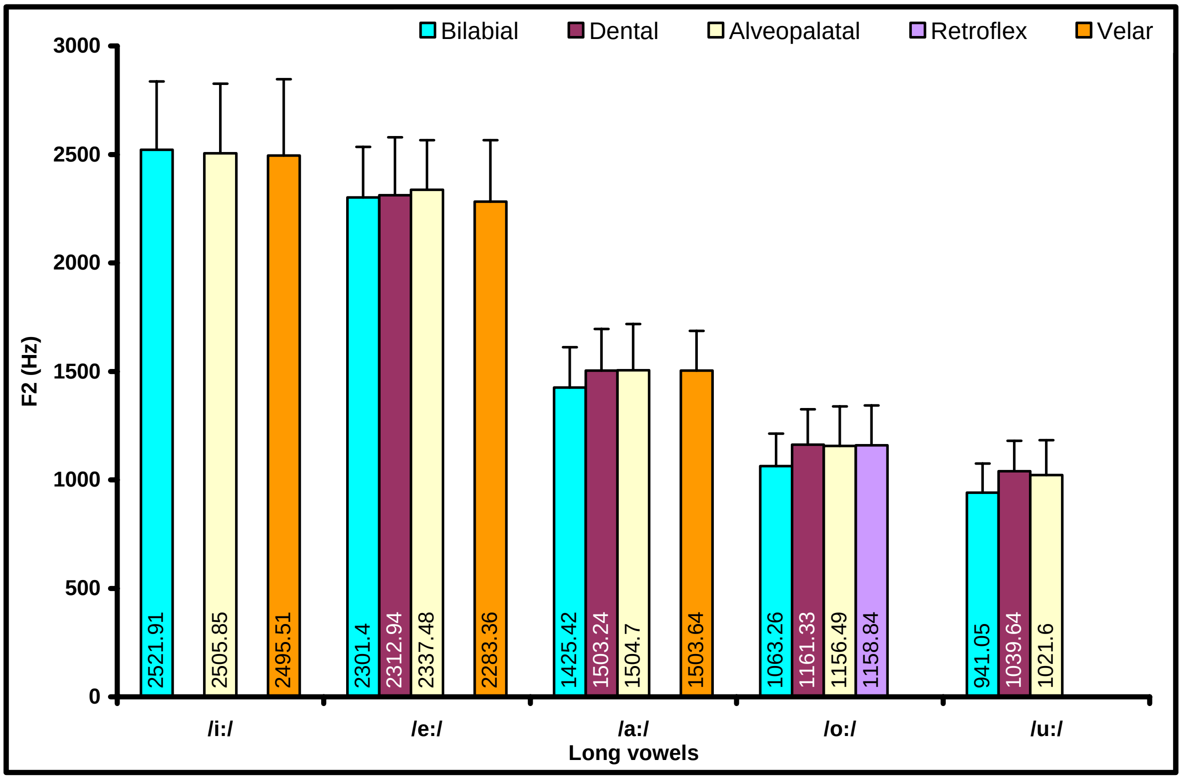


Figure 4.2.3.6b: Mean F2 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

Vowels when preceded by voiceless consonants had higher mean F2 than when preceded by voiceless consonants except for /e/ and /a/ among short vowels and /o:/ and /u:/ among long vowels The mean F2 and 1 SD bars of all vowels across the voicing feature of the preceding consonant are depicted in Figure 4.2.3.7. The means and SD of all the vowels for different voiced and voiceless consonants are given in Appendix VIII d (Table 4.2.3.8).

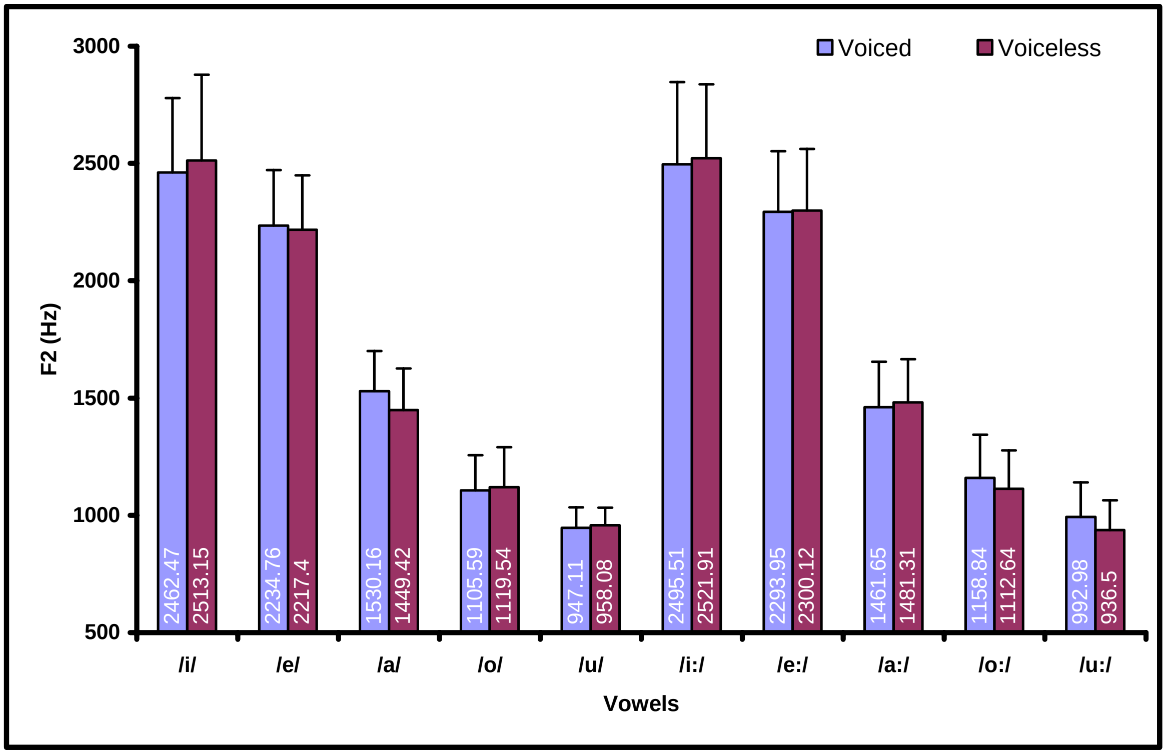


Figure 4.2.3.7: Mean F2 (Hz) of vowels preceded by different voicing feature of consonants

Do age, gender and region have any association with F2 and if so what kind of association and which of the vowels studied have significant difference in F2 among the age, gender and region groups were the questions posed to further understand the variations in the F2 observed in the analysis. Random intercept model 3 was used (as described in the method) to understand if there was any association between F2 and age, gender and region groups. The results are given in Table 4.2.3.a.

Table 4.2.3.a: Statistical analysis using random intercept model for F2

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	1856.94	99.89	18.59	< 0.01
Age (β_{1ijk})	-8.84	0.47	-18.81	< 0.01
Gender (β_{2ijk})	-102.66	5.97	-17.19	< 0.01
Region (β_{3ijk})	3.79	3.64	1.04	0.15
Variance components				
Random Error:	34461.97			
Consonant Level:	7129.79			
Individual level:	337364.30			
Total variation:	378956.06			
*-2*log likelihood(IGLS) = 57632.38*				

**significant at 0.05 level*

Model: Second formant frequency (F2) = 1856.94 – 8.84age –102.66gender + 3.79region

From Table 4.2.3.a, it is observed that, there is a significant association between F2 and age, gender and region. Further, age and gender have negative association with F2.

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was done and the results suggested that F2 of all vowels showed statistically significant difference between children, adolescents and adults (Table 4.2.3.b) except for front and back vowels /i/, /e/, /o/ and /u:/ between children and adolescents; /u/ and /e:/ in all age groups and /i:/ in children – adults and adolescents – adult groups. Within the region groups, all the vowels had statistically no significant difference in F2 between Coastal, Rayalaseema and Telengana speakers, except for mid vowel /a:/ between Coastal – Telengana (Table 4.2.3.c). Student's *t*-test was done to study which of the vowels significantly differed with the gender groups. The results are given in Table 4.2.3.d.

Table 4.2.3.b: Post hoc results for each vowel between age groups for F2

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	-33.72	0.822
	Children	Adult	139.02(*)	0.038
	Adolescent	Adult	172.74(*)	0.007
/e/	Children	Adolescent	53.73	0.114
	Children	Adult	197.27(*)	< 0.01
	Adolescent	Adult	143.54(*)	< 0.01
/a/	Children	Adolescent	78.40(*)	< 0.01
	Children	Adult	190.51(*)	< 0.01
	Adolescent	Adult	112.11(*)	< 0.01
/o/	Children	Adolescent	26.95	0.377
	Children	Adult	166.76(*)	< 0.01
	Adolescent	Adult	139.81(*)	< 0.01
/u/	Children	Adolescent	3.83	0.876
	Children	Adult	8.24	0.544
	Adolescent	Adult	4.41	0.839
/i:/	Children	Adolescent	-145.47(*)	0.005
	Children	Adult	-106.76	0.057
	Adolescent	Adult	38.70	0.682
/e:/	Children	Adolescent	-14.76	0.877
	Children	Adult	7.75	0.964
	Adolescent	Adult	22.51	0.736
/a:/	Children	Adolescent	129.53(*)	< 0.01
	Children	Adult	280.26(*)	< 0.01
	Adolescent	Adult	150.73(*)	< 0.01
/o:/	Children	Adolescent	53.93(*)	0.030
	Children	Adult	227.96(*)	< 0.01
	Adolescent	Adult	174.03(*)	< 0.01
/u:/	Children	Adolescent	34.53	0.165
	Children	Adult	169.56(*)	< 0.01
	Adolescent	Adult	135.04(*)	< 0.01

*significant at 0.05 level

Table 4.2.3.c: Post hoc results for each vowel between region groups for F2

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-21.26	0.928
	Coastal	Telengana	43.82	0.725
	Rayalaseema	Telengana	65.07	0.498
/e/	Coastal	Rayalaseema	-65.07	0.498
	Coastal	Telengana	-29.83	0.546
	Rayalaseema	Telengana	29.83	0.546
/a/	Coastal	Rayalaseema	-4.37	0.972
	Coastal	Telengana	-1.75	0.995
	Rayalaseema	Telengana	2.62	0.990
/o/	Coastal	Rayalaseema	-.91	0.999
	Coastal	Telengana	-25.84	0.478
	Rayalaseema	Telengana	-24.93	0.502
/u/	Coastal	Rayalaseema	4.69	0.821
	Coastal	Telengana	-3.05	0.919
	Rayalaseema	Telengana	-7.74	0.583
/i:/	Coastal	Rayalaseema	24.22	0.865
	Coastal	Telengana	35.72	0.730
	Rayalaseema	Telengana	11.50	0.968
/e:/	Coastal	Rayalaseema	-2.88	0.995
	Coastal	Telengana	-14.96	0.874
	Rayalaseema	Telengana	-12.08	0.915
/a:/	Coastal	Rayalaseema	-6.05	0.940
	Coastal	Telengana	-43.29(*)	0.044
	Rayalaseema	Telengana	-37.24	0.097
/o:/	Coastal	Rayalaseema	-.81	0.999
	Coastal	Telengana	-57.14	0.060
	Rayalaseema	Telengana	-56.33	0.065
/u:/	Coastal	Rayalaseema	-17.12	0.712
	Coastal	Telengana	-17.79	0.691
	Rayalaseema	Telengana	-.67	0.999

*significant at 0.05 level

Table 4.2.3.d: Student's *t*-test results for all vowels between two gender groups for F2

Vowel	Mean Difference	df	t
/i/	209.48	203.737	4.679*
/e/	233.66	407.832	11.269*
/a/	122.88	557.402	8.245*
/o/	119.14	355	6.991*
/u/	1.30	636	0.204
/i:/	102.85	285.293	2.705*
/e:/	147.19	427	6.239*
/a:/	111.45	709.980	7.862*
/o:/	60.32	284	2.961*
/u:/	72.58	282	4.220*

*significant at 0.05 level

From the Table 4.2.3.d, it is observed that all the vowels had statistically significant difference in F2 between females and males except for back high vowel /u/.

From the results, it is inferred that there is a significant association between age, gender and region with F2. As age increased, there was a significant decrease in F2 and also significant variation among the region and gender groups. However, individual vowel variations within the region groups were not significant; they tend to be significant with influence of consonant and individual level variations. It is also inferred that, individual variations contribute higher than consonant contexts for the F2 of the vowels in Telugu.

From the results of the current study it is observed that, F2 varied depending upon the transition of the tongue in the vocal tract. The current findings support the rules given by Pickett (1996) that, the frequency of F2 is lowered by back tongue constriction and F2 is raised by a front tongue constriction. Similar results are noted in the literature *viz.,* Joos (1948), Peterson & Barney (1952), Fant (1960), Hasegawa-Johnson, Pizza, Alwan, Cha & Hake, (2003), Whalen et.al., (2004), Riyamol (2007), Nagamma Reddy (1999). The results of the current study support the findings of Nagamma Reddy (1998), that long vowels have higher F2 than short vowels. It was observed that, F2 variations based on the tongue transition, causing variations in the vocal tract length were concurrent with the findings observed in all the languages.

The findings in the current study of F2 decreasing as age progressed has been reported in English (Peterson & Barney, 1952; Eguchi & Hirish, 1969; Kent, 1976) in Hebrew (Most et.al., 2000), in New Zealand English (Watson et.al., 2004) and in Indian languages (Sreedevi, 2000; Ampathu, 1998). It may be inferred that F2 variations are consistent with age related changes in the vocal tract length and resonance (Monsen & Engerbretson, 1983; Watson et.al., 2004) and get established during adolescence (Most et.al., 2000). The results of the current study are not in consonance with the findings of Peterson and Barney (1952), especially vowel /a:/ having higher F2 than /e/. This probably could be due to the tongue position and its variations due to linguistic differences. Nagamma Reddy (1999) in her study in understanding coarticulatory effects in Telugu did comment that, F2 in vowel /a/ was reduced when followed by /i/. In the current study, most of the words where vowel /a/ was studied had /i/ as the following vowel.

Gender variations (females having higher F2 compared to males) as observed in the current study, were also reported in English (Peterson & Barney, 1952; Kent, 1976; Cox, 2004) in Hebrew (Most et.al., 2000), in Mexican Hakka Chinese (Man, 2007) in Indian languages (Sreedevi, 2000; Riyamol, 2007), suggesting it as an universal phenomenon. In the literature, the variations among the gender were attributed to the vocal tract anatomy and physiology.

From the current study, it may be inferred that, regional variations do occur across the speakers for F2, though statistically not significant. Most et.al., (2000) had commented that regional, cultural variations for formants can exist. The variations in F2 can be attributed to the anatomical (Watson et.al., 2004) and dialectal differences (Venkateswara Sastry, 1990-91) in the different regions. Although Nagamma Reddy (1999) did palatographical studies to understand the tongue movement in Telugu, regional variations were not reported. Further research to understand these differences could throw light on the anatomical and physiological variations if any that could contribute to variations between the regions.

Influence of preceding consonant on F2 of the following vowel was observed in English (Black, 1939; Stevens & House, 1963; Hillenbrand et.al., 1995; Nagamma Reddy, 1999). As commented by Stevens & House (1963), F2 of the vowel differed considerably from one to another and the consonantal context did cause systematic shift in the vowel formant frequencies depending upon the place, manner and voicing characteristics of the consonant.

4.2.3.2 Summary of F2

From the current study, it can be concluded that, in Telugu:

- The long vowels had higher F2 compared to short vowels.
- High front vowel /i/ and /i:/ had the highest F2 and back high vowel /u/ and /u:/ the lowest F2, in all age, gender and region groups.
- Front vowels had higher F2 followed by central and back.
- F2 decreased as age increased.
- Children had higher F2followed by adolescents and adults.
- Females had higher F2 values when as compared to males for all vowels.
- Regional variation of second formant was observed more in short vowels than for long vowels.
- Rayalaseema speakers had higher F2 for vowels /i/, /e/ and /a/ while Telengana speakers had higher F2 for vowel /o/ and /u/.
- Telengana speakers had consistently higher F2 for long vowels /e:/, /a:/, /o:/ and /u:/ except for /i:/ where speakers from Coastal region had higher F2.
- Vowels when preceded by voiced consonants had higher F2 than when followed by voiceless consonants.
- Vowels following lateral consonants had higher F2 followed by affricatives, semivowels, nasals, stops, trills and fricatives.
- Vowels when preceded by Velar consonants had higher F2 followed by retroflex, alveopalatal, bilabial and dental consonants.

- Central vowels when preceded by stop consonants had higher F2 followed by fricative and nasal consonants.
- Back vowels had higher F2 when preceded by nasal consonants followed by stop and fricative consonants.
- Central vowels had higher F2 when preceded by velar consonants followed by dental and bilabial consonants.
- Back vowels had higher F2 when preceded by dental consonants followed by bilabial and velar consonants.

4.2.4 Third Formant Frequency (F3)

Long vowels had higher mean F3 compared to short vowels. High front vowel /i/ and /i:/ had the highest mean F3 and back high vowel /u/ and /u:/, the lowest F3. Front vowels had higher mean F3 followed by central and back vowels. As the phonetic length of the vowel increased, mean F3 increased for all the vowels. The mean F3 and 1 SD bars of all vowels are depicted in Figure 4.2.4.1. The means, SD and 95% confidence interval for mean of all the vowels; and for central, front and back vowels across the age groups are given in Appendix VIII e (Tables 4.2.4.1 and 4.2.4.2 respectively).

It was observed that as age increased, F3 decreased. Children have higher F3 followed by adolescents and adults. It was noted that, the front high vowel /i/ and /i:/ have higher mean F3 values and high back vowel /u/ and /u:/, lower mean F3 values across the age groups. As the phonetic length of the vowel increased, mean F3 increased for all vowels except for /a/ and /o/ in children and /u/ in adolescents. The mean F3 and 1 SD bars of all vowels across different age groups are depicted in Figure 4.2.4.2. The means, SD and 95% confidence interval for mean of all the vowels for all the three age groups are given in Appendix VIII e (Table 4.2.4.3).

As a gender, females had higher F3 values when compared to males for all vowels. The high front vowel /i/ and /i:/ had higher mean F3 while back high vowel /u/ and /u:/, lower mean F3 in both the genders. Observation of the data based on phonetic length, indicated enhanced mean F3 values as the phonetic length increased, except for mid vowel /a/ in females. The mean F3 and 1 SD bars of all vowels across gender groups are depicted in Figure 4.2.4.3. The means, SD and 95% confidence interval for mean of all the vowels for the two gender groups are given in Appendix VIII e (Table 4.2.4.4).

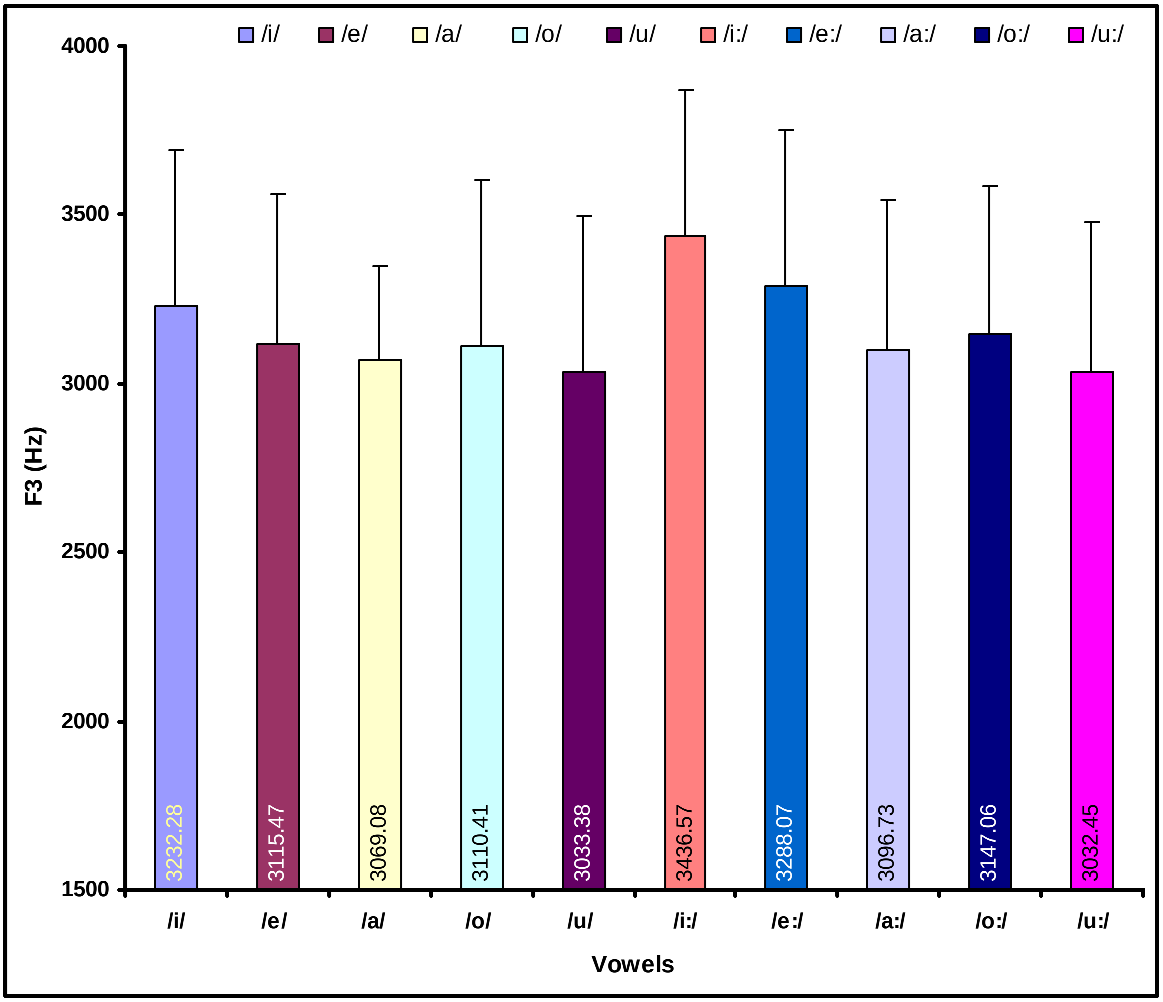


Figure 4.2.4.1: Mean F3 (Hz) and 1 SD bars of all vowels

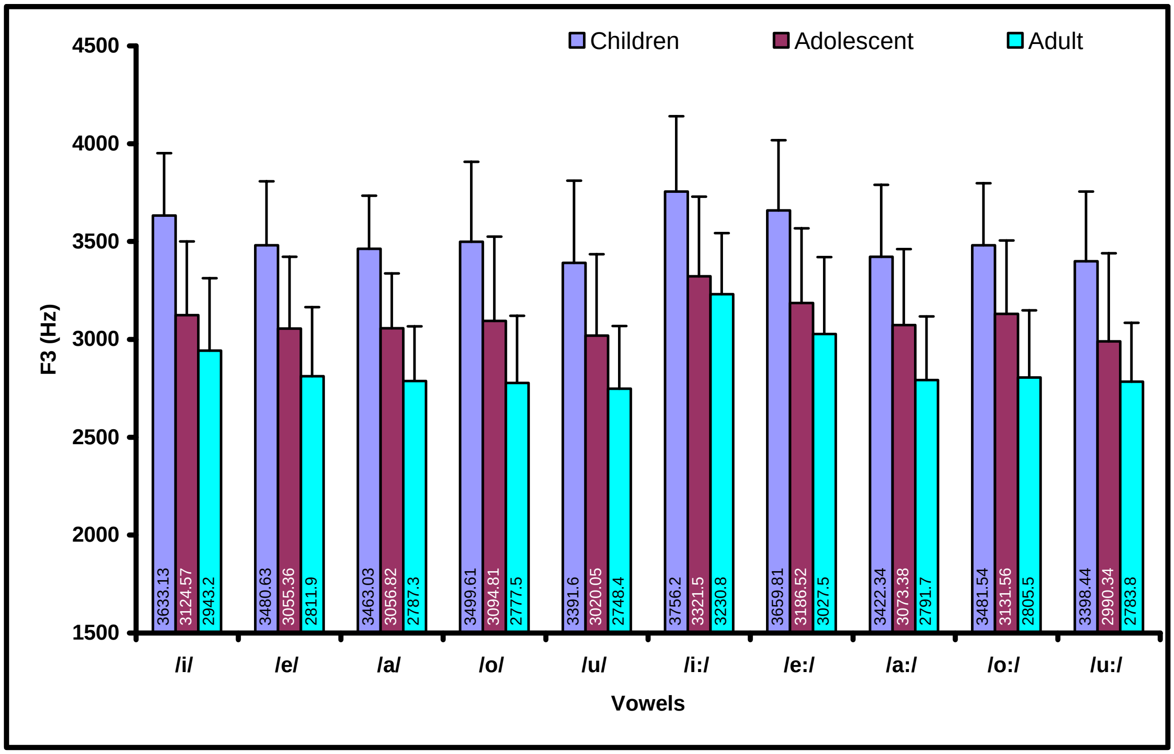


Figure 4.2.4.2: Mean F3 (Hz) and 1 SD bars across age groups

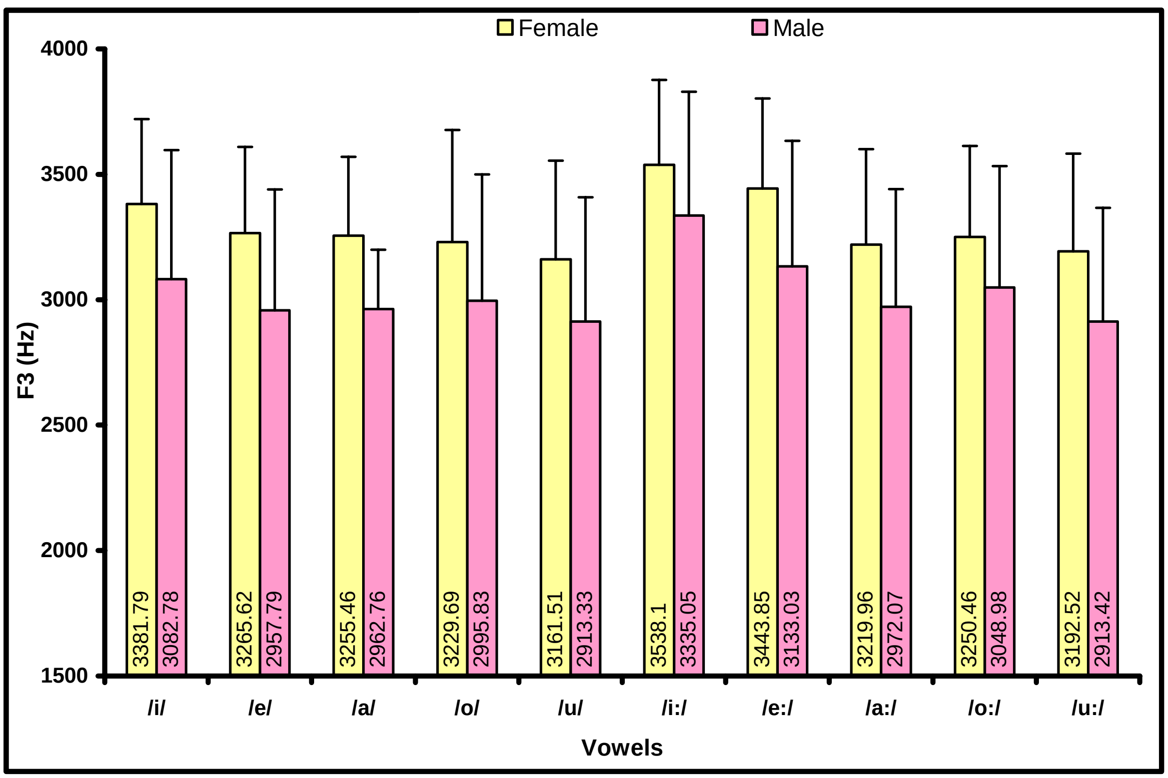


Figure 4.2.4.3: Mean F3 (Hz) and 1 SD bars across gender groups

As a regional group, speakers from Rayalaseema region had higher F3 followed by Telengana and Coastal speakers for all the vowels. It was also seen that, front high vowels /i/ and /i:/ had higher mean F3 while back high vowels /u/ and /u:/, lower mean F3. On scrutiny of the data based on phonetic length, it was noted that, as phonetic length increased, mean F3 increased in all regions except for mid vowel (/a/) in Coastal speakers, back vowel (/o/) in Rayalaseema speakers and mid & back vowels (/a/ & /u/) in Telengana speakers. The mean F3 and 1 SD bars of all vowels across different regional groups are depicted in Figure 4.2.4.4. The means, SD and 95% confidence interval for mean of all the vowels for all the three region groups are given in Appendix VIII e (Table 4.2.4.5).

There was an effect on the F3 of the following vowel in Telugu by the manner of articulation of the preceding consonant. Front and mid vowels (/i/, /e/, /a/, /i:/, /e:/, and /a:/) had higher mean F3 when preceded by nasal consonants as compared to stop consonants, while for back vowels (/o/ & /u:/) the reverse was seen. It was also observed that vowels (/e/, /u/, /i:/, /e:/, /a:/ and /o:/) had higher mean F3 when preceded by stop consonants as compared to affricates. Both /e/ and /a/ had higher mean F3 when preceded by semivowel followed by lateral and stop consonants. Short vowels /a/ and /u/ had higher mean F3 when preceded by fricatives as compared to stop consonants. The mean F3 and 1 SD bars of short and long vowels across different manner of articulation of the preceding consonant are depicted in Figures 4.2.4.5a and 4.2.4.5b respectively. The means and SD of all the vowels preceded by different (manner of articulation) consonants are given in Appendix VIII e (Table 4.2.4.6).

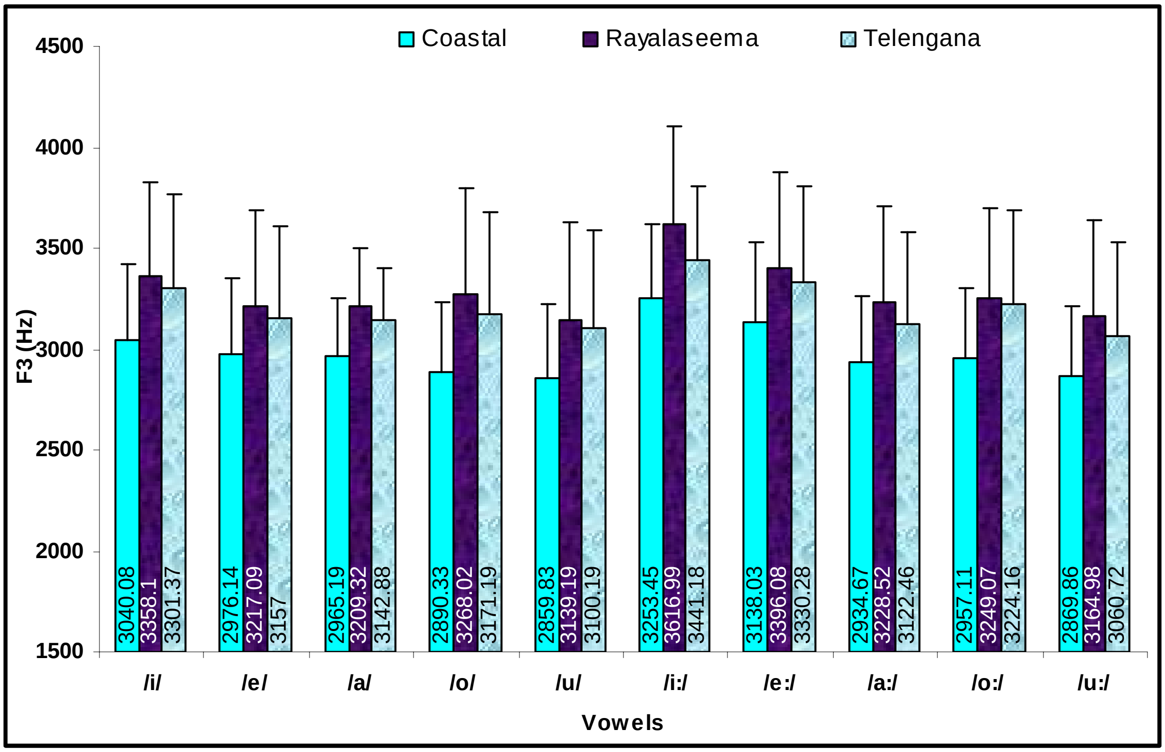


Figure 4.2.4.4: Mean F3 (Hz) and 1 SD bars across region groups

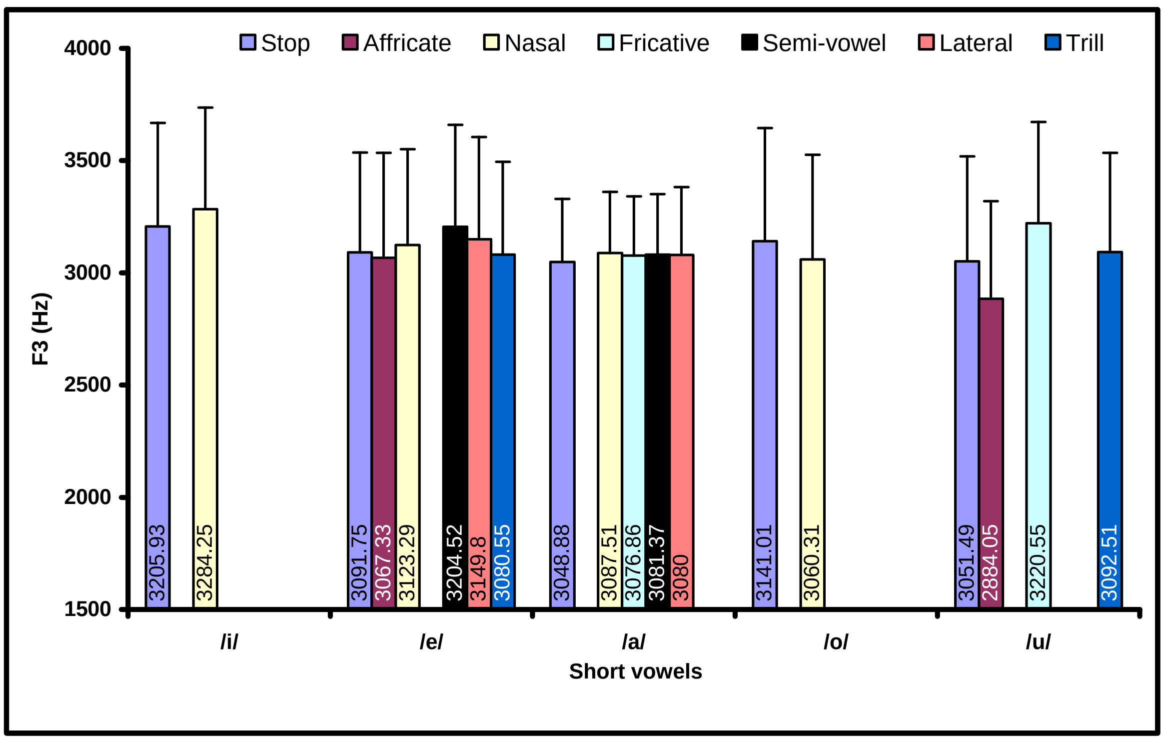


Figure 4.2.4.5a: Mean F3 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

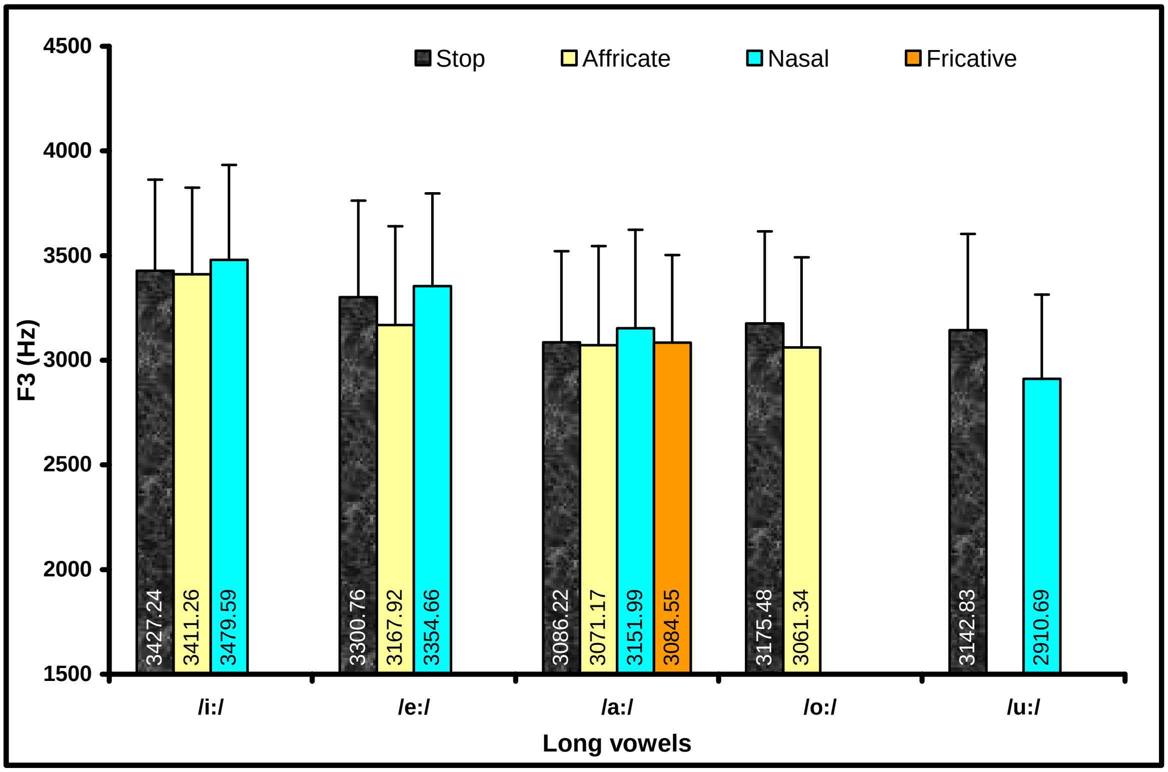


Figure 4.2.4.5b: Mean F3 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

Place of articulation of the preceding consonant also had an influence on the F3 of the following vowel in Telugu. Vowels /e/, /a/, /i:/, /e:/, /a:/, /o:/ and /u:/ had higher mean F3 when preceded by bilabials as compared to alveopalatals; however, front and back short vowels /i/, /o/ and /u/ had higher mean F3 when preceded by alveopalatals. Vowels /i/, /o/, /u/, /a:/ and /u:/ had higher mean F3 when preceded by dentals as compared to bilabials; however, front and back long vowels /e:/ and /o:/ had higher mean F3 when preceded by bilabials. Vowels /a/, /u/, /i:/ and /a:/ had higher mean F3 when preceded by alveopalatals as compared to velar consonants while front mid long vowel /e:/, higher mean F3 when preceded by velars. Front and mid vowels /a/, /i:/ and /a:/ had higher mean F3 when preceded by bilabials followed by alveopalatals and velar consonants, while back vowel /u/, higher mean F3 when preceded by alveopalatals followed by velar and bilabials. Short and long mid vowels /a/ and /a:/ had higher mean F3 when preceded by bilabials as compared to velars. Short and long back vowels /o/, /u/ and /u:/ had higher mean F3 when preceded by dentals as compared to bilabials while /o:/ had higher mean F3 when preceded by bilabials. The mean F3 and 1 SD bars of short and long vowels across different place of articulation of the preceding consonant are depicted in Figures 4.2.4.6a and 4.2.4.6b respectively. The means and SD of all the vowels preceded by different (place of articulation) consonants are given in Appendix VIII e (Table 4.2.4.7).

Short vowels had higher mean F3 when preceded by voiced consonants except for /o/ while long vowels had higher mean F3 when preceded by voiceless consonants except for /a:/. Front short vowels (/i/ & /e/) had higher mean F3 when preceded by voiced consonants while long vowels (/i:/ & /e:/) had higher mean F3 when preceded by voiceless consonants. The mean F3 and 1 SD bars of all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.4.7. The means and SD of all the vowels for different voiced and voiceless consonants are given in Appendix VIII e (Table 4.2.4.8).

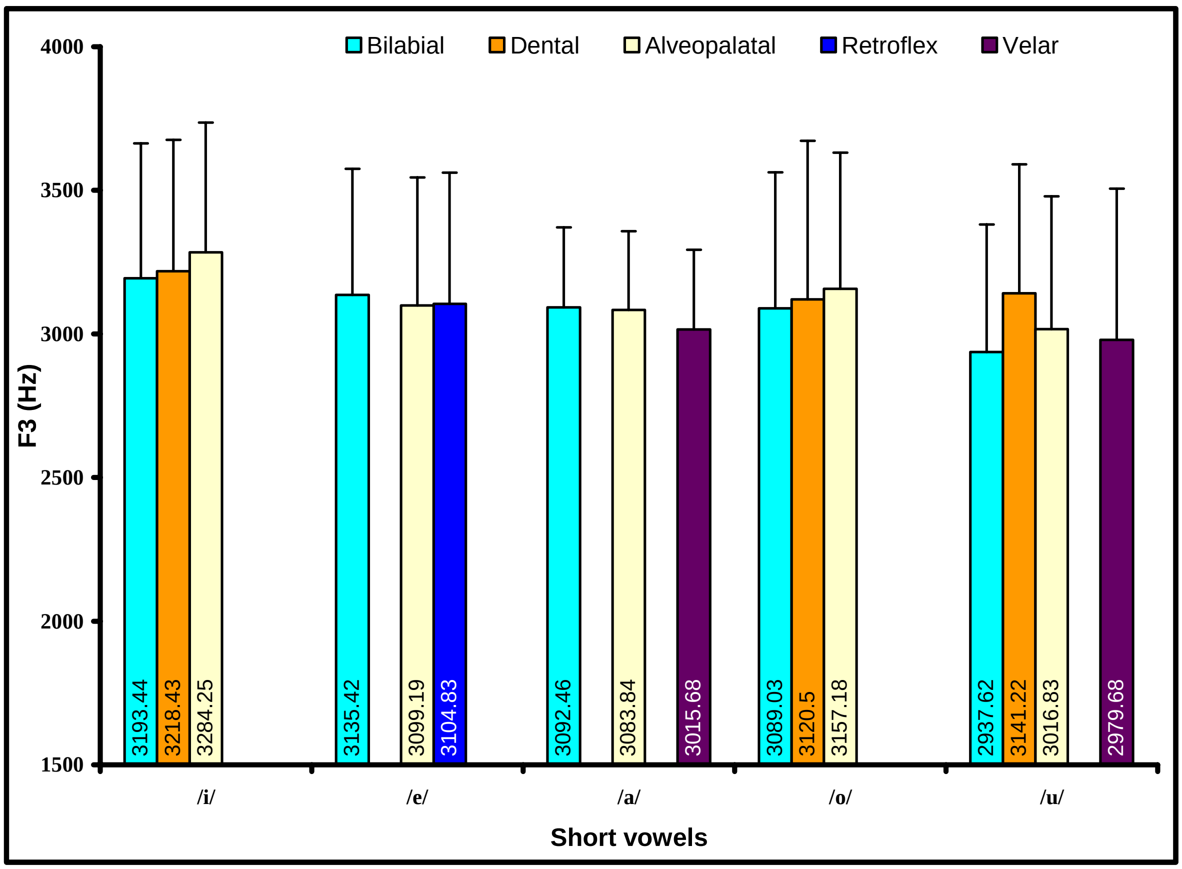


Figure 4.2.4.6a: Mean F3 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

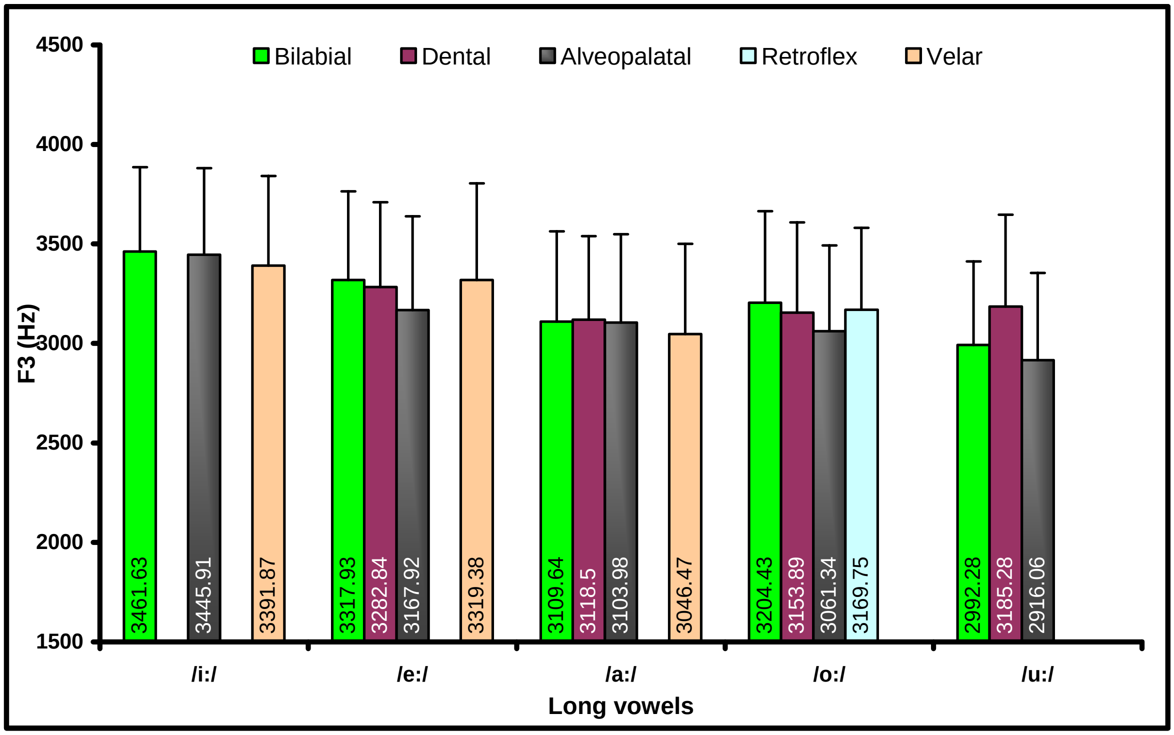


Figure 4.2.4.6b: Mean F3 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

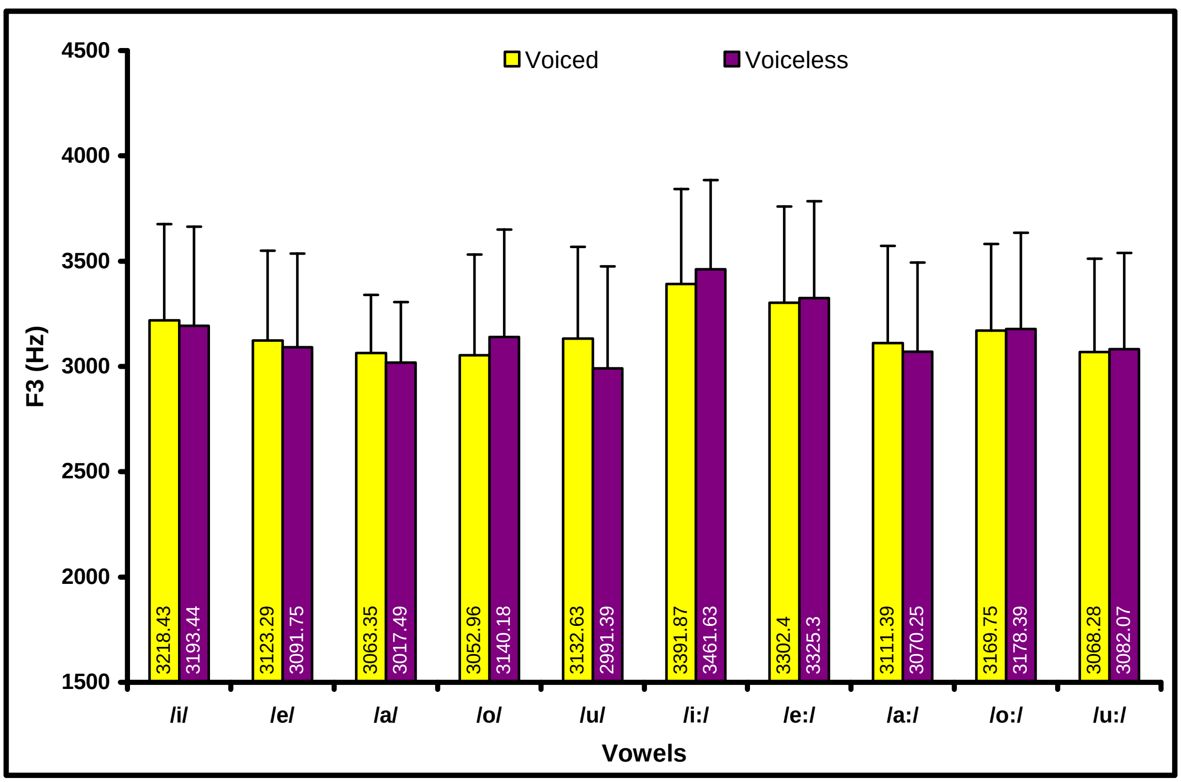


Figure 4.2.4.7: Mean F3 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

Queries on whether age, gender and region have any association with F3 and if so the kind of association and which of the vowels studied have significant difference in F3 among the age, gender and region groups were addressed to further understand the variations in the F3 observed in the analysis. Random intercept model 3 was used (as described in the method) to understand if there was any association between F3 and age, gender and region groups. The results are given in Table 4.2.4.a. and it is observed that, there is a significant association between F3 and age, gender and region, with age and gender have negative association with F3.

Table 4.2.4.a: Statistical analysis using random intercept model for F3

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	3427.99	49.67	69.02	< 0.01
Age (β_{1ijk})	-215.87	18.72	-11.53	< 0.01
Gender (β_{2ijk})	-5.82	2.36	-2.47	0.01
Region (β_{3ijk})	83.00	6.82	12.17	< 0.01
Variance components				
Random Error:	99282.01			
Consonant Level:	51653.04			
Individual level:	42397.89			
Total variation:	193332.94			
*-2*log likelihood(IGLS) = 57059.31*				

***significant at 0.05 level**

Model: Third formant frequency (F3) = 3427.99 – 215.87age – 5.82gender + 83.00region

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was done and the results suggested that F3 of all vowels showed statistically significant difference between children, adolescents and adults (Table 4.2.4.b) except for mid vowel /a/ between all age groups and /i:/ between adolescents and adults. Within the region groups, majority of vowels (/i/, /e/, /o/, /u/, /e:/, /o:/ and /u:/) did not significantly differ in F3 between Rayalaseema and Telengana speakers and in all regional groups for mid vowel /a/ (Table 4.2.4.c). Student's *t*-test reflected that all vowels had statistically significant difference in F3 between females and males except for mid low vowel /a/ (Table 4.2.4.d).

Table 4.2.4.b: Post hoc results for each vowel between age groups for F3

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	508.56(*)	< 0.01
	Children	Adult	689.90(*)	< 0.01
	Adolescent	Adult	181.35(*)	0.007
/e/	Children	Adolescent	425.27(*)	< 0.01
	Children	Adult	668.71(*)	< 0.01
	Adolescent	Adult	243.44(*)	< 0.01
/a/	Children	Adolescent	6.20	0.975
	Children	Adult	-24.27	0.681
	Adolescent	Adult	-30.47	0.549
/o/	Children	Adolescent	404.80(*)	< 0.01
	Children	Adult	722.09(*)	< 0.01
	Adolescent	Adult	317.29(*)	< 0.01
/u/	Children	Adolescent	371.56(*)	< 0.01
	Children	Adult	643.22(*)	< 0.01
	Adolescent	Adult	271.66(*)	< 0.01
/i:/	Children	Adolescent	434.69(*)	< 0.01
	Children	Adult	525.39(*)	< 0.01
	Adolescent	Adult	90.70	0.213
/e:/	Children	Adolescent	473.29(*)	< 0.01
	Children	Adult	632.29(*)	< 0.01
	Adolescent	Adult	159.01(*)	< 0.01
/a:/	Children	Adolescent	348.96(*)	< 0.01
	Children	Adult	630.62(*)	< 0.01
	Adolescent	Adult	281.66(*)	< 0.01
/o:/	Children	Adolescent	349.98(*)	< 0.01
	Children	Adult	676.06(*)	< 0.01
	Adolescent	Adult	326.08(*)	< 0.01
/u:/	Children	Adolescent	408.10(*)	< 0.01
	Children	Adult	614.67(*)	< 0.01
	Adolescent	Adult	206.57(*)	0.003

*significant at 0.05 level

Table 4.2.4.c: Post hoc results for each vowel between region groups for F3

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-318.02(*)	< 0.01
	Coastal	Telengana	-261.29(*)	0.001
	Rayalaseema	Telengana	56.73	0.723
/e/	Coastal	Rayalaseema	-240.95(*)	< 0.01
	Coastal	Telengana	-180.86(*)	0.001
	Rayalaseema	Telengana	60.09	0.425
/a/	Coastal	Rayalaseema	-14.13	0.879
	Coastal	Telengana	2.31	0.997
	Rayalaseema	Telengana	16.44	0.839
/o/	Coastal	Rayalaseema	-377.69(*)	< 0.01
	Coastal	Telengana	-280.86(*)	< 0.01
	Rayalaseema	Telengana	96.82	0.310
/u/	Coastal	Rayalaseema	-279.36(*)	< 0.01
	Coastal	Telengana	-240.36(*)	< 0.01
	Rayalaseema	Telengana	39.01	0.712
/i:/	Coastal	Rayalaseema	-363.54(*)	< 0.01
	Coastal	Telengana	-187.73(*)	0.005
	Rayalaseema	Telengana	175.80(*)	0.010
/e:/	Coastal	Rayalaseema	-258.05(*)	< 0.01
	Coastal	Telengana	-192.25(*)	0.001
	Rayalaseema	Telengana	65.80	0.434
/a:/	Coastal	Rayalaseema	-293.85(*)	< 0.01
	Coastal	Telengana	-187.79(*)	< 0.01
	Rayalaseema	Telengana	106.06(*)	0.021
/o:/	Coastal	Rayalaseema	-291.96(*)	< 0.01
	Coastal	Telengana	-267.05(*)	< 0.01
	Rayalaseema	Telengana	24.91	0.917
/u:/	Coastal	Rayalaseema	-295.12(*)	< 0.01
	Coastal	Telengana	-190.86(*)	0.031
	Rayalaseema	Telengana	104.26	0.344

*significant at 0.05 level

Table 4.2.4.d: Student's *t*-test results for all vowels between two gender groups for F3

Vowel	Mean Difference	df	t
/i/	299.01	183	5.026*
/e/	307.83	428	8.097*
/a/	12.70	502	0.533
/o/	233.86	294	4.239*
/u/	248.19	478	6.180*
/i:/	203.05	249	4.042*
/e:/	310.82	387	7.370*
/a:/	247.89	657	7.618*
/o:/	201.48	250	3.847*
/u:/	279.10	198	4.717*

*significant at 0.05 level

From the results, it is inferred that there is a significant association between age, gender and region with F3. As age increased, there was a significant decrease in F3 and also significant variation among the region and gender groups. However, individual vowel variations within the region groups are not significant; they tend to be significant with influence of consonant and individual level variations. It can also be inferred that, consonants were contributing more than individual variations to F3 changes.

The results indicate that F3 varied depending upon the transition of the tongue in the vocal tract. The findings of the current study endorse the reports by Pickett (1996), Monsen & Engebretson (1983); Peterson & Barney (1952) that, the frequency of F3 is lowered by back tongue constriction and raised by a front tongue constriction and relative volume of the vocal tract. Similar results have been reported by Joos (1948), Peterson & Barney (1952), Fant (1960), Kent (1976), Kent & Read (1995), Hasegawa-Johnson et.al., (2003), Whalen et.al., (2004), Riyamol (2007), Nagamma Reddy, (1999). The results support the findings of Nagamma Reddy (1998), that long vowels have higher F3 than short vowels. It was observed that, F3 variations based on the tongue transition, causing variations in the vocal tract length were concurrent with the findings observed in all the languages.

The findings of the current study that as age progresses, F3 decreases has also been reported in English (Peterson & Barney, 1952; Eguchi & Hirish, 1969; Kent, 1976), in Hebrew (Most et.al., 2000), in New Zealand English (Watson et.al., 2004) and in Indian languages (Sreedevi, 2000; Ampathu, 1998). It may be inferred that F3 variations are consistent with age related changes in the vocal tract length and resonance (Monsen & Engerbretson, 1983; Watson et.al., 2004). Nagamma Reddy (1999) in her study in understanding coarticulatory effects in Telugu did comment that, F3 in vowel /a/ was reduced when followed by /i/. In the current study, most of the words where vowel /a/ was studied had /i/ as the following vowel.

Gender variations (females having higher F3 as compared to males) as observed in the current study, were reported in English (Peterson & Barney, 1952; Kent, 1976; Cox, 2004) in Hebrew (Most et.al., 2000), in Mexican Hakka Chinese (Man, 2007) and in Indian languages (Sreedevi, 2000; Riyamol, 2007), suggesting it as an universal phenomenon in the languages studied. In the literature, the variations among the gender were attributed to the vocal tract anatomy and physiology and its resonance characteristics.

Based on the current analysis, it could be inferred that, regional variations are observed across the speakers for F3. Most et.al., (2000) had commented that regional, cultural variations for formants could exist. Venkateswara Sastry (1990-91), commented that, there are dialectal variations observed among the three regions. This could be contributing to variations in F3 along with anatomical differences, if any, in the different regions of the present study. Earlier reports of Nagamma Reddy (1999) on tongue movement using radiological and palatography studies did not reflect the variations among the different region speakers. Further research to understand these differences could clarify if anatomical and physiological variations existed between the regions.

Very few studies in the literature have reported of F3 variations with different consonant contexts. F3 is reported to be influenced by both preceding and following consonant context (Stevens & House, 1963; Nagamma Reddy, 1999; Hillenbrand et.al., 1995) as observed in this study also. Hillenbrand et.al., (1995) reported of F3 shift in alveolar environments, also observed in the current study. However, in the current study, the consonant environment studied was alveopalatal, that resulted in higher F3 for rounded vowels in only certain contexts. This could be due to the influence of the following consonant, phonetic rules and co-articulatory effects observed in Telugu (Nagamma Reddy, 1999).

4.2.4.2 Summary of F3

In the current study, F3 data revealed that

- Long vowels had higher F3 as compared to short vowels.
- High front vowel /i/ and /i:/ had the highest F3 and back high vowel /u/ and /u:/ had the lower F3 for all age, gender and region groups.
- Front vowels had higher F3 followed by central and back vowels.
- Children had higher F3 followed by adolescents and adults.
- Females had higher F3 values when as compared to males for all vowels.
- Speakers from Rayalaseema region had higher F3 followed by Telengana and Coastal speakers for all the vowels.
- Front and mid vowels had higher F3 when preceded by nasal consonants compared to stop consonants, while for back vowels (/o/ & /u:/) the opposite was noticed.
- Vowels had higher F3 when preceded by stop consonants as compared to affricates.
- Both /e/ and /a/ had higher F3 when preceded by semivowel followed by lateral and stop consonants.
- Short vowels /a/ and /u/ had higher F3 when preceded by fricatives as compared to stop consonants.
- Vowels /e/, /a/, /i:/, /e:/, /a:/, /o:/ and /u:/ had higher F3 when preceded by bilabials as compared to alveopalatals; however, front and back short vowels /i/, /o/ and /u/ had higher F3 when preceded by alveopalatals.
- Vowels /i/, /o/, /u/, /a:/ and /u:/ had higher F3 when preceded by dentals as compared to bilabials; however front and back long vowels /e:/ and /o:/ had higher F3 when preceded by bilabials.

- Vowels /a/, /u/, /i:/ and /a:/ had higher F3 when preceded by alveopalatals as compared to velar consonants while front mid long vowel /e:/ had higher F3 when preceded by velars.
- Front and mid vowels /a/, /i:/ and /a:/ had higher F3 when preceded by bilabials followed by alveopalatals and velar consonants, while back vowel /u/ had higher F3 when preceded by alveopalatals followed by velar and bilabials.
- Short and long mid vowels had higher F3 when preceded by bilabials as compared to velars.
- Short and long back vowels /o/, /u/ and /u:/ had higher F3 when preceded by dentals as compared to bilabials while /o:/ had higher F3 when preceded by bilabials.
- Short vowels had higher F3 when preceded by voiced consonants except for /o/ while long vowels had higher F3 when preceded by voiceless consonants except for /a:/.
- Front short vowels had higher F3 when preceded by voiced consonants while long vowels when preceded by voiceless consonants.

4.2.5 Fourth Formant Frequency (F4)

On scrutiny of the collected data, it was seen that long vowels had higher F4 as compared to short vowels. High front vowels /i/ and /i:/ had the highest mean F4 and back high vowels /u/ and /u:/, the lowest mean F4. Front vowels had higher mean F4 followed by central and back vowels. As the phonetic length of the vowel increased, mean F4 increased for all vowels. The mean F4 and 1 SD bars of all vowels are depicted in Figure 4.2.5.1. The means, SD and 95% confidence interval for mean of all the vowels; and for central, front and back vowels across the age groups are given in Appendix VIII f (Tables 4.2.5.1 and 4.2.5.2 respectively).

From the data, it was observed that mean F4 decreased from children to adults. Children have higher F4 followed by adolescents and adults. It was observed that, the front high vowel /i/ and /i:/ have higher mean F4 values while high back vowel /u/ and /u:/, lower mean F4 values across the age groups. As the phonetic length of the vowel increased, mean F4 increased for all vowels across the age groups except for /a/, /o/ and /u/

in adults. The mean F4 and 1 SD bars of all vowels across different age groups are depicted in Figure 4.2.5.2. The means, SD and 95% confidence interval for mean of all the vowels for all the three age groups are given in Appendix VIII f (Table 4.2.5.3).

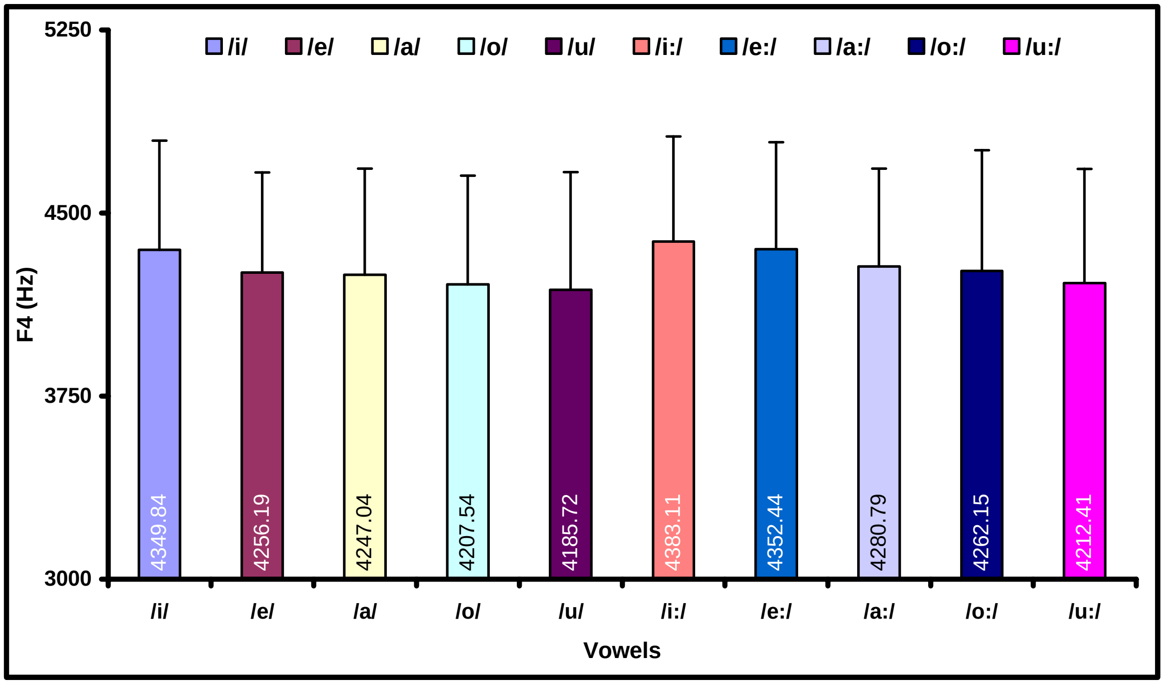


Figure 4.2.5.1: Mean F4 (Hz) and 1 SD bars of all vowels

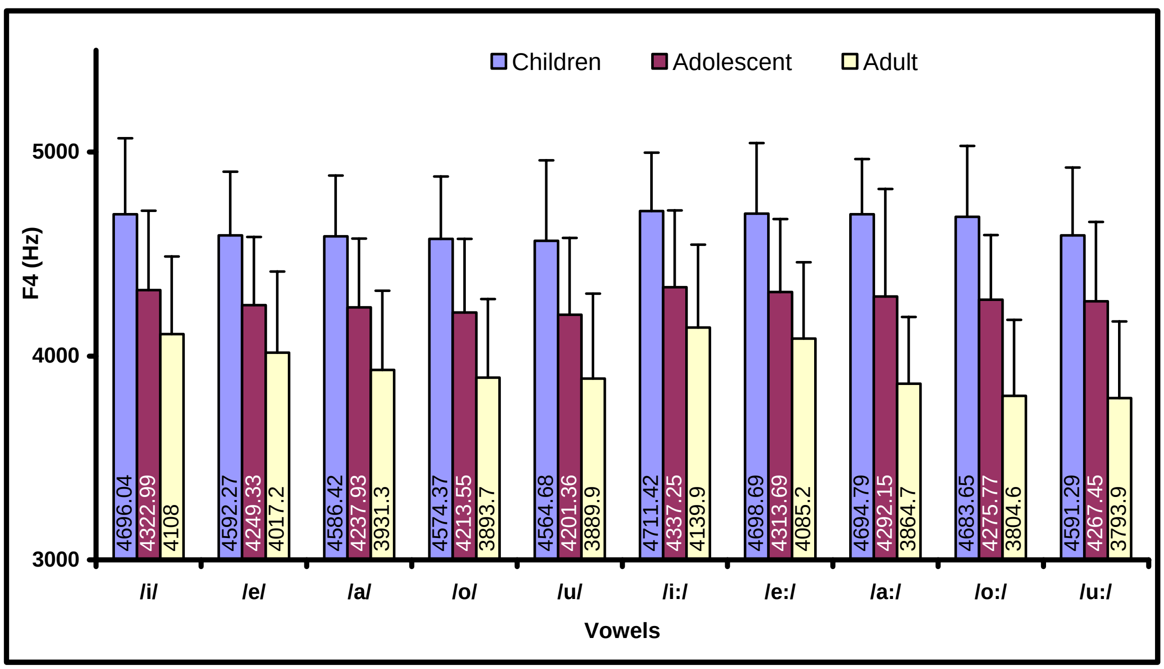


Figure 4.2.5.2: Mean F4 (Hz) and 1 SD bars across age groups

In the current study, females had higher F4 values when compared to males for all vowels. The high front vowel /i/ and /i:/ had higher F4 while back high vowel /u/ and /u:/ had lower F4 in both genders. On further observation of the data, it was found that, there was an increase in F4 values as the phonetic length increased in both genders. The mean F4 and 1 SD bars of all vowels across gender groups are depicted in Figure 4.2.5.3. The means, SD and 95% confidence interval for mean of all the vowels for the two gender groups are given in Appendix VIII f (Table 4.2.5.4).

From the data, it was observed that speakers from Rayalaseema region had higher F4 followed by Telengana and Coastal speakers for short vowels while Telengana speakers had higher mean F4 followed by Rayalaseema and Coastal speakers for long vowels. Further, it was observed that front high vowels /i/ and /i:/ had higher mean F4 while back high vowels /u/ and /u:/ had lower mean F4. On scrutiny of the data based on phonetic length, it was noted that, as phonetic length increased, mean F4 increased in all regions except for mid (/a/) in Rayalaseema speakers. The mean F4 and 1 SD bars of all vowels across regional groups are depicted in Figure 4.2.5.4. The means, SD and 95% confidence interval for mean of all the vowels for all the three region groups are given in Appendix VIII f (Table 4.2.5.5).

Manner of articulation of the preceding consonant did have an effect on F4 of the following vowel in Telugu. In the current study, it was observed that, front and mid short vowels (/i/ and /a:/) had higher mean F4 when preceded by nasal consonants as compared to stop consonants, while for vowels /e/, /o/, /i:/, /e:/, /a:/ and /u:/ the reverse was noticed. All long vowels had higher mean F4 when preceded by stop consonants as compared to nasals or affricates. From the data, it was also observed that vowels (/e/, /u/, /i:/, /e:/, /a:/ and /o:/) had higher mean F4 when preceded by stop consonants as compared to affricates. Both /e/ and /a/ had higher mean F4 when preceded by lateral followed by semivowel and stop consonants. Short vowels /a/ and /u/ had higher mean F4 when preceded by fricatives as compared to stop consonants. The mean F4 and 1 SD bars of short and long vowels across different manner of articulation of the preceding consonant are depicted in Figures 4.2.5.5a and 4.2.5.5b respectively. The means and SD of all the vowels preceded by different (manner of articulation) consonants are given in Appendix VIII f (Table 4.2.5.6).

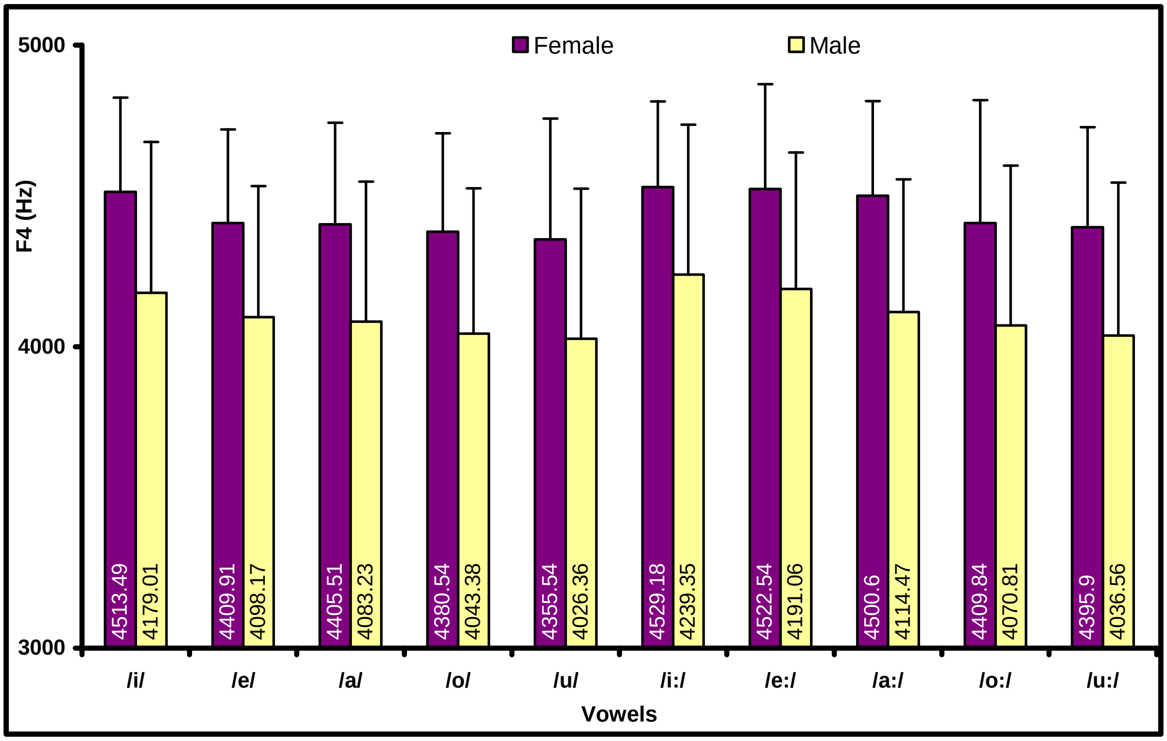


Figure 4.2.5.3: Mean F4 (Hz) and 1 SD bars across gender groups

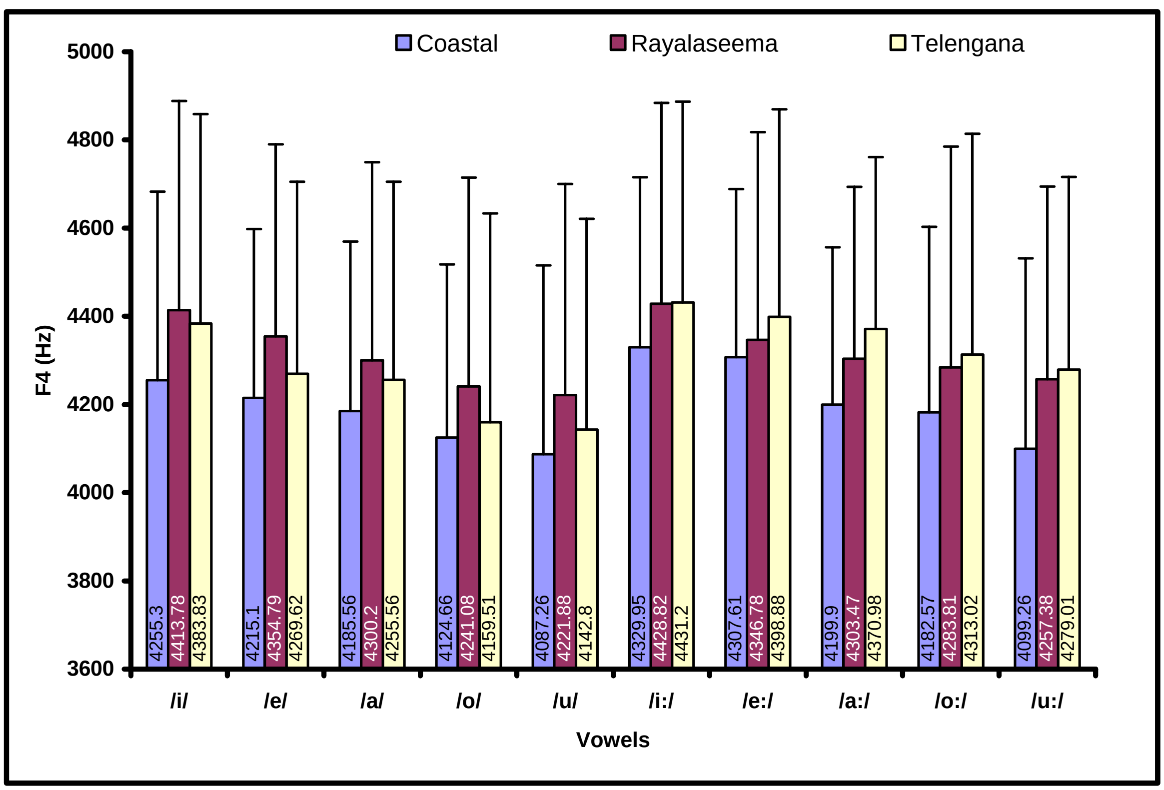


Figure 4.2.5.4: Mean F4 (Hz) and 1 SD bars across region groups

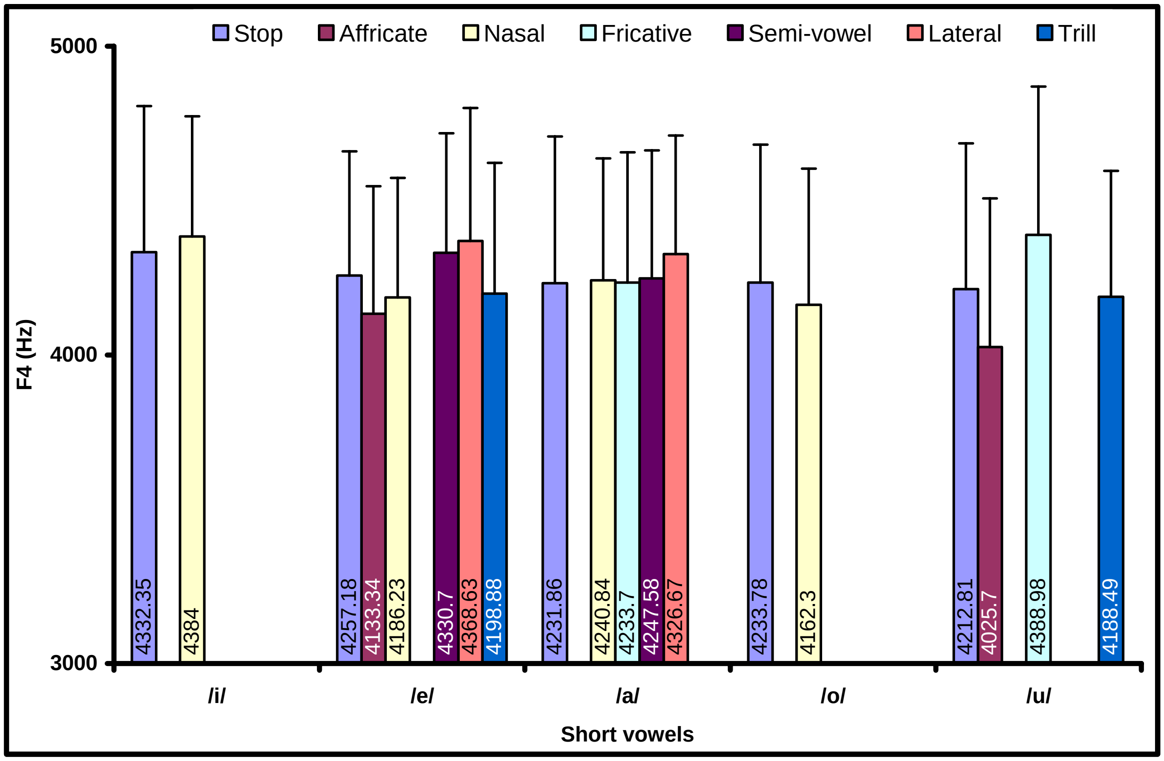


Figure 4.2.5.5a: Mean F4 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

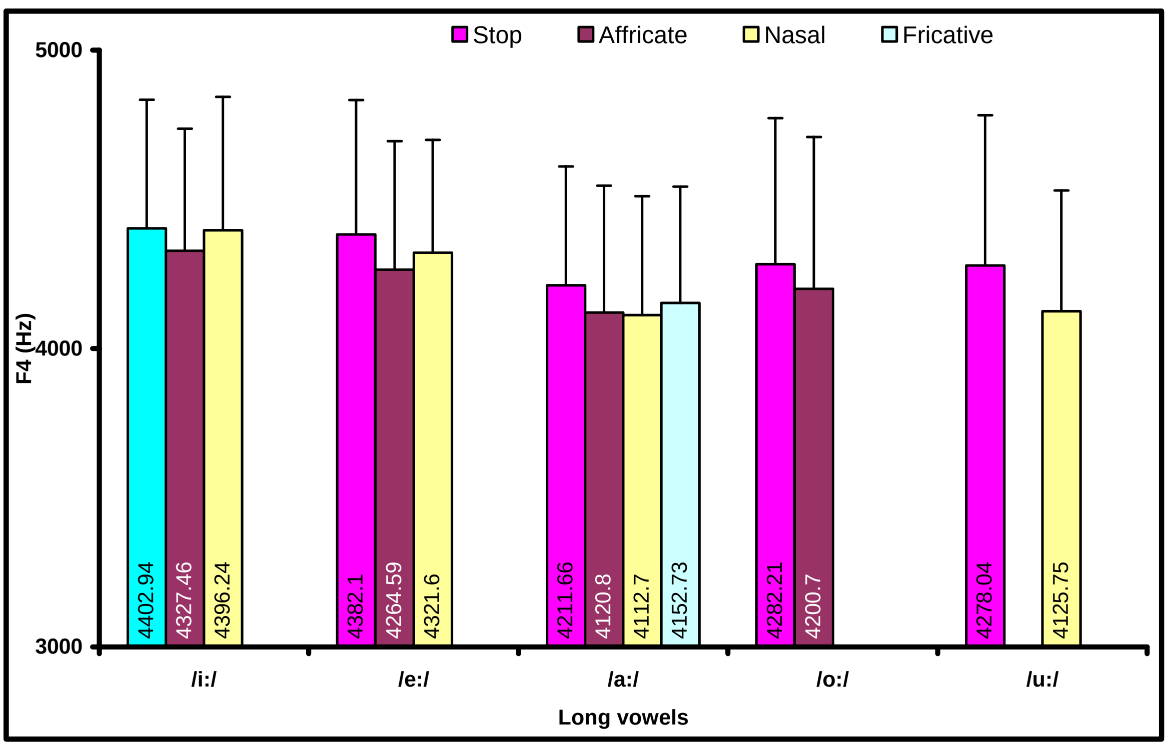


Figure 4.2.5.5b: Mean F4 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

Place of articulation of the preceding consonant also had an influence on the F4 of the following vowel in Telugu. Vowels /e/, /a/, /o/, /i:/, /e:/, /a:/, /o:/ and /u:/ had higher mean F4 when preceded by bilabials as compared to alveopalatals; however, front and back short vowels /i/ and /u/ had higher mean F4 when preceded by alveopalatals. Vowels /i/, /o/, /u/, /e:/, /a:/ and /u:/ had higher mean F4 when preceded by dentals as compared to bilabials; however back long vowel /o:/ had higher mean F4 when preceded by bilabials. Vowels /u/, /i:/, /e:/ and /a:/ had higher mean F4 when preceded by velars as compared to alveopalatal consonants while mid short vowel /a/ had higher mean F4 when preceded by alveopalatals. High vowels /i/, /u/ and /u:/ had higher mean F4 when preceded by dentals as compared to bilabial or alveopalatal consonants. Short and long mid vowels /a/ and /a:/ had higher mean F4 when preceded by bilabials as compared to alveopalatals. Short and long back vowels /o/, /u/ and /u:/ had higher mean F4 when preceded by dentals as compared to alveopalatals. The mean F4 and 1 SD bars of short and long vowels across different place of articulation of the preceding consonant are depicted in Figures 4.2.5.6a and 4.2.5.6b respectively. The means and SD of all the vowels for different preceding place of articulation consonants are given in Appendix VIII f (Table 4.2.5.7).

From the data of the current study, it is observed that voicing feature of the consonants have an influence on F4 and vary between the short and long vowels. For low and high vowels (/i/, /a/ and /u/), the mean F4 reduced with increase in phonetic length, while for mid vowels (/e/ and /o/) it increased when preceded by voiced consonants. No consistency was observed in voiceless consonant context. Vowels had higher mean F4 when preceded by voiced consonants except for high vowels (/i/, /u/ and /u:/). The mean F4 and 1 SD bars of all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.5.7. The means and SD of all the vowels for different voiced and voiceless consonants are given in Appendix VIII f (Table 4.2.5.8).

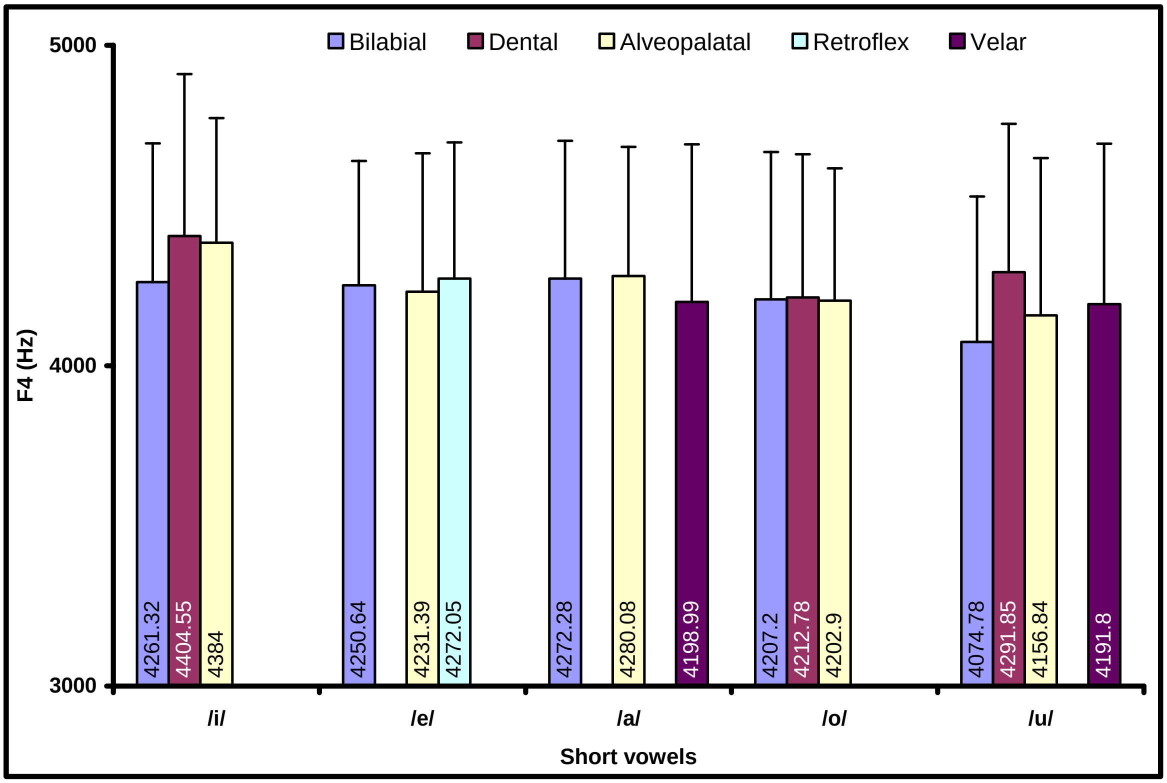


Figure 4.2.5.6a: Mean F4 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

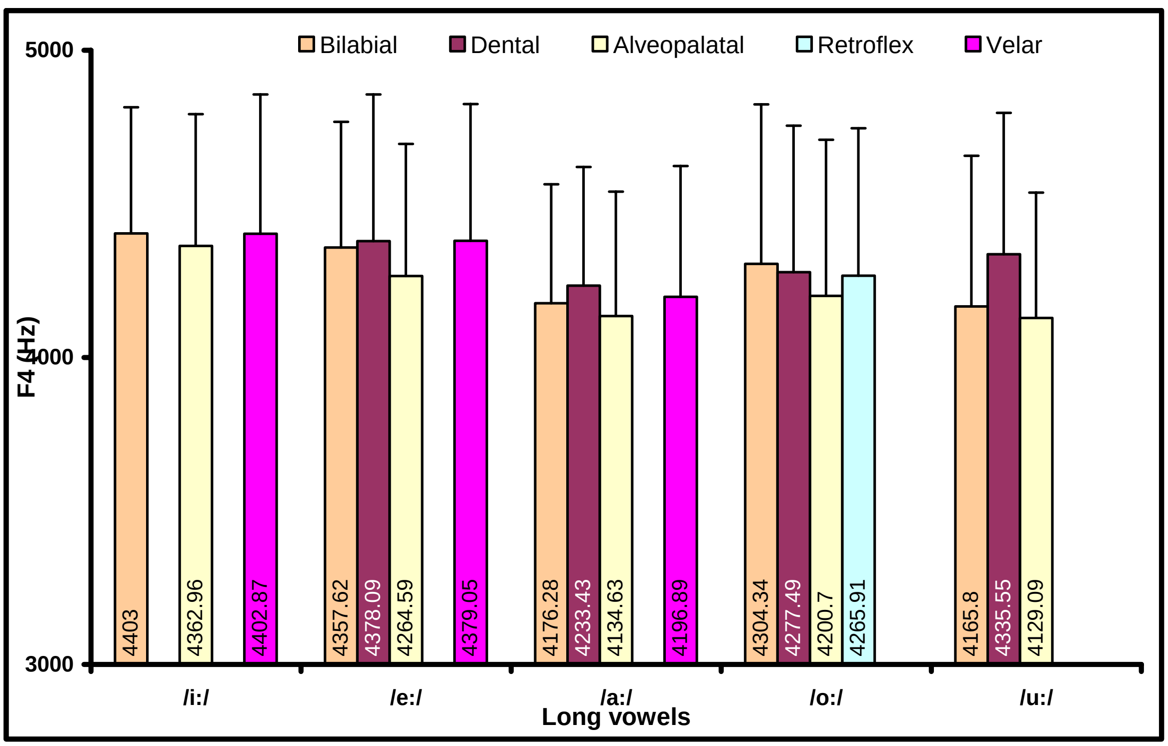


Figure 4.2.5.6b: Mean F4 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

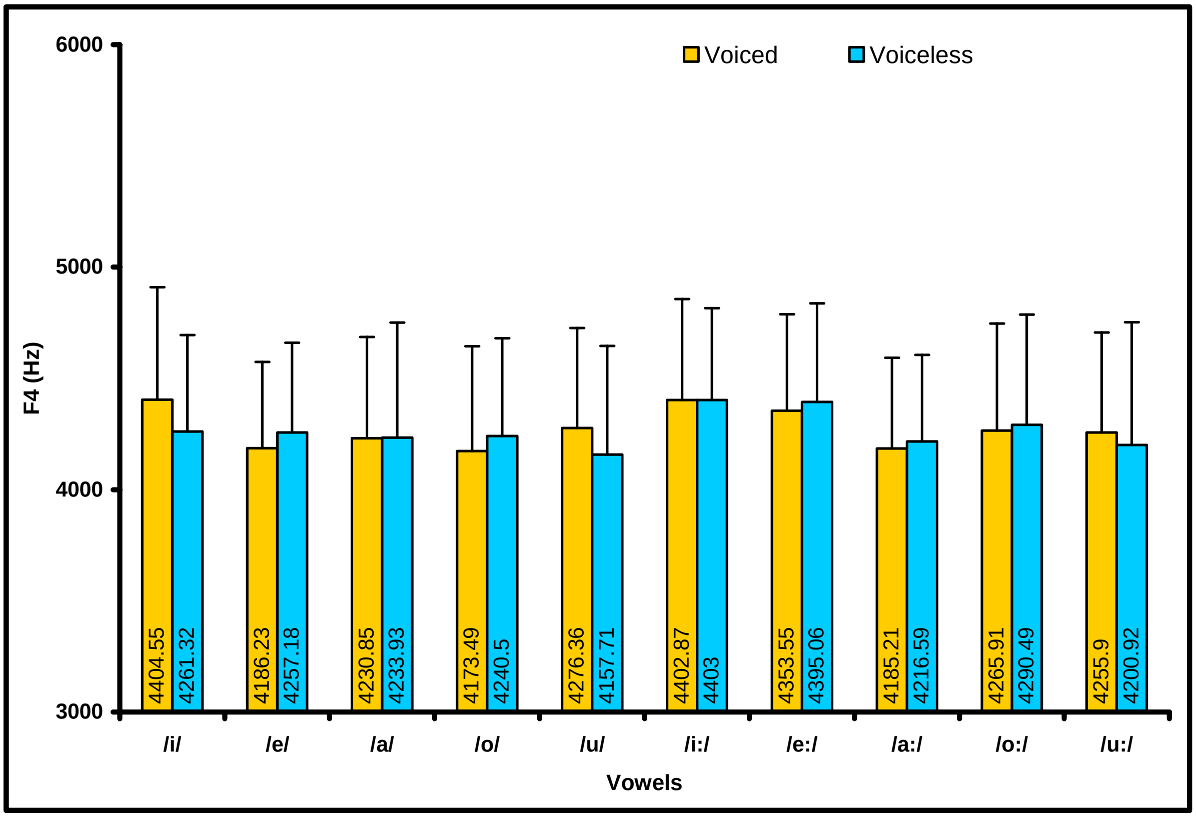


Figure 4.2.5.7: Mean F4 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

The questions “Do age, gender and region have any association with F4, if so what kind of association? and which of the vowels studied have significant difference in F4 among the age, gender and region groups” to further understand the variations in the F4 observed in the analysis were addressed by Random intercept model 3 (as described in the method) to understand if there was any association between F4 and age, gender and region groups. The results are given in Table 4.2.5.a.

Table 4.2.5.a: Statistical analysis using random intercept model for F4

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	4816.64	27.71	173.82	< 0.01
Age (β_{1ijk})	-126.00	19.61	-6.43	< 0.01
Gender (β_{2ijk})	-25.35	2.47	-10.26	< 0.01
Region (β_{3ijk})	35.99	7.07	5.09	< 0.01
Variance components				
Random Error:	106087.80			
Consonant Level:	22349.65			
Individual level:	3526.07			
Total variation:	131963.52			
*-2*log likelihood(IGLS) = 50081.62*				

**significant at 0.05 level*

Model: Fourth formant frequency (F4) = 4816.64 – 126age – 25.35gender + 35.99region

From Table 4.2.5.a, it is observed that, there is a significant association between F4 and age, gender and region. Further, age and gender have negative association with F4.

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was administered and the results suggested that F4 of all vowels showed statistically significant difference between children, adolescents and adults (Table 4.2.5.b). Within the region groups, all vowels had statistically no significant difference in F4 between the three region groups, except for /u/ between Coastal and Telengana and /a:/ between Costal and Rayalaseema speakers (Table 4.2.5.c). Student's *t*-test was done to study which of the vowels significantly differed with the gender groups. The results are given in Table 4.2.5.d.

Table 4.2.5.b: Post hoc results for each vowel between age groups for F4

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	373.05(*)	< 0.01
	Children	Adult	588.02(*)	< 0.01
	Adolescent	Adult	214.97(*)	0.004
/e/	Children	Adolescent	322.94(*)	< 0.01
	Children	Adult	525.10(*)	< 0.01
	Adolescent	Adult	202.16(*)	< 0.01
/a/	Children	Adolescent	348.48(*)	< 0.01
	Children	Adult	655.12(*)	< 0.01
	Adolescent	Adult	306.63(*)	< 0.01
/o/	Children	Adolescent	360.82(*)	< 0.01
	Children	Adult	680.69(*)	< 0.01
	Adolescent	Adult	319.87(*)	< 0.01
/u/	Children	Adolescent	363.33(*)	< 0.01
	Children	Adult	674.83(*)	< 0.01
	Adolescent	Adult	311.50(*)	< 0.01
/i:/	Children	Adolescent	374.17(*)	< 0.01
	Children	Adult	571.52(*)	< 0.01
	Adolescent	Adult	197.35(*)	0.001
/e:/	Children	Adolescent	385.00(*)	< 0.01
	Children	Adult	613.52(*)	< 0.01
	Adolescent	Adult	228.52(*)	< 0.01
/a:/	Children	Adolescent	322.64(*)	< 0.01
	Children	Adult	630.14(*)	< 0.01
	Adolescent	Adult	307.50(*)	< 0.01
/o:/	Children	Adolescent	407.88(*)	< 0.01
	Children	Adult	879.03(*)	< 0.01
	Adolescent	Adult	471.15(*)	< 0.01
/u:/	Children	Adolescent	323.84(*)	< 0.01
	Children	Adult	727.42(*)	< 0.01
	Adolescent	Adult	403.58(*)	< 0.01

*significant at 0.05 level

Table 4.2.5.c: Post hoc results for each vowel between region groups for F4

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-158.47	.134
	Coastal	Telengana	-128.53	.225
	Rayalaseema	Telengana	29.94	.926
/e/	Coastal	Rayalaseema	-39.69	.707
	Coastal	Telengana	-54.51	.475
	Rayalaseema	Telengana	-14.83	.952
/a/	Coastal	Rayalaseema	-114.64	.051
	Coastal	Telengana	-70.01	.314
	Rayalaseema	Telengana	44.63	.625
/o/	Coastal	Rayalaseema	-116.42	.189
	Coastal	Telengana	-134.85	.105
	Rayalaseema	Telengana	-18.43	.959
/u/	Coastal	Rayalaseema	-134.62	.054
	Coastal	Telengana	-155.54(*)	.022
	Rayalaseema	Telengana	-20.91	.929
/i:/	Coastal	Rayalaseema	-98.86	.315
	Coastal	Telengana	-71.24	.509
	Rayalaseema	Telengana	27.62	.914
/e:/	Coastal	Rayalaseema	-39.17	.767
	Coastal	Telengana	-91.27	.202
	Rayalaseema	Telengana	-52.10	.617
/a:/	Coastal	Rayalaseema	-133.56(*)	.003
	Coastal	Telengana	-81.08	.097
	Rayalaseema	Telengana	52.48	.382
/o:/	Coastal	Rayalaseema	-101.24	.387
	Coastal	Telengana	-130.45	.207
	Rayalaseema	Telengana	-29.21	.920
/u:/	Coastal	Rayalaseema	-158.12	.139
	Coastal	Telengana	-179.75	.100
	Rayalaseema	Telengana	-21.63	.964

*significant at 0.05 level

Table 4.2.5.d: Student's *t*-test results for all vowels between two gender groups for F4

Vowel	Mean Difference	df	t
/i/	334.48	149	5.445*
/e/	326.67	390	8.990*
/a/	307.34	451	8.345*
/o/	337.16	241	6.721*
/u/	329.18	398	7.388*
/i:/	289.83	200	5.677*
/e:/	331.48	363	8.025*
/a:/	229.80	572	7.451*
/o:/	295.37	235	4.959*
/u:/	319.34	177	5.107*

*significant at 0.05 level

From Table 4.2.5.d, it is observed that, all vowels had statistically significant difference in F4 between females and males.

From the results, it is inferred that, there is a significant association between age, gender and region with F4. As age increased, there was a significant decrease in F4 and also significant variation among the region and gender groups. Individual vowel variations within the region groups were not significant; however, they tend to be significant when other individual and consonant context variations are considered. From the statistical analysis, it could also be inferred that the effect of consonant on F4 is higher than the individual variations.

From the results of the current study it is observed that, F4 varied depending upon the transition of the tongue and constriction in the vocal tract. The current findings support the studies mentioned in the literature (Pickett, 1996; Monsen & Engebretson, 1983; Peterson & Barney, 1952) which stated that, the frequency of F4 is lowered by back tongue constriction and raised by a front tongue constriction and the relative volume of the vocal tract. Similar findings are reported in the literature by Joos (1948), Peterson & Barney (1952), Fant (1960), Kent (1976), Kent & Read (1995), Hasegawa-Johnson et.al., (2003) and Whalen et.al., (2004). F4 for vowel /e:/ was higher than the reported values by Kostić, Mitter & Krishnamurti (1977) in Telugu literature. This could be due to the heterogeneous and cross sectional sample of the current study.

The findings observed in the current study that as age progresses, F4 decreases has been reported in English (Peterson & Barney, 1952; Eguchi & Hirish, 1969; Kent, 1976). It may now be inferred that F4 variations are consistent with age related changes in the vocal tract length and resonance (Monsen & Engerbretson, 1983; Watson et.al., 2004).

Gender variations (females having higher F4 compared to males) as observed in the current study, are reported in English (Peterson & Barney, 1952; Kent, 1976), suggesting that, gender variation is an universal phenomenon. In the literature, the variations among the gender were attributed to the vocal tract anatomy and physiology and its resonance characteristics, which could be applicable to the present study also.

From the results, it may be inferred that, regional variations are observed across the speakers for F4. Most et.al., (2000) had commented that regional, cultural variations for formants can exist, but did not specify if it was applicable for F4. Venkateswara Sastry (1990-91), commented that, there are dialectal variations observed among the three regions. It's presumed that, this could be contributing to variations in F4 along with anatomical differences, if any, in the different regions. More research is warranted to know if anatomical and physiological variations do exist between the regions contributing to the differences.

Very few studies in the literature have reported of F4 variations with different consonant contexts. It is observed that, F4 of the vowel is influenced by preceding manner, place and voicing feature of the consonant. Nagamma Reddy (1999) did comment that consonant context and following vowel have an influence on temporal and spectral characteristics of the preceding vowel in Telugu with no data available with specific reference to F4 changes. Since the word list of the current study was heterogeneous, further comments on the influence of preceding consonant on the F4 of the vowel are beyond the scope of the study. The data of the current study should hence be cautiously used.

4.2.5.2 Summary of F4

In the current study F4 data revealed

- Long vowels had higher F4 as compared to short vowels.
- High front vowels /i/ and /i:/ had the highest F4 and back high vowels /u/ and /u:/ had the lowest F4 in all gender, region and age groups.
- Front vowels had higher F4 followed by central and back vowels.
- Phonetic length of the vowel increased F4 for all vowels.
- F4 decreased from children to adults.
- Children had higher F4 followed by adolescents and adults.
- Among the age groups, as the phonetic length of the vowel increased F4 increased for all vowels across the age groups except for /a/, /o/ and /u/ in adults.
- Females had higher F4 values when as compared to males for all vowels.
- F4 increased as the phonetic length increased in both genders.
- Rayalaseema region had higher F4 followed by Telengana and Coastal speakers for short vowels
- Telengana speakers had higher F4 followed by Rayalaseema and Coastal speakers for long vowels.
- F4 increased in all regions with increase in phonetic length, except for mid (/a/) in Rayalaseema speakers.
- Front and mid short vowels (/i/ and /a:/) had higher F4 when preceded by nasal consonants as compared to stop consonants, while vowels /e/, /o/, /i:/, /e:/, /a:/ and /u:/ opposite was noticed.
- All long vowels had higher F4 when preceded by stop consonants as compared to nasals or affricates.
- Vowels (/e/, /u/, /i:/, /e:/, /a:/ and /o:/) had higher F4 when preceded by stop consonants as compared to affricates.
- Both /e/ and /a/ had higher F4 when preceded by lateral followed by semivowel and stop consonants.

- Short vowels /a/ and /u/ had higher F4 when preceded by fricatives as compared to stop consonants.
- Vowels /e/, /a/, /o/, /i:/, /e:/, /a:/, /o:/ and /u:/ had higher F4 when preceded by bilabials as compared to alveopalatals; however, front and back short vowels /i/ and /u/, higher F4 when preceded by alveopalatals.
- Vowels /i/, /o/, /u/, /e:/, /a:/ and /u:/ had higher F4 when preceded by dentals as compared to bilabials; however, back long vowel /o:/, higher F4 when preceded by bilabials.
- Vowels /u/, /i:/, /e:/ and /a:/ had higher F4 when preceded by velars as compared to alveopalatal consonants while mid short vowel /a/, higher F4 when preceded by alveopalatals.
- High vowels /i/, /u/ and /u:/ had higher F4 when preceded by dentals as compared to bilabial or alveopalatal consonants.
- Short and long mid vowels /a/ and /a:/ had higher F4 when preceded by bilabials as compared to alveopalatals.
- Short and long back vowels /o/, /u/ and /u:/ had higher F4 when preceded by dentals as compared to alveopalatals.
- Vowels had higher F4 when preceded by voiced consonants except for high vowels (/i/, /u/ and /u:/).
- In low and high vowels (/i/, /a/ and /u/), F4 reduced with increase in phonetic length, while mid vowels (/e/ and /o/) F4 increased with increase in phonetic length when preceded by voiced consonants.

4.2.6.1 Formant bandwidths (B1, B2 & B3):

Scrutiny of the collected data revealed very minimal variations in the band widths among the vowels. The front high short and long vowels /i/ and /i:/ had larger mean bandwidth for F1 compared to front mid vowel /e/. The front mid short and long vowels /e/ and /e:/ had larger mean bandwidth for F2 as compared to front high vowels /i/ and /i:/. The front high short and long vowels /o/ and /i:/ had larger mean bandwidth for F3 as compared to vowels /a/ and /o/. Central vowels had larger mean bandwidth for F1 and F2 while front vowels had larger mean bandwidth for F3. It was also observed that, mean B1 and B2 varied with increase in the phonetic length of the vowel. The mean and 1 SD bars for all vowels are depicted in Figure 4.2.6.1 for B1, Figure 4.2.6.2 for B2 and Figure 4.2.6.3 for B3. The means, SD and 95% confidence interval for mean of all the vowels; and for central, front and back vowels are given in Appendix VIII g (Tables 4.2.6.1 and 4.2.6.2) for B1; Appendix VIII h (Tables 4.2.7.1 and 4.2.7.2) for B2 and Appendix VIII i (Tables 4.2.8.1 and 4.2.8.2) for B3 respectively.

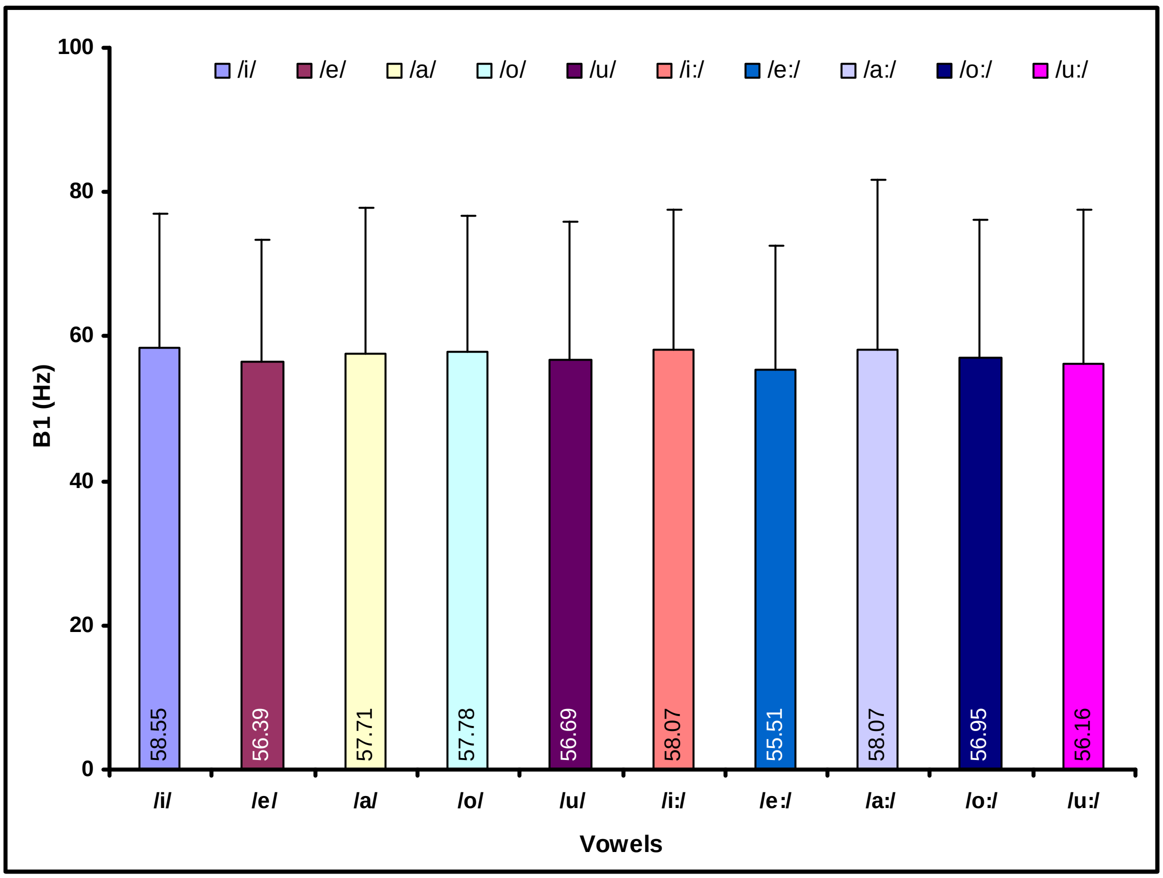


Figure 4.2.6.1: Mean B1 (Hz) and 1 SD bars of all vowels

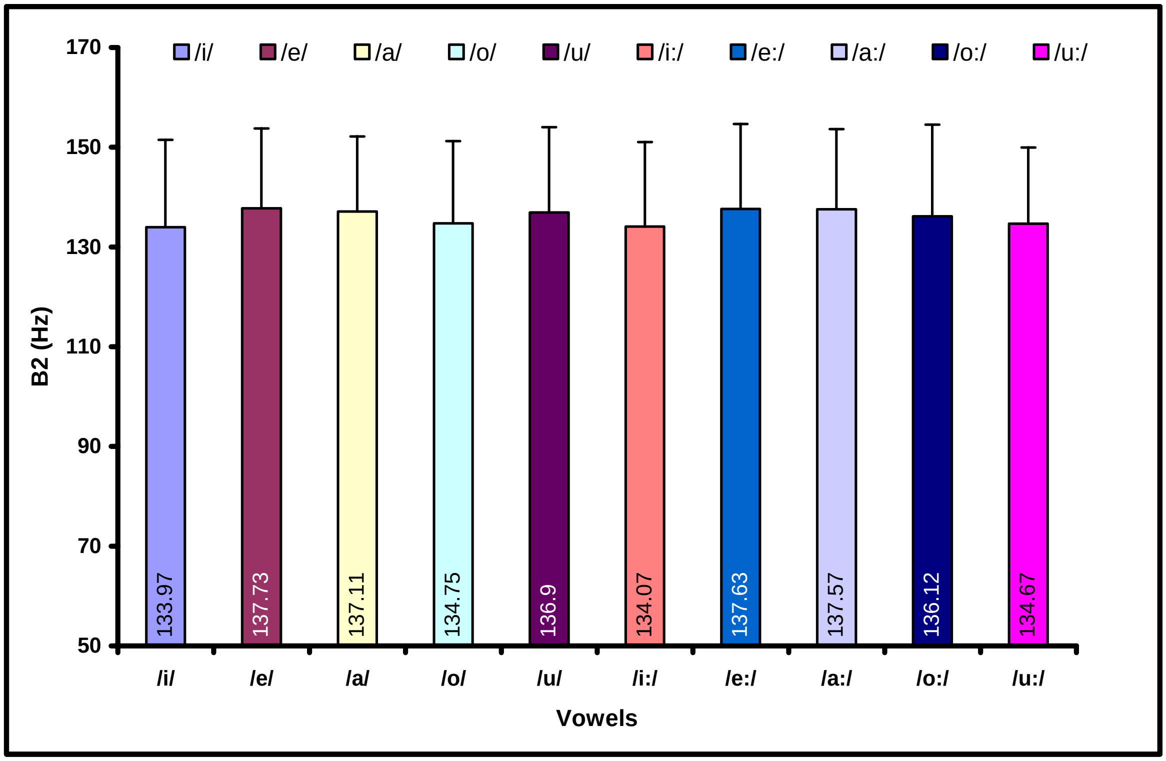


Figure 4.2.6.2: Mean B2 (Hz) and 1 SD bars of all vowels

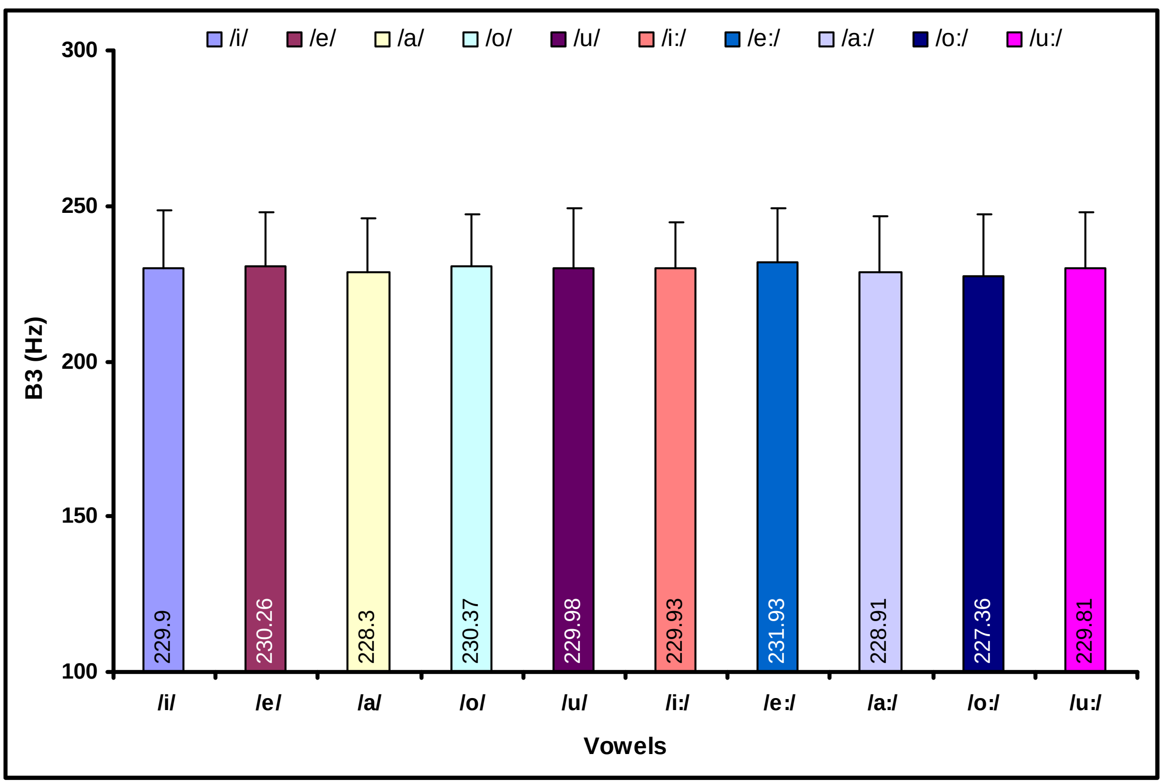


Figure 4.2.6.3: Mean B3 (Hz) and 1 SD bars of all vowels

In the current study, bandwidths (B1, B2 and B3) varied across the age group for all vowels. In children, vowels /i/ and /a:/ had larger mean B1 and vowels /e/ and /e:/ had small mean B1; vowels /e/ and /e:/ had larger mean B2 and vowels /o/ and /o:/ had small mean B2; vowels /e/ and /u:/ had larger mean B3 and vowels /a/ and /o:/ had small mean B3. In adolescents, /a/ and /i:/ had larger mean B1 while /u/ and /u:/ had lower values; vowels /u/ and /a:/ had larger mean B2 while it was lower for /o/ and /i:/; vowels /u/ and /e:/ had larger mean B3 while for /o/ and /u:/ it was lower. Adults had larger mean B1 values for vowels /o/ and /o:/ and smaller for /a/ and /u:/; vowels /a/ and /o:/ had larger mean B2 and smaller for /i/ and /i:/; larger mean B3 values for vowels /o/ and /e:/ and smaller for /a/ and /a:/. The mean and 1 SD bars of all vowels are depicted in Figure 4.2.6.4 for B1, Figure 4.2.6.5 for B2 and Figure 4.2.6.6 for B3. The means, SD and 95% confidence interval for mean of all the vowels for all the three age groups are given in Appendix VIII g (Table 4.2.6.3) for B1, Appendix VIII h (Table 4.2.7.3) for B2 and Appendix VIII i (Table 4.2.8.3) for B3.

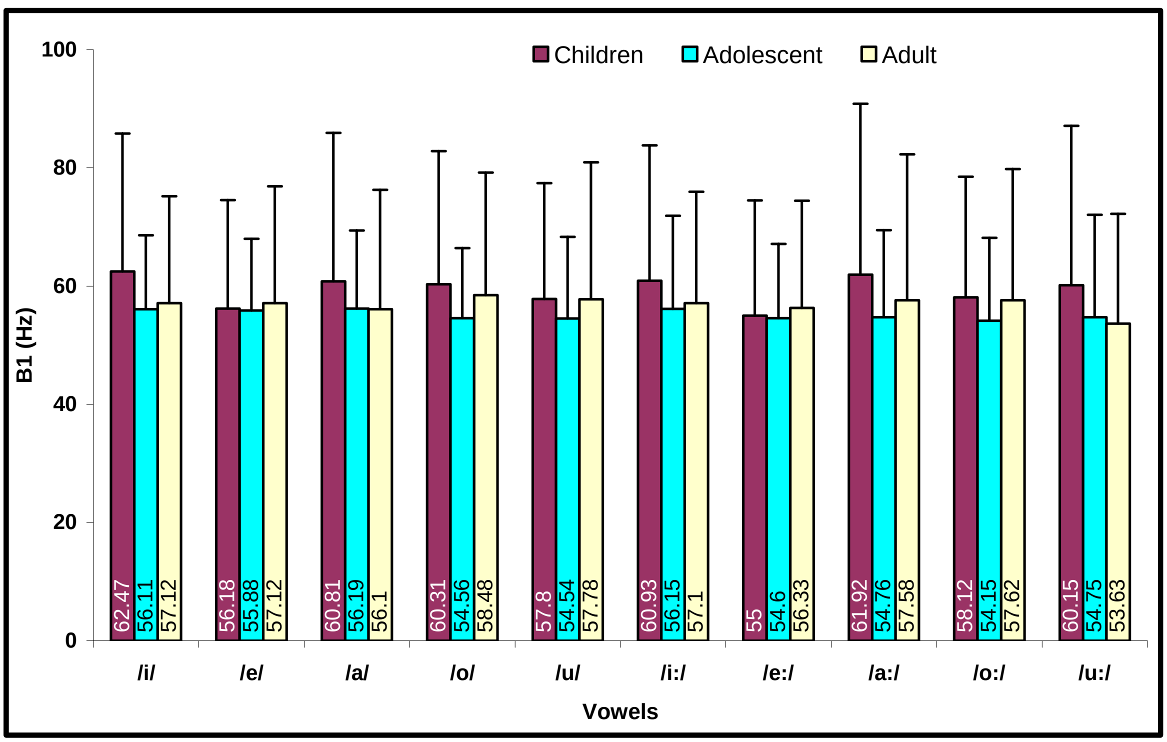


Figure 4.2.6.4: Mean B1 (Hz) and 1 SD bars across age groups

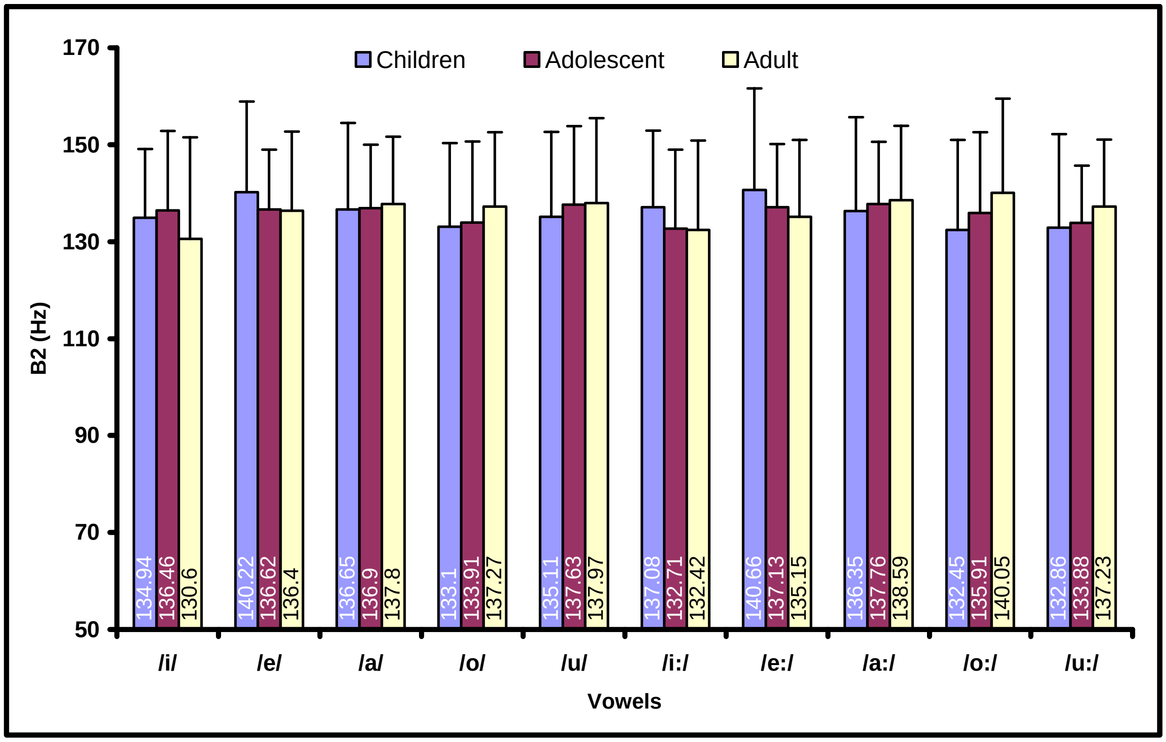


Figure 4.2.6.5: Mean B2 (Hz) and 1 SD bars across age groups

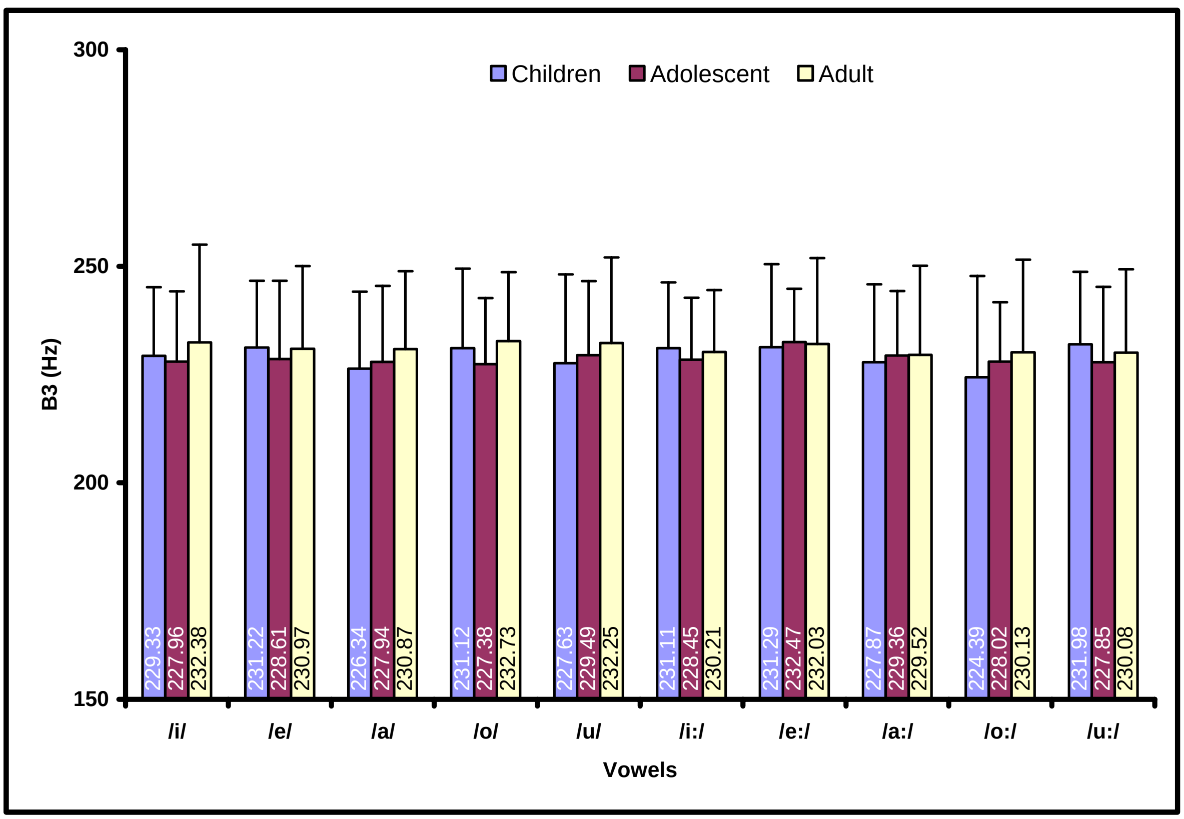


Figure 4.2.6.6: Mean B3 (Hz) and 1 SD bars across age groups

Females had larger B1 & B2 values when compared to males for majority of the vowels while males tend to have higher B3 values. In females, mean B1 was larger in vowels /i/ and /i:/, mean B2 in /a/ and /e:/ and mean B3 in /e/ and /e:/. In males, mean B1 was larger in /i/ and /i:/ and mean B2 and B3 in /u/ and /e:/. The mean B1 was lower for vowels /e/ and /e:/, B2 for /o/ and /u:/ and B3 for /u/ and /o:/ in females while, the mean B1 of vowels /a/ and /u:/, B2 of /i/ and /i:/ and B3 of /a/ and /o:/ were lower in males. On further scrutiny, it was found that mean bandwidth of all formants varied with increase in phonetic length. The mean (B1, B2 and B3) and 1 SD bars of all vowels are depicted in Figure 4.2.6.7, Figure 4.2.6.8 and Figure 4.2.6.9 respectively. The means, SD and 95% confidence interval for mean bandwidths, B1, B2 and B3 of all the vowels for the both gender groups are given in Appendix VIII g (Table 4.2.6.4), Appendix VIII h (Table 4.2.7.4) and Appendix VIII i (Table 4.2.8.4) respectively.

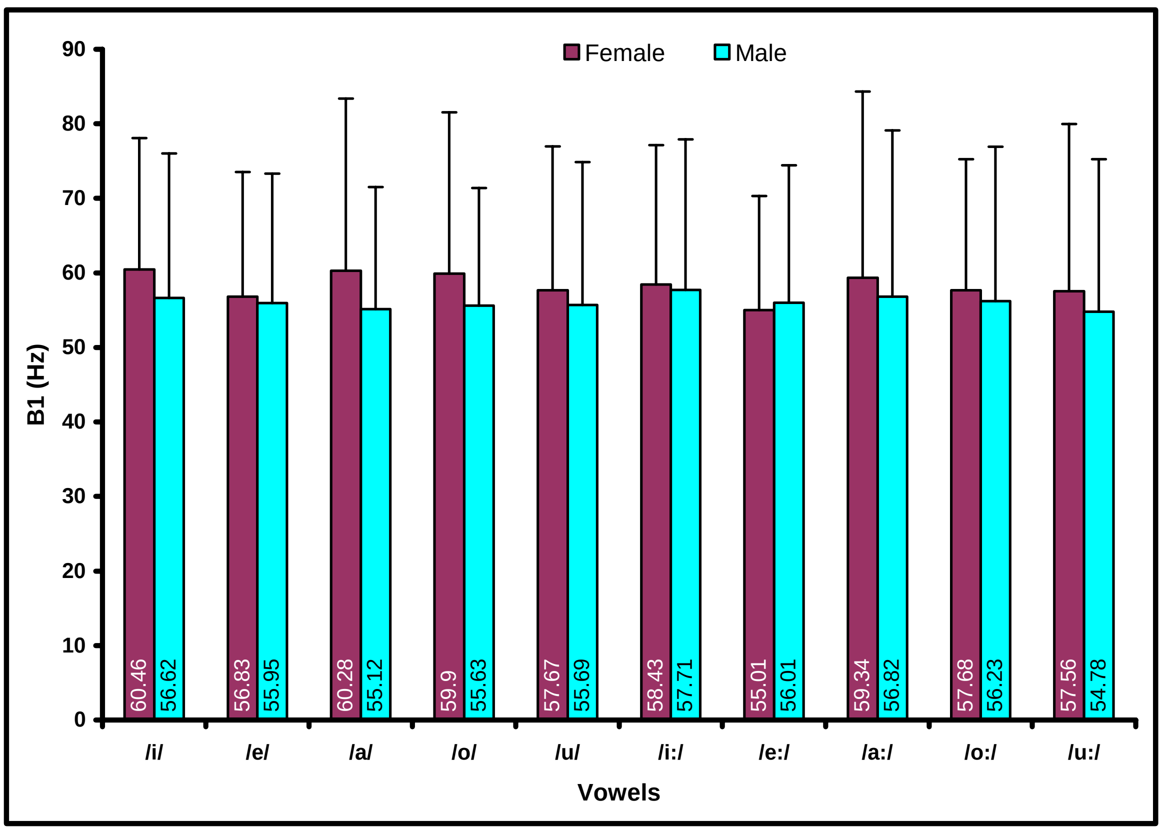


Figure 4.2.6.7: Mean B1 (Hz) and 1 SD bars across gender groups

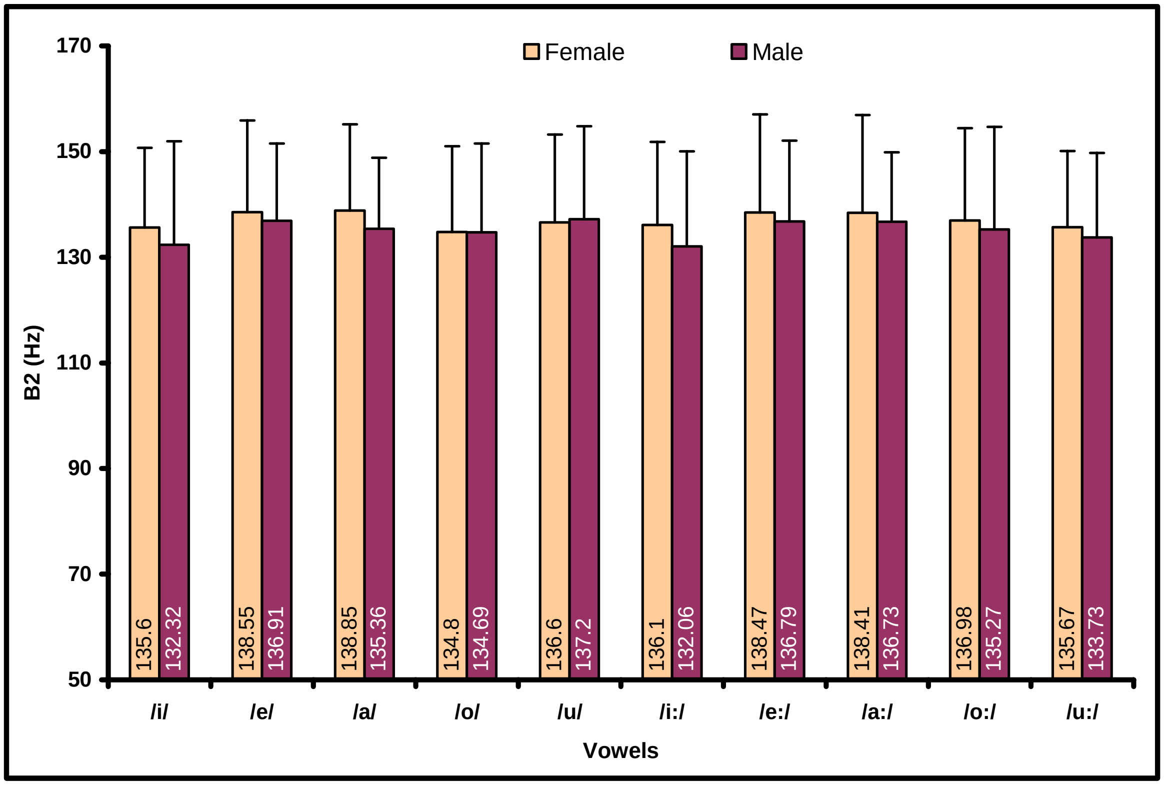


Figure 4.2.6.8: Mean B2 (Hz) and 1 SD bars across gender groups

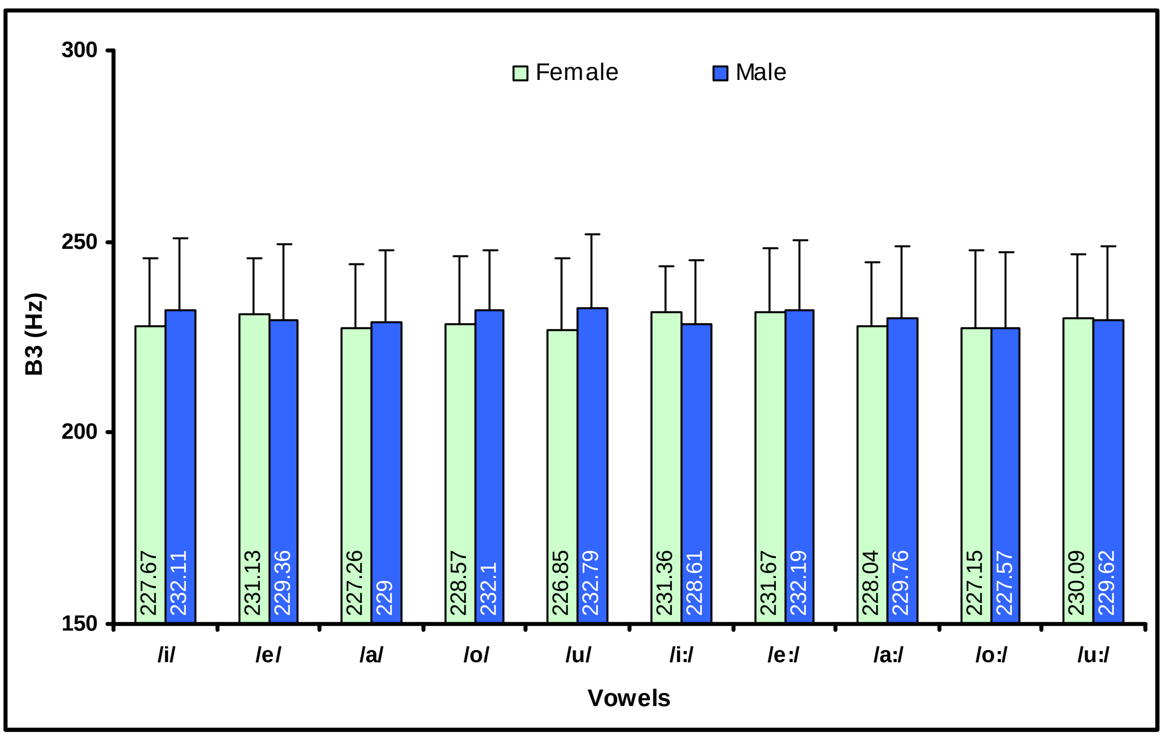


Figure 4.2.6.9: Mean B3 (Hz) and 1 SD bars across gender groups

From the data, it is observed that speakers from Coastal region had larger mean B1 followed by Rayalaseema and Telengana speakers for all vowels respectively. Further, it was observed that, Coastal speakers had larger mean B1 for vowels /o/ and /i:/ and lower for /a/ and /u:/; Rayalaseema speakers had larger mean B1 for vowels /a/ and /a:/ and smaller for /e/ and /e:/; Telengana speakers had larger mean B1 for vowels /i/ and /i:/ and smaller for /a/ and /a:/. Inspection of the data based on phonetic length did not reveal a consistent pattern as phonetic length varied. The mean B1 and 1 SD bars of all vowels across regional groups are depicted in Figure 4.2.6.10.The means, SD and 95% confidence interval for mean of all the vowels for all the three region groups are given in Appendix VIII g (Table 4.2.6.5).

From the data, it is observed that speakers from Rayalaseema region had larger mean B2 followed by Coastal and Telengana speakers for all vowels except short and long vowels /i/ & /o/ and long vowel /u:/. Further, it was observed that, Coastal speakers had larger mean B2 for vowels /e/ and /a:/ and lower for /i/ and /i:/; Rayalaseema speakers had larger mean B2 for vowels /e/ and /e:/ and smaller for /i/ and /o:/; Telengana speakers had larger mean B2 for vowels /a/ and /o:/ and smaller for /i/ and /e:/. On scrutiny of the data based on phonetic length, it was noted that no consistent pattern was observed as phonetic length varied. The mean B2 and 1 SD bars of all vowels across different regional groups are depicted in Figure 4.2.6.11. The means, SD and 95% confidence interval for mean of all the vowels for all the three region groups are given in Appendix VIII h (Table 4.2.7.5).

Regionally, speakers from Rayalaseema region had larger mean B3 followed by Telengana and Rayalaseema speakers for all vowels except /i/, /u/ and /u:/. Further, it was observed that Coastal speakers had larger mean B3 for vowels /o/ and /e:/ and lower for /i/ and /o:/; Rayalaseema speakers had larger mean B3 for vowels /u/ and /e:/ and smaller for /a/ and /o:/; Telengana speakers had larger mean B3 for vowels /i/ and /e:/ and smaller for /a/ and /o:/. On scrutiny of the data based on phonetic length, it was noted that, mid front vowel /e/ consistently had higher mean B3 with increase in phonetic length, while back mid vowel /o/ had lower mean B3. The mean B3 and 1 SD bars of all vowels across regional groups are depicted in Figure 4.2.6.12. The means, SD and 95% confidence interval for mean of all the vowels for all the three region groups are given in Appendix VIII i (Table 4.2.8.5).

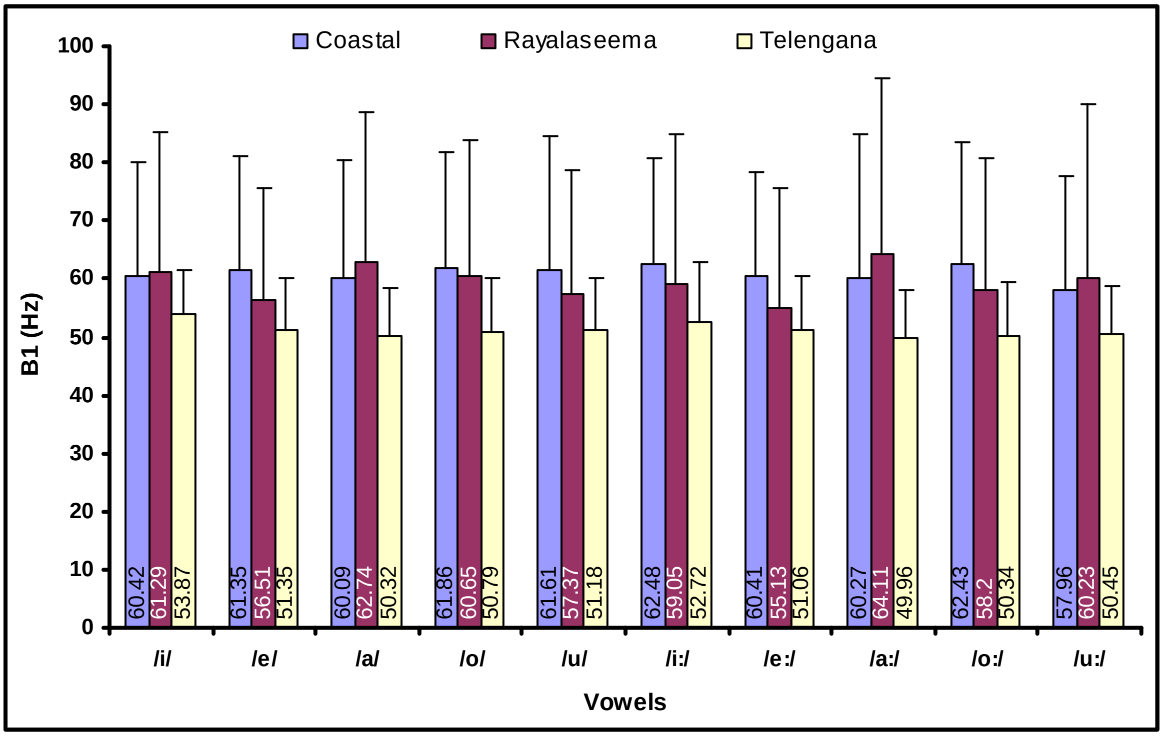


Figure 4.2.6.10: Mean B1 (Hz) and 1 SD bars across region groups

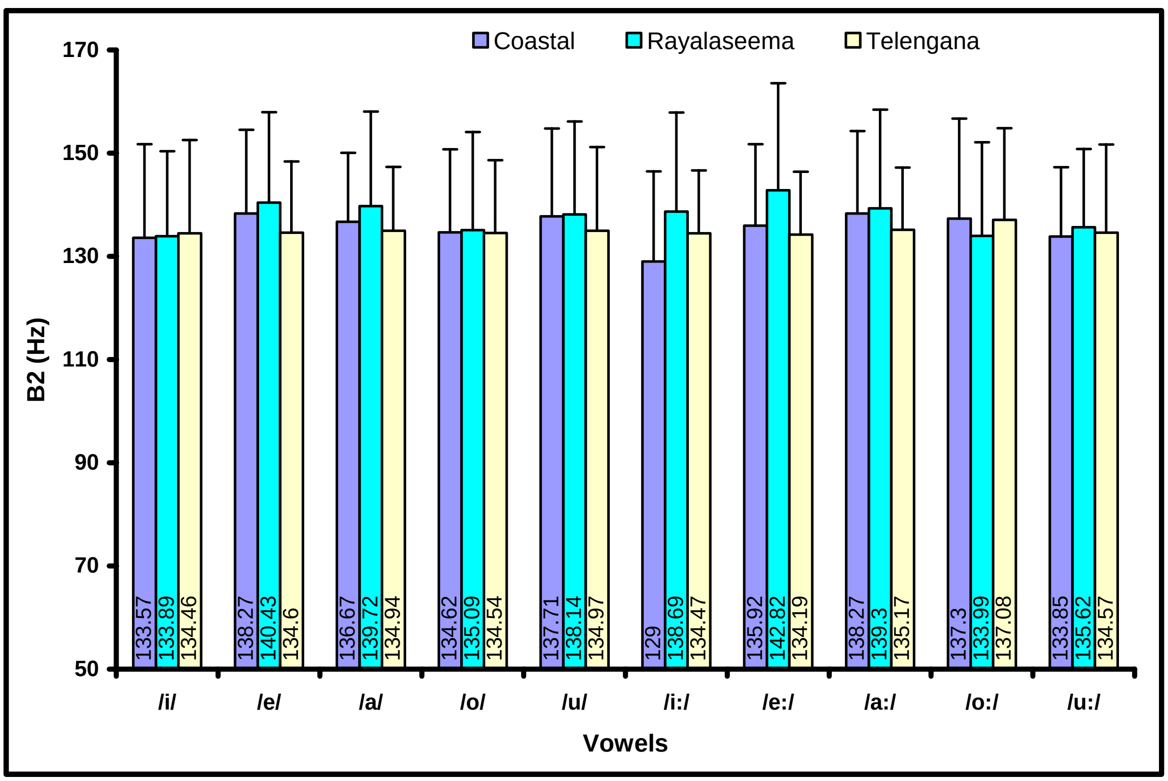


Figure 4.2.6.11: Mean B2 (Hz) and 1 SD bars across region groups

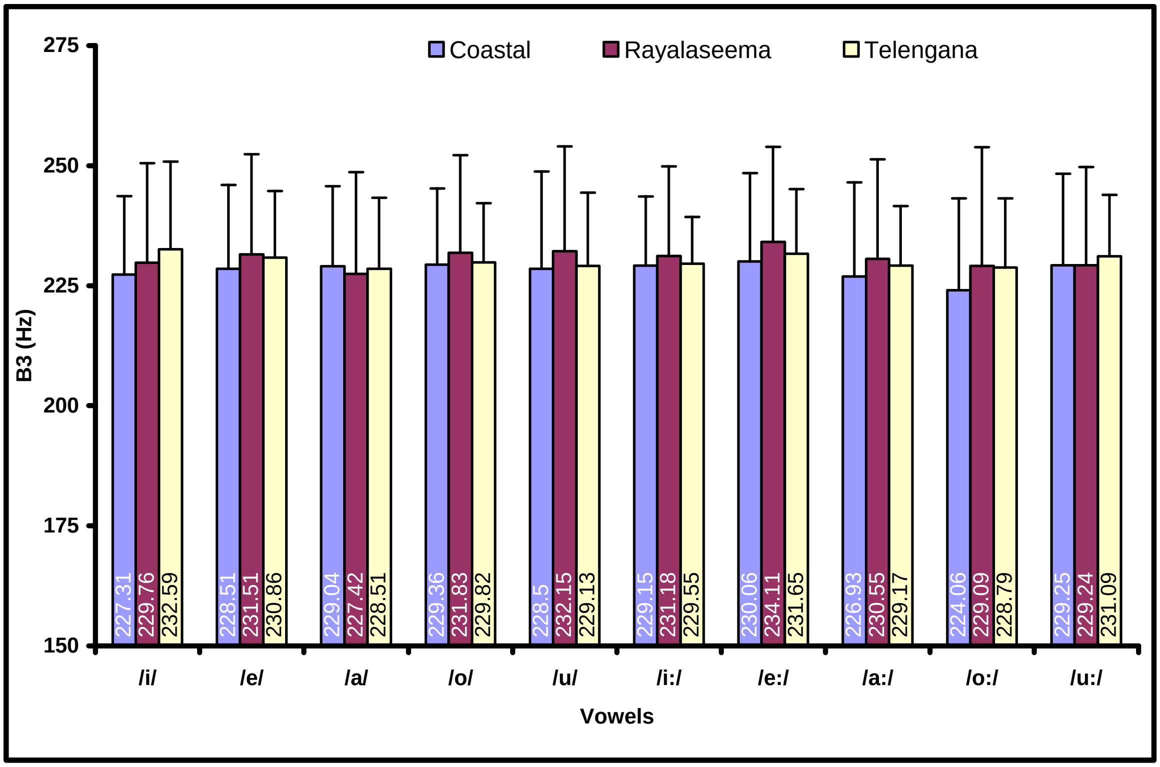


Figure 4.2.6.12: Mean B3 (Hz) and 1 SD bars across region groups

Manner and place of articulation of the preceding consonant had minimal effect on B1 of the following vowel in Telugu. Front vowels /e/, /i:/ and /e:/ have lower mean B1 when preceded by affricates as compared to nasal consonants. Most of the other vowels differed by 2 to 3 Hz in different manner and place of articulation. The mean B1 and 1 SD bars for short and long vowels across different manner and place of articulation of the preceding consonant are depicted in Figures 4.2.6.13a, 4.2.6.13b, 4.2.6.14a and 4.2.6.14b respectively and the values are given in Appendix VIII g (Tables 4.2.6.6 and 4.2.6.7 respectively).

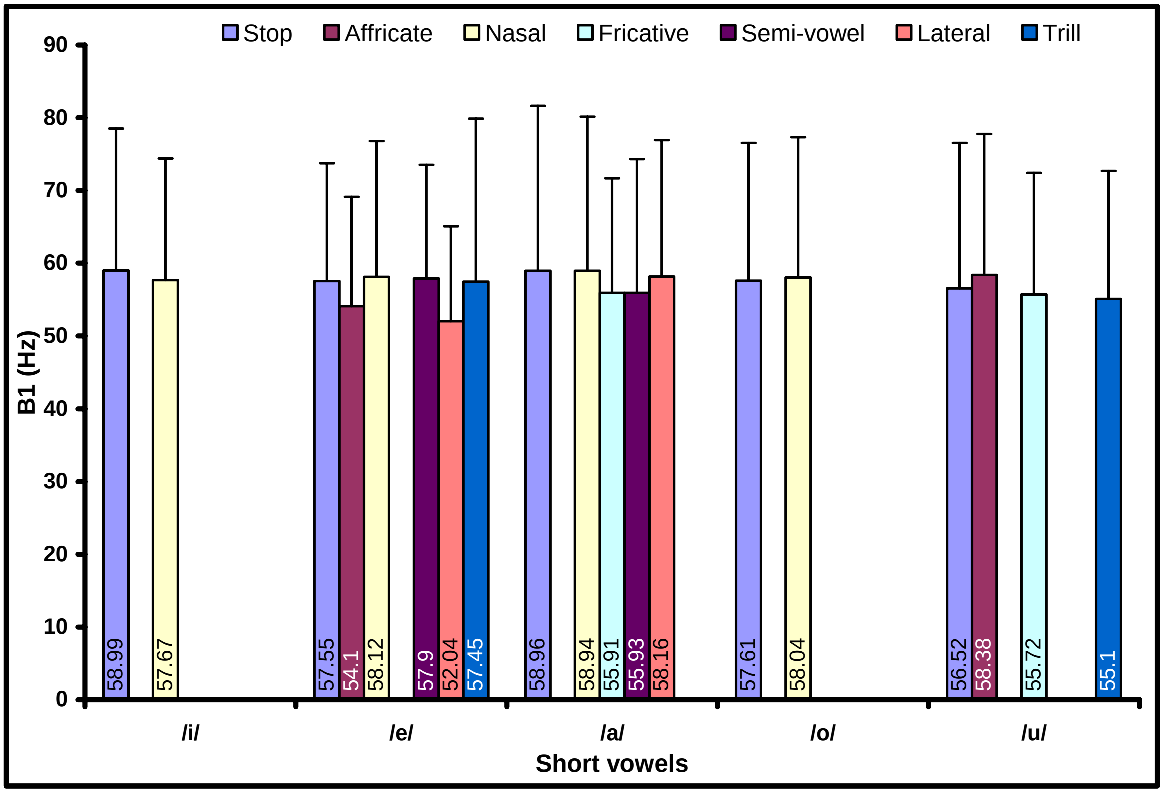


Figure 4.2.6.13a: Mean B1 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

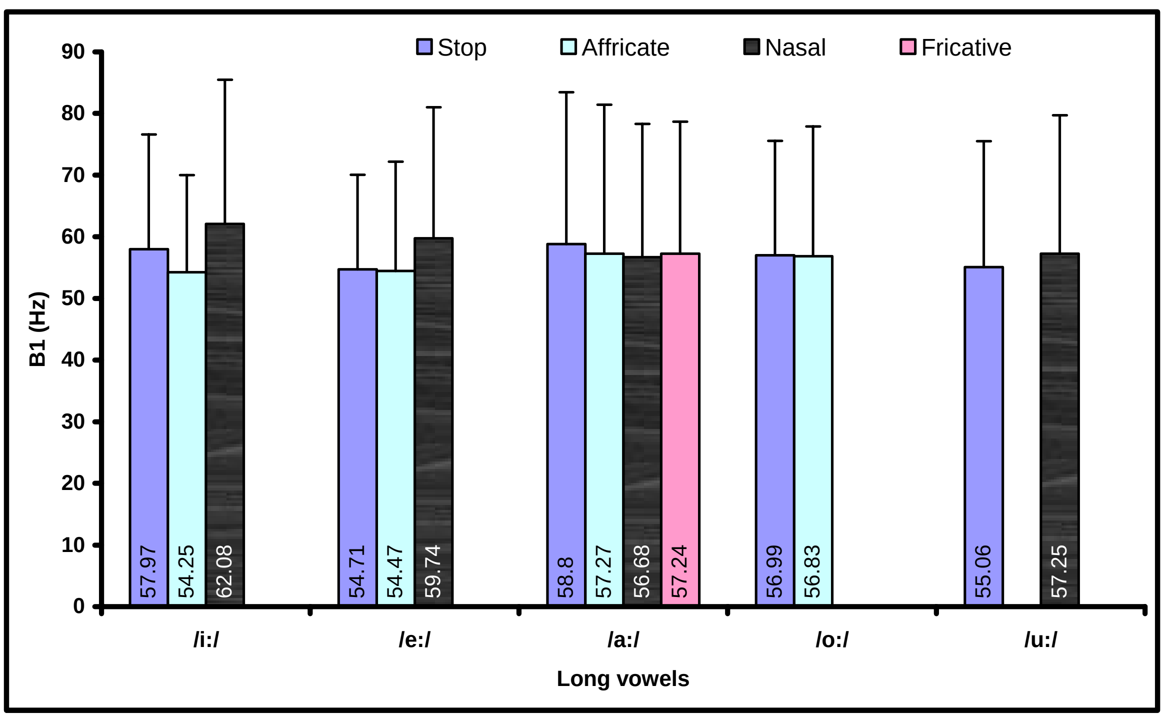


Figure 4.2.6.13b: Mean B1 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

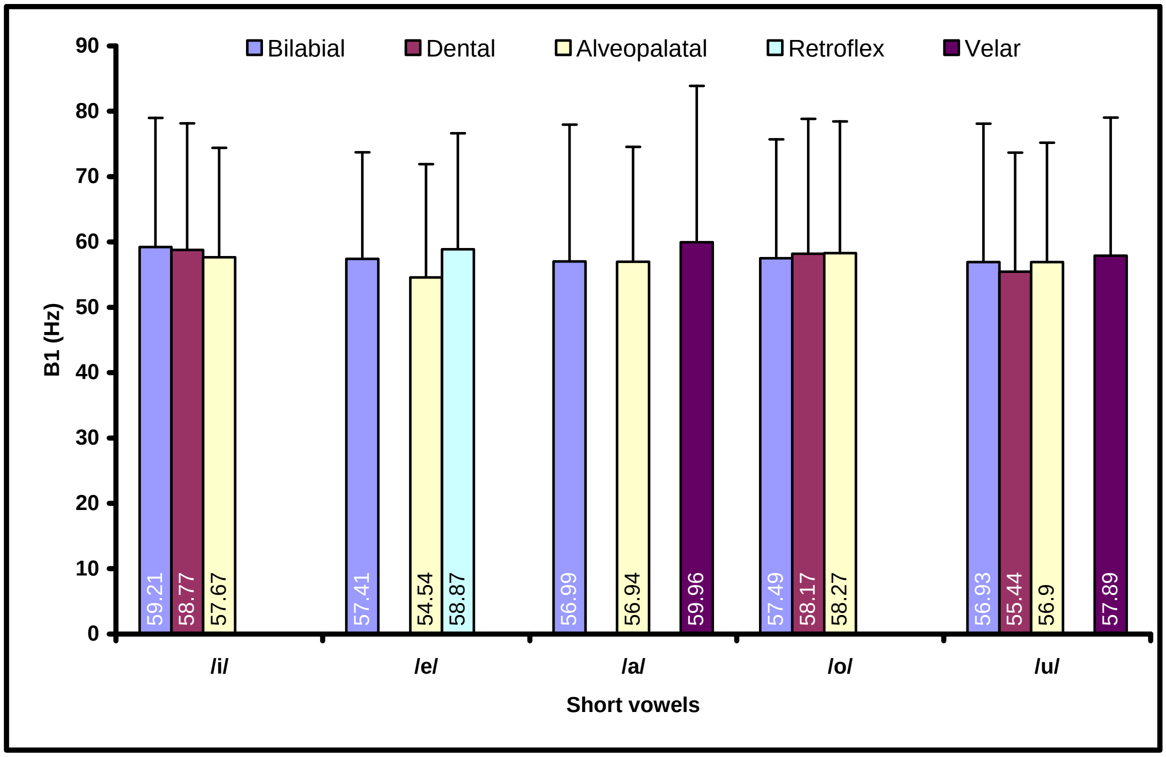


Figure 4.2.6.14a: Mean B1 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

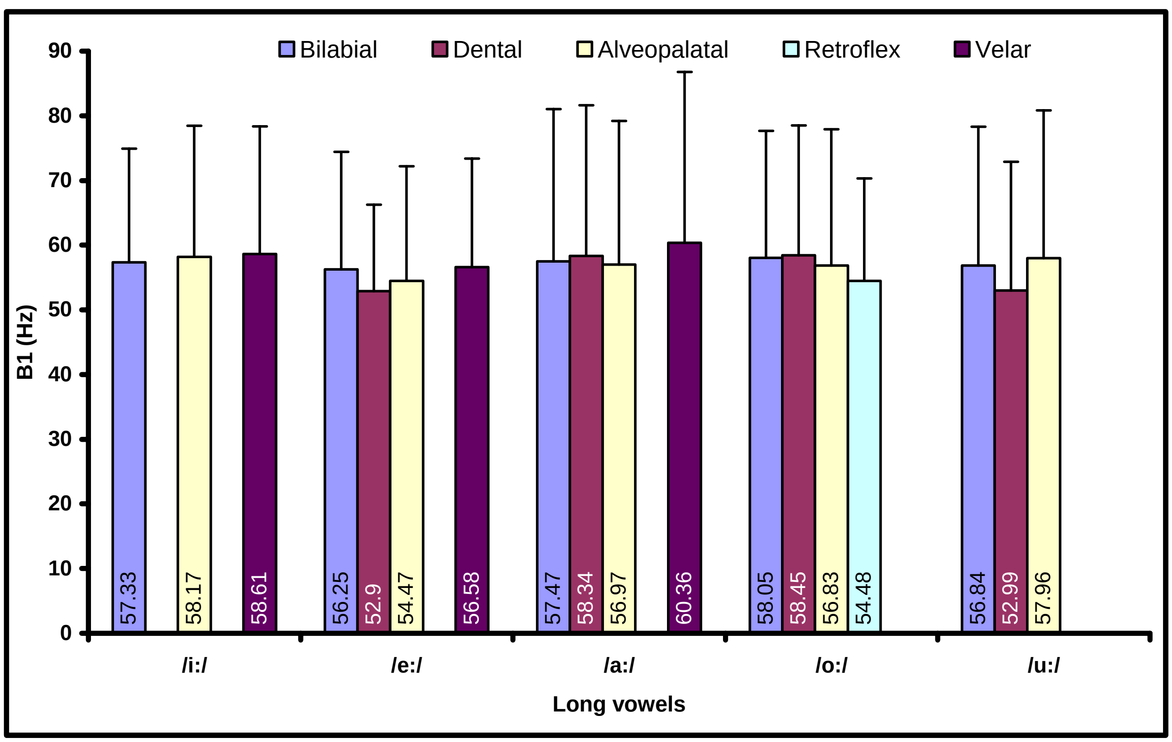


Figure 4.2.6.14b: Mean B1 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

Manner and place of articulation of the preceding consonant had minimal effect on B2 too of the following vowel in Telugu. Most of the vowels differed by 2 to 3 Hz in different manner and place of articulation except for /a/ and /u/. The mean B2 and 1 SD bars for short and long vowels across different manner and place of articulation of the preceding consonant are depicted in Figures 4.2.6.15a, 4.2.6.15b, 4.2.6.16a and 4.2.6.16b respectively. The means and SD of all the vowels preceded by different (manner and place of articulation) consonants are given in Appendix VIII h (Tables 4.2.7.6 and 4.2.7.7 respectively).

Manner and place of articulation of the preceding consonant had minimal effect also on B3 of the following vowel in Telugu. Vowel /a/ had lower mean B3 when preceded by fricatives as compared to semivowel consonants. Vowel /i:/ had lower mean B3 when preceded by velars as compared to bilabial consonants. Most of the other vowels differed by 2 to 3 Hz in different manner and place of articulation. The mean B3 and 1 SD bars for short and long vowels preceded by different (manner and place of articulation) consonants are depicted in Figures 4.2.6.17a, 4.2.6.17b, 4.2.6.18a and 4.2.6.18b respectively. The means and SD of all the vowels preceded by different (manner and place of articulation) consonants are given in Appendix VIII i (Tables 4.2.8.6 and 4.2.8.7 respectively).

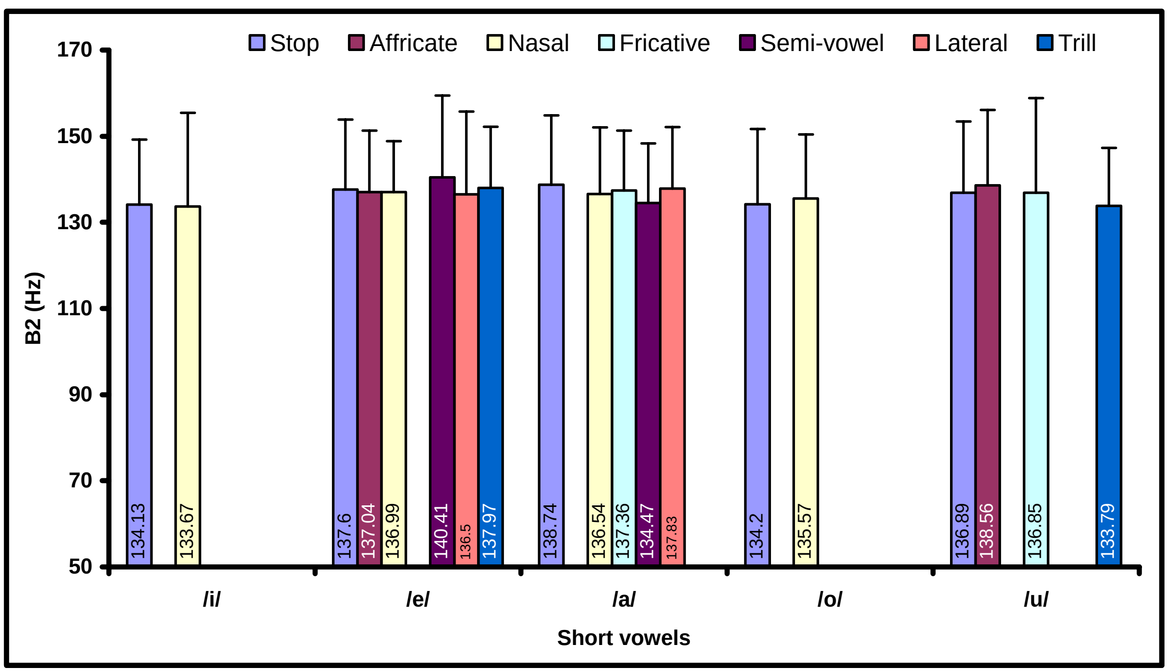


Figure 4.2.6.15a: Mean B2 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

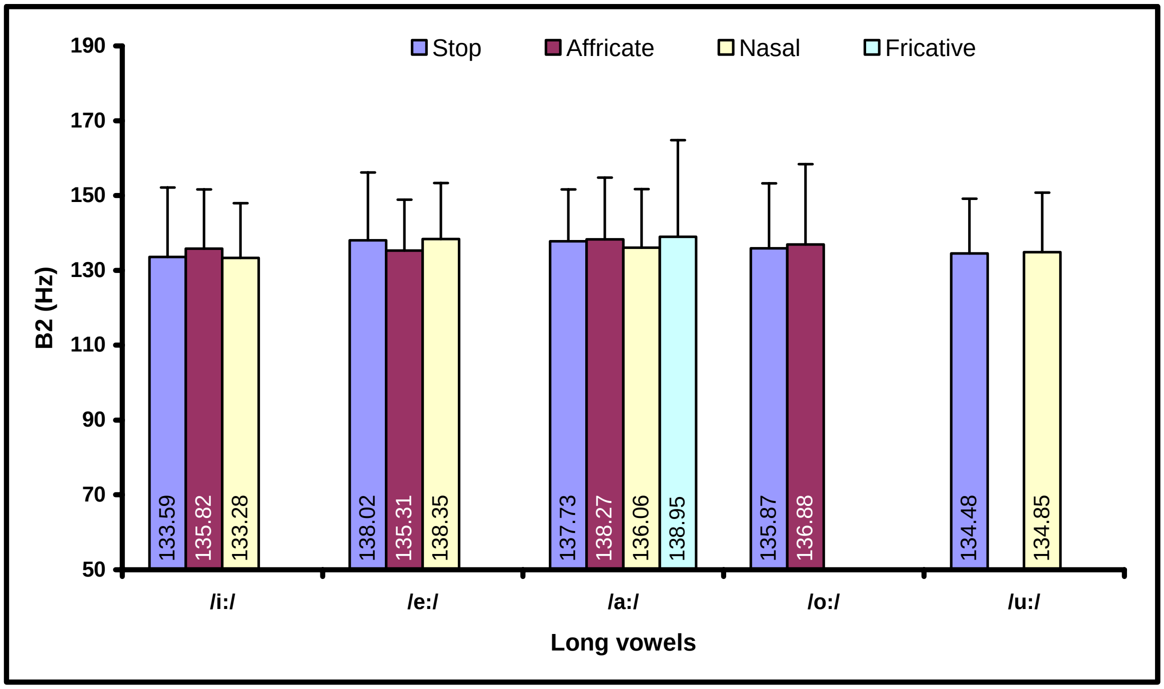


Figure 4.2.6.15b: Mean B2 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

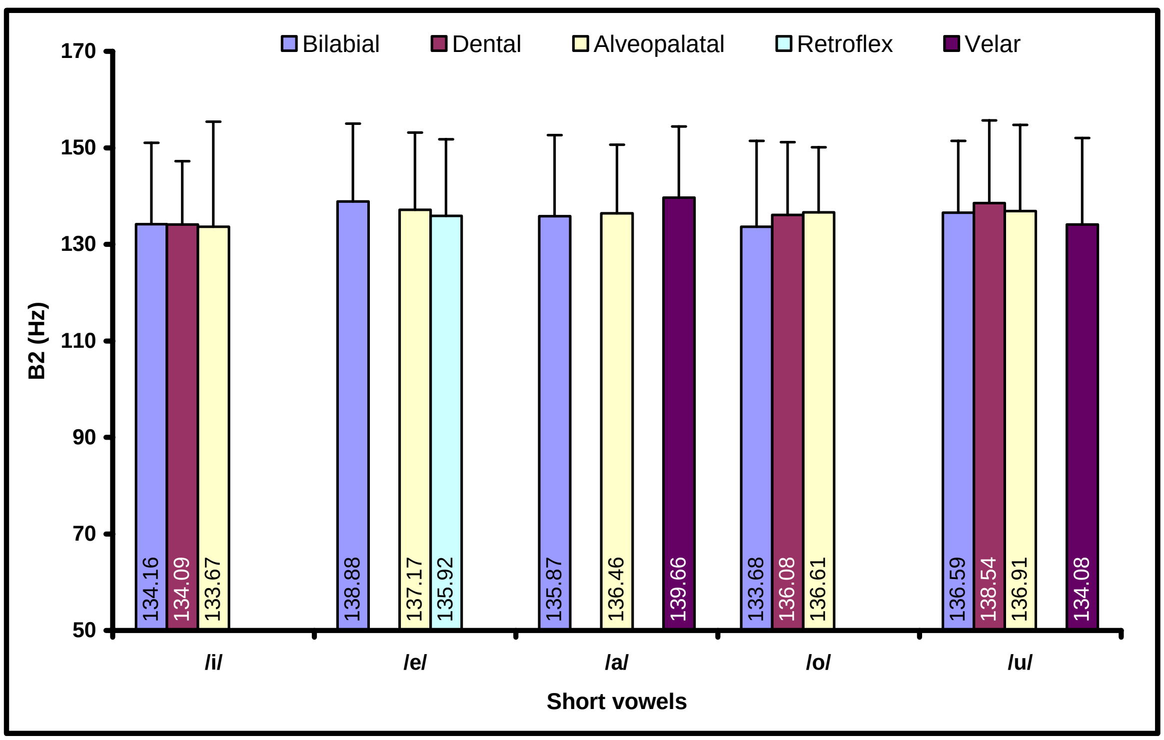


Figure 4.2.6.16a: Mean B2 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

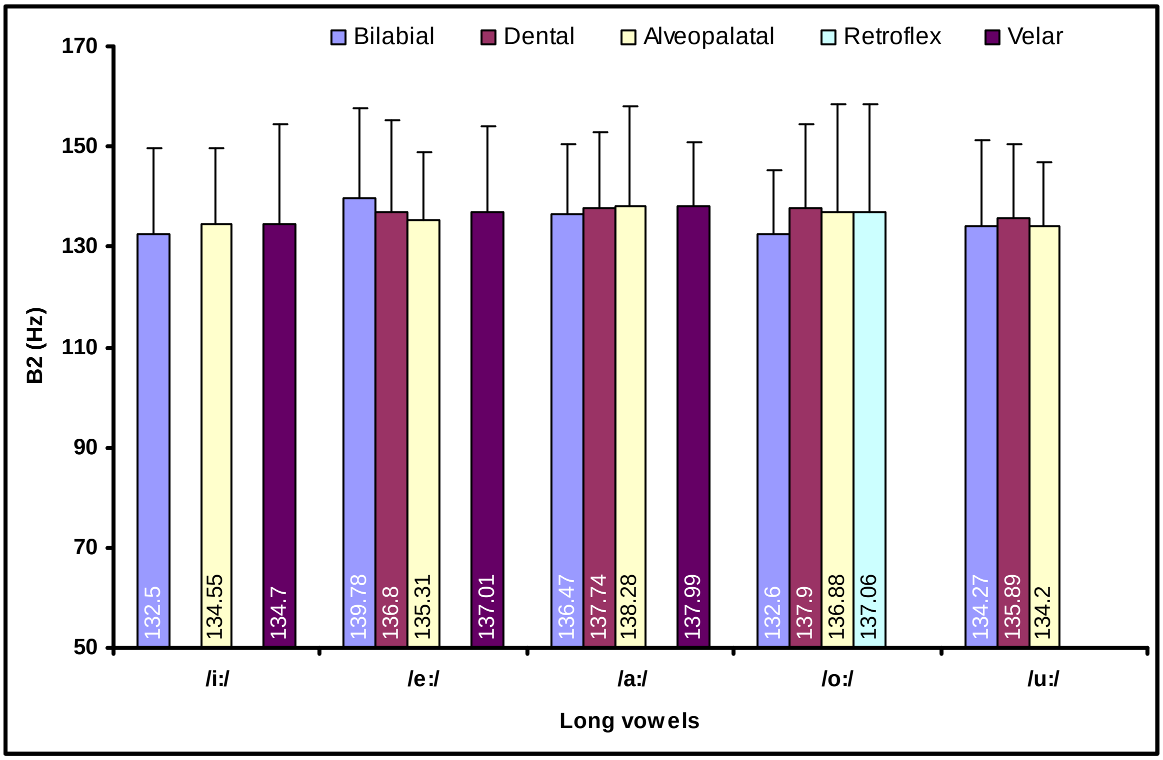


Figure 4.2.6.16b: Mean B2 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

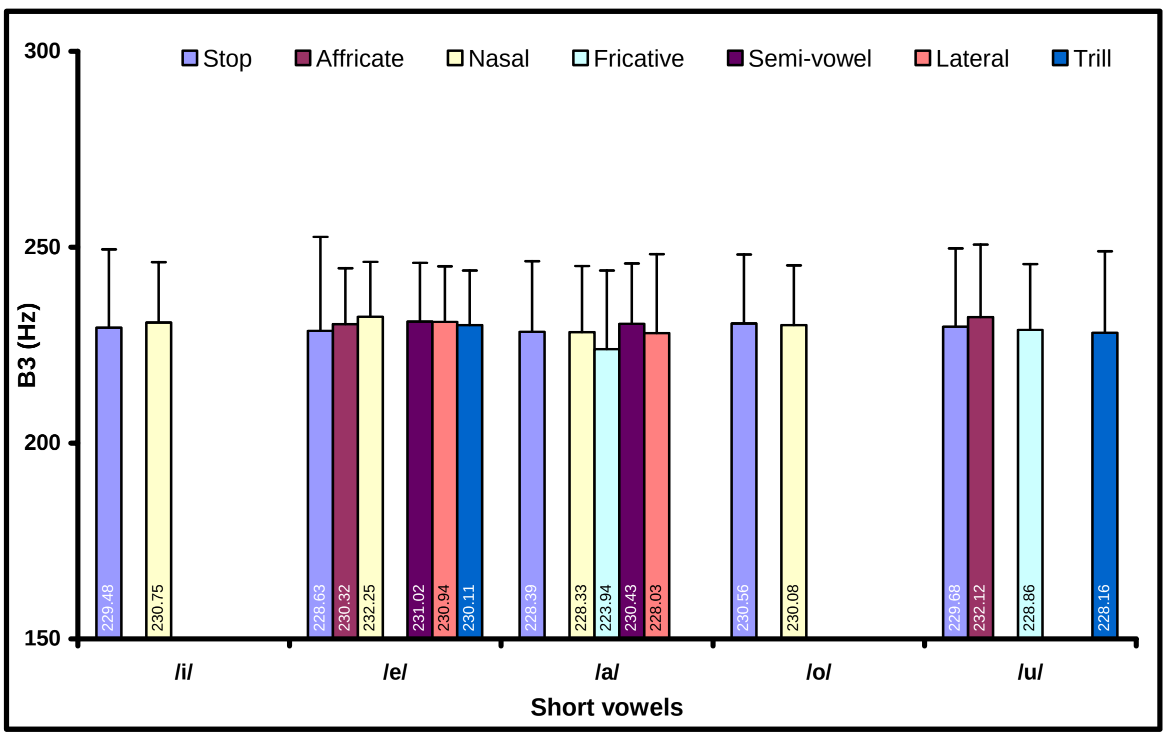


Figure 4.2.6.17a: Mean B3 (Hz) and 1 SD bars of short vowels preceded by different manner of articulation consonants

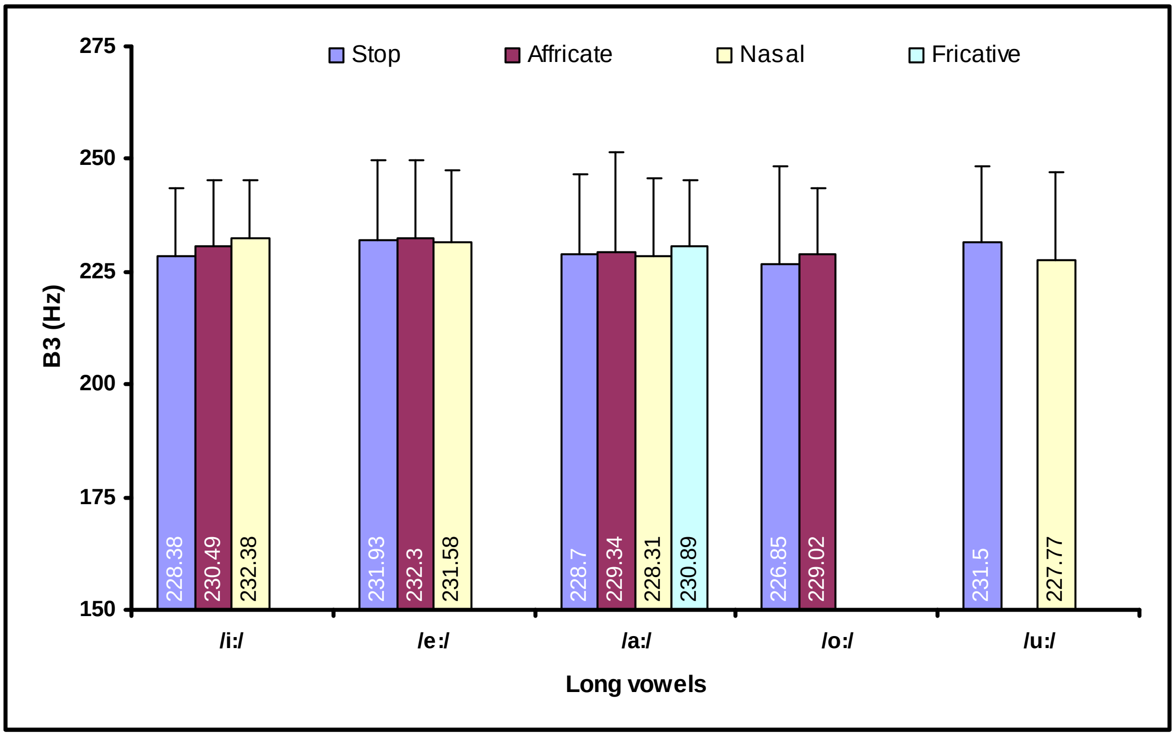


Figure 4.2.6.17b: Mean B3 (Hz) and 1 SD bars of long vowels preceded by different manner of articulation consonants

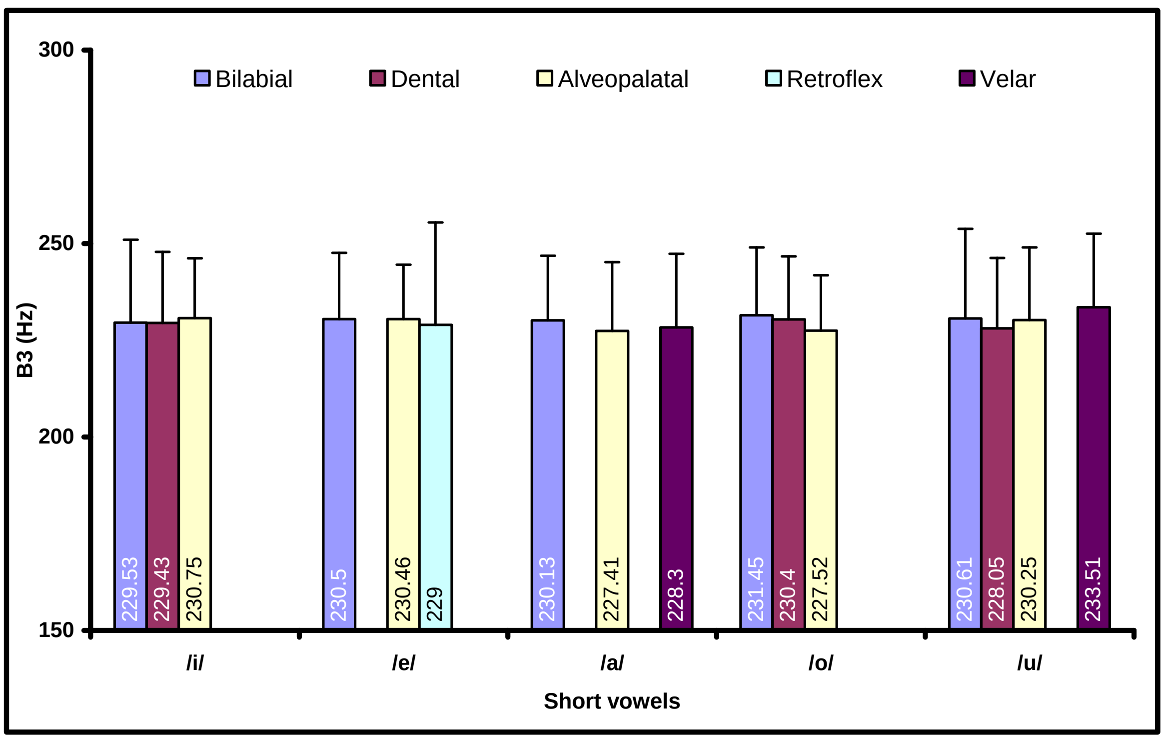


Figure 4.2.6.18a: Mean B3 (Hz) and 1 SD bars of short vowels preceded by different place of articulation consonants

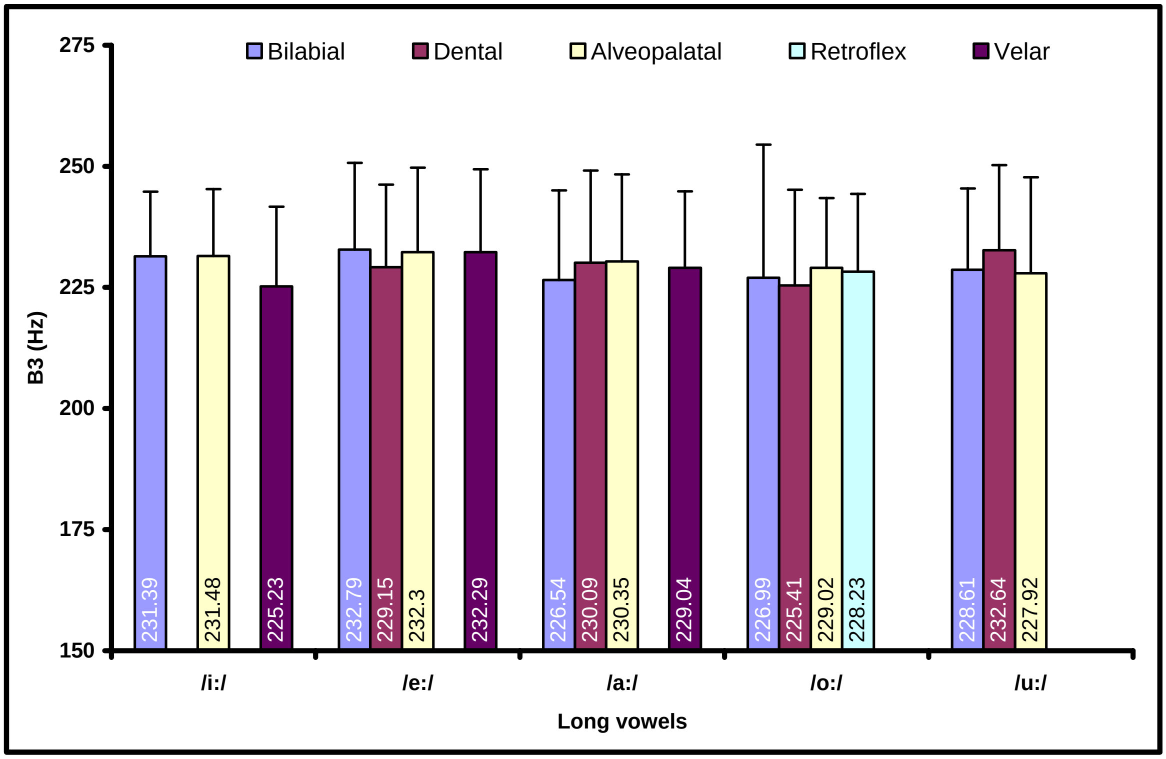


Figure 4.2.6.18b: Mean B3 (Hz) and 1 SD bars of long vowels preceded by different place of articulation consonants

From the data of the current study, it is observed that voicing feature of the consonant has minimal influence on B1 and varies between the short and long vowels. Except for vowels /a/, /o:/ and /u:/, B1 varied less than 2 Hz in different preceding voicing feature of the consonant. The mean B1 and 1 SD bars for all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.6.19 and values are given in Appendix VIII g (Table 4.2.6.8).

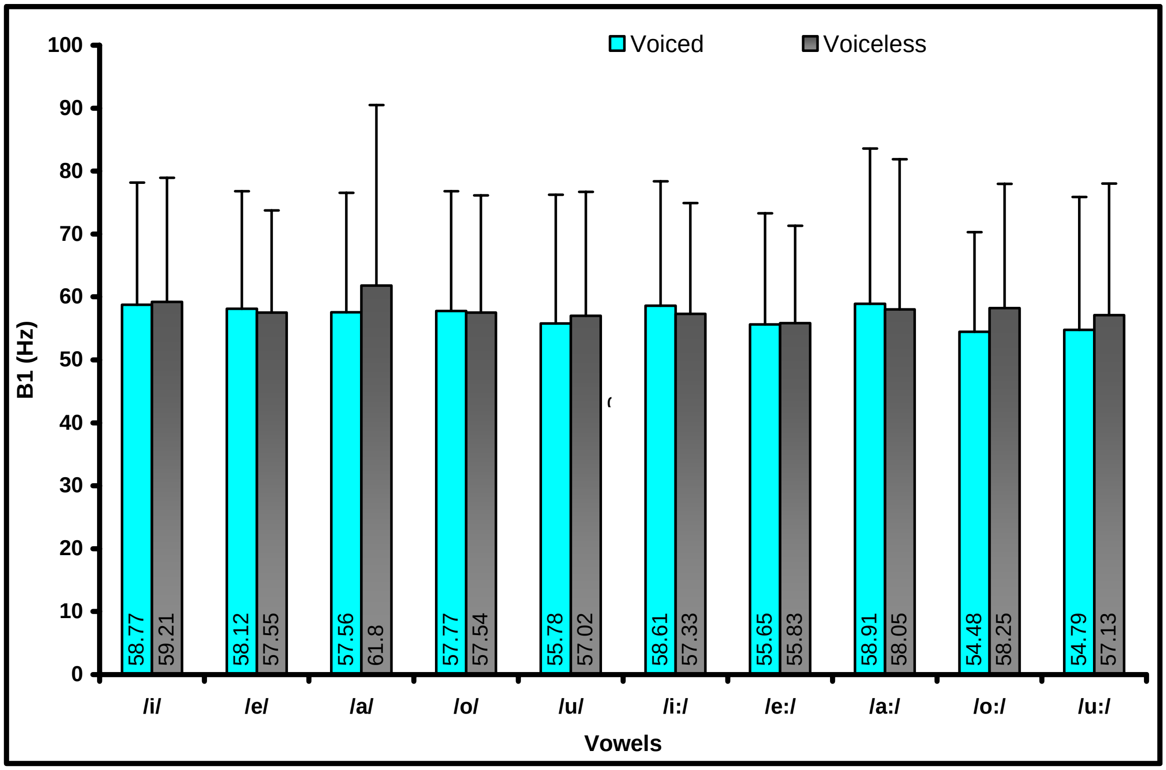


Figure 4.2.6.19: Mean B1 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

Voicing feature of the consonant has minimal influence also on B2 and varies between the short and long vowels. Vowels when preceded by voiceless consonants seem to have slightly higher B2. Most of the vowels had a variation of less than 2 Hz in different preceding voicing feature of the consonant. The mean B2 and 1 SD bars for all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.6.20 and the values are given in Appendix VIII h (Table 4.2.7.8).

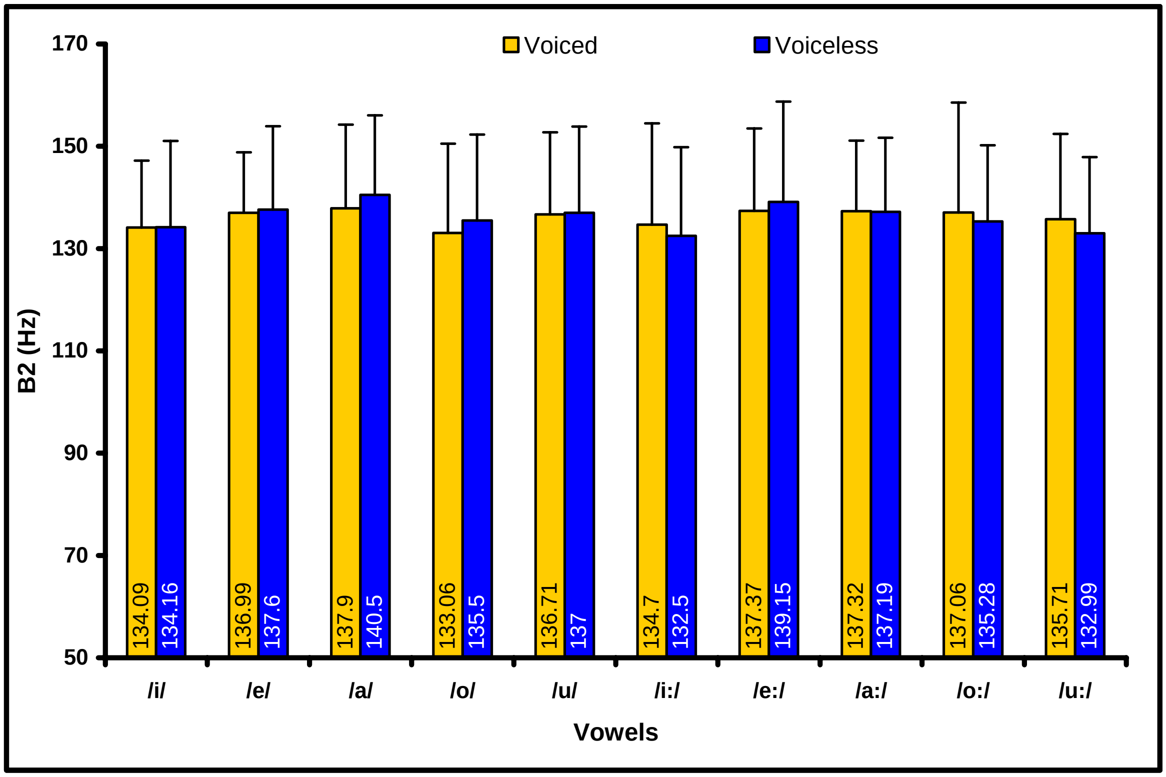


Figure 4.2.6.20: Mean B2 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

B3 is also minimally influenced by voicing feature of the preceding consonant and varies between the short and long vowels. Vowels /e/, /a/, /o/, /o:/ and /u:/ had decreased mean B3 when preceded by voiceless consonants. The mean B3 varied less than 2 Hz in different preceding voicing feature of the consonant in most of the vowels. The mean B3 and 1 SD bars for all vowels across voicing feature of the preceding consonant are depicted in Figure 4.2.6.21 and the values are given in Appendix VIII i (Table 4.2.8.8).

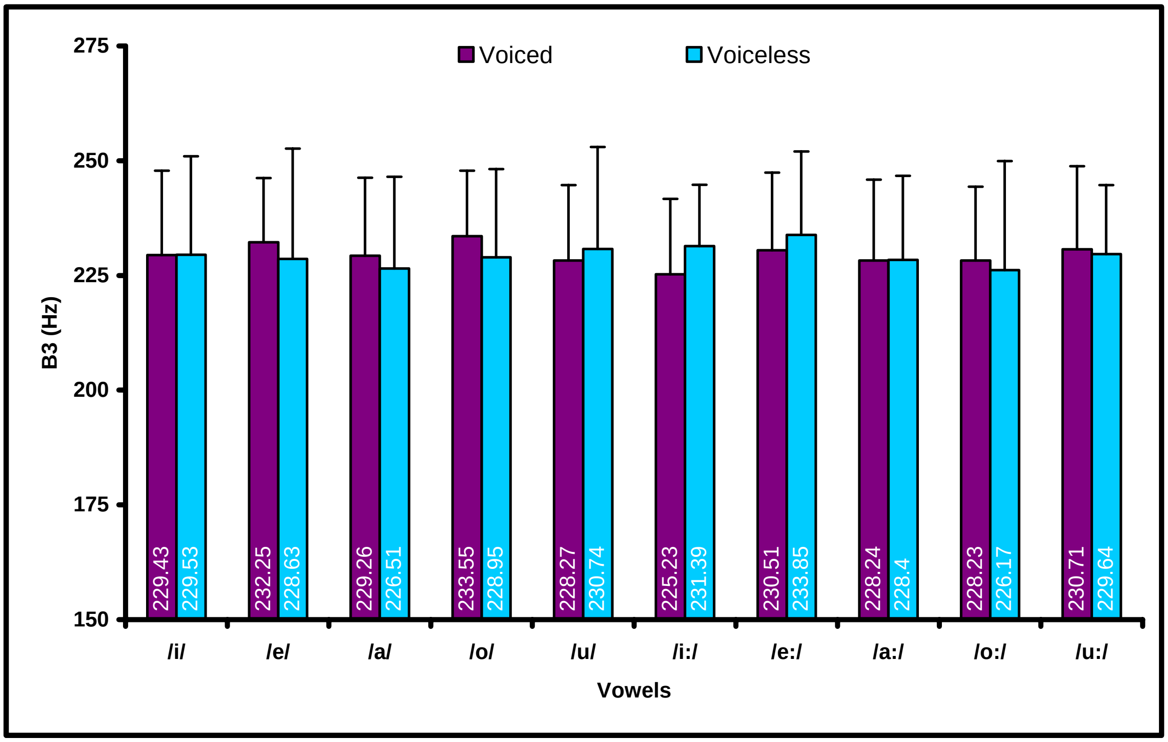


Figure 4.2.6.21: Mean B3 (Hz) and 1 SD bars of vowels preceded by different voicing feature of consonants

Questions of age, gender and region having any association and it's kind with B1, B2 and B3 and of which vowels studied have significant difference in bandwidths among the age, gender and region groups were addressed by Random intercept model 3 (as described in the method) for a better understanding of any association between bandwidths (B1, B2 & B3) and age, gender and region groups. The results for B1, B2 and B3 are given in Tables 4.2.6.a, 4.2.6.b and 4.2.6.c respectively.

Table 4.2.6.a: Statistical analysis using random intercept model for B1

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	68.94	1.07	64.43	< 0.01
Age (β_{1ijk})	-4.89	1.01	-4.84	< 0.01
Gender (β_{2ijk})	0.52	0.13	4	< 0.01
Region (β_{3ijk})	-4.86	0.36	-13.5	< 0.01
Variance components				
Random Error:	374.95			
Consonant Level:	0.00			
Individual level:	0.00			
Total variation:	374.95			
*-2*log likelihood(IGLS) = 37416.36*				

**significant at 0.05 level*

Model: Bandwidth of F1 (B1) = 68.94 – 4.89age + 0.51gender – 4.86region

Table 4.2.6.b: Statistical analysis using random intercept model for B2

N=4320

Covariates	**Estimate**	**Std. Error**	**Wald ratio**	**P value***
Constant (β_{0ij})	137.59	0.93	147.95	< 0.01
Age (β_{1ijk})	2.75	0.86	3.19	< 0.01
Gender (β_{2ijk})	-0.34	0.11	-3.09	< 0.01
Region (β_{3ijk})	-0.74	0.31	-2.39	0.01
Variance components				
Random Error:	269.19			
Consonant Level:	2.09			
Individual level:	0.13			
Total variation:	271.41			
*-2*log likelihood(IGLS) = 35594.57*				

**significant at 0.05 level*

Model: Bandwidth of F2 (B2) = 137.59 + 2.75age – 0.34gender – 0.74region

Table 4.2.6.c: Statistical analysis using random intercept model for B3

N=4320

Covariates	Estimate	Std. Error	Wald ratio	P value*
Constant (β_{0ij})	226.00	1.08	209.26	< 0.01
Age (β_{1ijk})	3.21	0.99	3.24	< 0.01
Gender (β_{2ijk})	-0.29	0.13	-2.23	0.01
Region (β_{3ijk})	0.78	0.36	2.17	0.02
Variance components				
Random Error:	316.91			
Consonant Level:	0.39			
Individual level:	0.02			
Total variation:	317.32			
*-2*log likelihood(IGLS) = 31227.03*				

***significant at 0.05 level**

Model: Bandwidth of F3 (B3) = 226 + 3.21age – 0.29gender + 0.78region

From Tables 4.2.6.a, 4.2.6.b and 4.2.6.c it could be observed that, there is a significant association between bandwidths (B1, B2, and B3) and age, gender and region. Further, region has negative association with B1, while for B2, it's for gender and region and B3, only gender. It may also be noted that, preceding consonant and individual variations were not affecting B1, suggesting that, only vowels caused variations. Age, gender and region seem to have significant association with B1; however, interpreting this variation or differences noted between the groups for clinical utility may not be significant at this juncture.

Further to study which of the vowels differed significantly among the age and region groups, Tukey HSD was employed and the results suggested that bandwidths (B1, B2 and B3) of all vowels showed statistically no significant differences between children, adolescents and adults (Tables 4.2.6.d; 4.2.6.e and 4.2.6.f for B1, B2 and B3 respectively) except for B1 of vowel /e/ & /o/ between children – adult and B2 of vowel /a:/ between children - adolescents .

Table 4.2.6.d: Post hoc results for each vowel between age groups for B1

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	6.37	0.100
	Children	Adult	5.35	0.195
	Adolescent	Adult	-1.01	0.942
/e/	Children	Adolescent	.29	0.986
	Children	Adult	-.94	0.869
	Adolescent	Adult	-1.24	0.784
/a/	Children	Adolescent	4.62	0.065
	Children	Adult	4.71	0.059
	Adolescent	Adult	.09	0.999
/o/	Children	Adolescent	5.74	0.054
	Children	Adult	1.83	0.739
	Adolescent	Adult	-3.92	0.250
/u/	Children	Adolescent	3.26	0.191
	Children	Adult	.02	1.000
	Adolescent	Adult	-3.25	0.193
/i:/	Children	Adolescent	4.79	0.205
	Children	Adult	3.84	0.358
	Adolescent	Adult	-.95	0.939
/e:/	Children	Adolescent	1.00	0.872
	Children	Adult	-.73	0.930
	Adolescent	Adult	-1.73	0.663
/a:/	Children	Adolescent	7.16(*)	0.003
	Children	Adult	4.34	0.111
	Adolescent	Adult	-2.82	0.393
/o:/	Children	Adolescent	3.97	0.325
	Children	Adult	-.49	0.983
	Adolescent	Adult	-4.47	0.242
/u:/	Children	Adolescent	5.40	0.195
	Children	Adult	6.52	0.095
	Adolescent	Adult	1.12	0.931

*significant at 0.05 level

Table 4.2.6.e: Post hoc results for each vowel between age groups for B2

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	-1.53	0.862
	Children	Adult	4.34	0.304
	Adolescent	Adult	5.87	0.112
/e/	Children	Adolescent	3.60	0.104
	Children	Adult	3.82	0.077
	Adolescent	Adult	.22	0.991
/a/	Children	Adolescent	-.24	0.986
	Children	Adult	-1.15	0.740
	Adolescent	Adult	-.91	0.829
/o/	Children	Adolescent	-.81	0.924
	Children	Adult	-4.17	0.130
	Adolescent	Adult	-3.36	0.263
/u/	Children	Adolescent	-2.52	0.298
	Children	Adult	-2.86	0.209
	Adolescent	Adult	-.34	0.978
/i:/	Children	Adolescent	4.37	0.175
	Children	Adult	4.66	0.137
	Adolescent	Adult	.29	0.992
/e:/	Children	Adolescent	3.52	0.185
	Children	Adult	5.51(*)	0.017
	Adolescent	Adult	1.98	0.580
/a:/	Children	Adolescent	-1.42	0.600
	Children	Adult	-2.24	0.279
	Adolescent	Adult	-.83	0.840
/o:/	Children	Adolescent	-3.46	0.393
	Children	Adult	-7.60(*)	0.013
	Adolescent	Adult	-4.13	0.267
/u:/	Children	Adolescent	-1.02	0.894
	Children	Adult	-4.37	0.135
	Adolescent	Adult	-3.35	0.294

*significant at 0.05 level

Table 4.2.6.f: Post hoc results for each vowel between age groups for B3

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Children	Adolescent	1.37	0.902
	Children	Adult	-3.04	0.602
	Adolescent	Adult	-4.42	0.346
/e/	Children	Adolescent	2.62	0.390
	Children	Adult	0.25	0.992
	Adolescent	Adult	-2.37	0.458
/a/	Children	Adolescent	-1.60	0.684
	Children	Adult	-4.53	0.054
	Adolescent	Adult	-2.92	0.302
/o/	Children	Adolescent	3.74	0.280
	Children	Adult	-1.61	0.791
	Adolescent	Adult	-5.35	0.073
/u/	Children	Adolescent	-1.85	0.723
	Children	Adult	-4.62	0.101
	Adolescent	Adult	-2.76	0.453
/i:/	Children	Adolescent	2.66	0.440
	Children	Adult	0.90	0.909
	Adolescent	Adult	-1.76	0.697
/e:/	Children	Adolescent	-1.18	0.840
	Children	Adult	-.74	0.934
	Adolescent	Adult	0.44	0.975
/a:/	Children	Adolescent	-1.49	0.660
	Children	Adult	-1.65	0.604
	Adolescent	Adult	-.16	0.995
/o:/	Children	Adolescent	-3.62	0.460
	Children	Adult	-5.74	0.156
	Adolescent	Adult	-2.12	0.782
/u:/	Children	Adolescent	4.13	0.449
	Children	Adult	1.90	0.842
	Adolescent	Adult	-2.24	0.761

*Significant at 0.05 level

Within the region groups, all vowels had statistically no significant difference in B3 between the three region groups; however, B1 had significant difference for all vowels except for /i/ between Coastal and Telengana speakers and B2 for vowels /e/, /a/, /e:/ and /a:/ between Rayalaseema and Telengana speakers (Tables 4.2.6.g, 4.2.6.h and 4.2.6.i for B1, B2 and B3 respectively).

Table 4.2.6.g: Post hoc results for each vowel between region groups for B1

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-.88	0.956
	Coastal	Telengana	6.54	0.087
	Rayalaseema	Telengana	7.42(*)	0.044
/e/	Coastal	Rayalaseema	4.83(*)	0.022
	Coastal	Telengana	10.00(*)	< 0.01
	Rayalaseema	Telengana	5.17(*)	0.012
/a/	Coastal	Rayalaseema	-2.65	0.383
	Coastal	Telengana	9.77(*)	< 0.01
	Rayalaseema	Telengana	12.42(*)	< 0.01
/o/	Coastal	Rayalaseema	1.21	0.869
	Coastal	Telengana	11.07(*)	< 0.01
	Rayalaseema	Telengana	9.86(*)	< 0.01
/u/	Coastal	Rayalaseema	4.24	0.056
	Coastal	Telengana	10.43(*)	< 0.01
	Rayalaseema	Telengana	6.19(*)	0.002
/i:/	Coastal	Rayalaseema	3.44	0.428
	Coastal	Telengana	9.76(*)	0.001
	Rayalaseema	Telengana	6.33	0.058
/e:/	Coastal	Rayalaseema	5.28(*)	0.020
	Coastal	Telengana	9.35(*)	< 0.01
	Rayalaseema	Telengana	4.07	0.095
/a:/	Coastal	Rayalaseema	-3.84	0.164
	Coastal	Telengana	10.31(*)	< 0.01
	Rayalaseema	Telengana	14.15(*)	< 0.01
/o:/	Coastal	Rayalaseema	4.22	0.262
	Coastal	Telengana	12.08(*)	< 0.01
	Rayalaseema	Telengana	7.86(*)	0.010
/u:/	Coastal	Rayalaseema	-2.27	0.745
	Coastal	Telengana	7.51(*)	0.041
	Rayalaseema	Telengana	9.78(*)	0.005

*Significant at 0.05 level

Table 4.2.6.h: Post hoc results for each vowel between region groups for B2

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-0.32	0.994
	Coastal	Telengana	-0.89	0.951
	Rayalaseema	Telengana	-0.57	0.980
/e/	Coastal	Rayalaseema	-2.17	0.432
	Coastal	Telengana	3.67	0.089
	Rayalaseema	Telengana	5.83(*)	0.003
/a/	Coastal	Rayalaseema	-3.04	0.120
	Coastal	Telengana	1.74	0.498
	Rayalaseema	Telengana	4.78(*)	0.005
/o/	Coastal	Rayalaseema	-0.47	0.974
	Coastal	Telengana	0.09	0.999
	Rayalaseema	Telengana	0.56	0.964
/u/	Coastal	Rayalaseema	-0.42	0.967
	Coastal	Telengana	2.74	0.232
	Rayalaseema	Telengana	3.16	0.150
/i:/	Coastal	Rayalaseema	-9.69(*)	< 0.01
	Coastal	Telengana	-5.47	0.059
	Rayalaseema	Telengana	4.22	0.182
/e:/	Coastal	Rayalaseema	-6.90(*)	0.002
	Coastal	Telengana	1.73	0.652
	Rayalaseema	Telengana	8.63(*)	< 0.01
/a:/	Coastal	Rayalaseema	-1.03	0.763
	Coastal	Telengana	3.11	0.085
	Rayalaseema	Telengana	4.14(*)	0.013
/o:/	Coastal	Rayalaseema	3.30	0.439
	Coastal	Telengana	0.22	0.996
	Rayalaseema	Telengana	-3.08	0.484
/u:/	Coastal	Rayalaseema	-1.77	0.720
	Coastal	Telengana	-0.72	0.945
	Rayalaseema	Telengana	1.04	0.891

*Significant at 0.05 level

Table 4.2.6.i: Post hoc results for each vowel between region groups for B3

N=4320

Vowel	(I) Age Group	(J) Age Group	Mean Difference (I-J)	Sig.
/i/	Coastal	Rayalaseema	-2.45	0.723
	Coastal	Telengana	-5.27	0.215
	Rayalaseema	Telengana	-2.82	0.648
/e/	Coastal	Rayalaseema	-3.00	0.287
	Coastal	Telengana	-2.35	0.463
	Rayalaseema	Telengana	0.65	0.943
/a/	Coastal	Rayalaseema	1.62	0.688
	Coastal	Telengana	0.53	0.961
	Rayalaseema	Telengana	-1.09	0.841
/o/	Coastal	Rayalaseema	-2.47	0.573
	Coastal	Telengana	-0.46	0.982
	Rayalaseema	Telengana	2.01	0.691
/u/	Coastal	Rayalaseema	-3.66	0.259
	Coastal	Telengana	-0.64	0.960
	Rayalaseema	Telengana	3.02	0.380
/i:/	Coastal	Rayalaseema	-2.03	0.625
	Coastal	Telengana	-0.40	0.981
	Rayalaseema	Telengana	1.64	0.734
/e:/	Coastal	Rayalaseema	-4.04	0.130
	Coastal	Telengana	-1.58	0.727
	Rayalaseema	Telengana	2.46	0.463
/a:/	Coastal	Rayalaseema	-3.62	0.094
	Coastal	Telengana	-2.24	0.394
	Rayalaseema	Telengana	1.38	0.699
/o:/	Coastal	Rayalaseema	-4.98	0.243
	Coastal	Telengana	-4.73	0.291
	Rayalaseema	Telengana	0.25	0.996
/u:/	Coastal	Rayalaseema	0.01	1.000
	Coastal	Telengana	-1.84	.850
	Rayalaseema	Telengana	-1.85	0.843

* Significant at 0.05 level

Student's *t*-test was done to study which of the vowels significantly differed with the gender groups. The results are given in Table 4.2.6.j.

Table 4.2.6.j: Student's *t*-test results for all vowels between two gender groups

Vowel	B1			B2			B3		
	Mean Dif.#	**df**	**t**	**Mean Dif.#**	**df**	**t**	**Mean Dif.#**	**df**	**t**
/i/	3.85	213	1.521	3.28	210	1.364	-4.44	203	-1.722
/e/	.88	500	0.579	1.64	494	1.141	1.77	467	1.090
/a/	5.16	514	3.077*	3.50	564	2.781*	-2.02	496	-1.264
/o/	4.27	326	2.127*	0.11	349	0.062	-3.53	272	-1.762
/u/	1.98	628	1.292	-0.60	606	-0.433	-5.95	418	-3.181*
/i:/	.72	285	0.313	4.05	285	2.034*	2.75	269	1.554
/e:/	-.99	427	-0.607	1.69	426	1.026	-.52	417	-.303
/a:/	2.52	711	1.421	1.68	712	1.401	-1.72	647	-1.221
/o:/	1.45	284	0.638	1.71	280	0.779	-.42	248	-.164
/u:/	2.78	280	1.090	1.94	271	1.050	.48	175	.174

*Significant at 0.05 level
#Mean Dif: Mean Difference

From Table 4.2.6.j, it is observed that, all vowels had statistically no significant difference in bandwidths between females and males except for vowel /a/ in B1 & B2; /o/ in B1; /u/ in B3 and /i:/ in B2.

From the results, it could be inferred that, there is a significant association between age, gender and region and bandwidths (B1, B2 and B3). Individual vowel variations within the region and gender groups are not significant; but tend to be significantly influenced with consonant and individual level variations.

Bandwidth increase with increase in formant frequency as noted in the current study has been reported (Dunn, 1961; Yosida, Kazama & Toyama, 2001; Yasojima, Takahashi & Tohyama, 2006). The changes noticed in bandwidths of the formant frequencies as the age progressed, could be attributed to the changes in vocal tract acoustics. Although bandwidth has a significant association with region, individual vowels did not show much significant differences. The significant association between bandwidth and region noted from multilevel analysis could be due to the preceding consonant and individual level influences.

Research on bandwidth did support the importance of bandwidth in speech intelligibility in normals and hearing impaired (Klatt, 1982; John, Margaret, Timothy & Laura, 1997; Cheveigne, 1999), but not much data is available on the variations of bandwidth across different linguistic and age groups. This could probably be due to the differences and various procedures adopted in the estimation of bandwidths by the investigators. The data obtained on bandwidths in the current study could be considered as an add on information to the existing knowledge.

4.2.6.2 Summary of Bandwidths (B1, B2 & B3)

In the current study, bandwidths (B1, B2 and B3) of the formants revealed:

- Very minimal variations among the vowels.
- The front high short and long vowels /i/ and /i:/ had larger bandwidth for F1 compared to front mid vowel /e/. The front mid short and long vowels /e/ and /e:/ had larger bandwidth for F2 as compared to front high vowels /i/ and /i:/. The front high short and long vowels /o/ and /i:/ had larger bandwidth for F3 as compared to vowels /a/ and /o/.
- Central vowels had larger bandwidth for F1 and F2 while front vowels had larger bandwidth for F3.
- Bandwidths B1 and B2 varied with increase in the phonetic length of the vowel.
- Bandwidths (B1, B2 and B3) varied across the age group for all vowels. In children, vowels /i/ and /a:/ had larger B1 and vowels /e/ and /e:/ had small B1; vowels /e/ and /e:/ had larger B2 and vowels /o/ and /o:/ had small B2; vowels /e/ and /u:/ had larger B3 and vowels /a/ and /o:/ had small B3. In adolescents, /a/ and /i:/ had larger B1 while /u/ and /u:/ had lower values; vowels /u/ and /a:/ had larger B2 while it was lower for /o/ and /i:/; vowels /u/ and /e:/ had larger B3 while for /o/ and /u:/ it was lower. Adults had larger B1 values for vowels /o/ and /o:/ and smaller for /a/ and /u:/; vowels /a/ and /o:/ had larger B2 and smaller for /i/ and /i:/; larger B3 values for vowels /o/ and /e:/ and smaller for /a/ and /a:/.

- Females had larger B1 & B2 values when compared to males for majority of the vowels while males tend to have higher B3 values.
- In females, B1 was larger in vowels /i/ and /i:/, B2 in /a/ and /e:/ and B3 in /e/ and /e:/. In males, B1 was larger in /i/ and /i:/ and B2 and B3 in /u/ and /e:/. B1 was lower for vowels /e/ and /e:/, B2 for /o/ and /u:/ and B3 for /u/ and /o:/ in females while, B1 of vowels /a/ and /u:/, B2 of /i/ and /i:/ and B3 of /a/ and /o:/ were lower in males.
- Speakers from Coastal region had larger B1 followed by Rayalaseema and Telengana speakers for all vowels.
- Speakers from Rayalaseema region had larger B2 followed by Coastal and Telengana speakers for all vowels except short and long vowels /i/ & /o/ and long vowel /u:/.
- Speakers from Rayalaseema region had larger B3 followed by Telengana and Rayalaseema speakers for all vowels except /i/, /u/ and /u:/.
- Manner and place of articulation of the preceding consonant had minimal effect on B1, B2 and B3 of the following vowel in Telugu.
- Voicing feature of the consonant had minimal influence on B1, B2 and B3 and varies between the short and long vowels.

4.3 Clinical implications

The temporal and spectral characteristics of vowels in Telugu described hitherto can be considered as the most descriptive so far reported. This information can be used in diverse clinical and research applications. Following are some of the areas where in the temporal and spectral parameters' information can be applied, especially with reference to the communication impaired with Telugu as their native language.

4.3.1 Differential diagnosis/Assessment

Vowel duration has been used as a measure in understanding the speech of hearing impaired, phonological disordered, apraxics, laryngectomees and cochlear implantees (Duggirala & Barbara, 2007; Collins, Rosenbek & Wertz, 1983 ; Krause, 1982, Poissant et.al., 2006; Manwal, Gilbert & Lerman, 2001).Vowel duration of the words in the current study can be used for comparison of the communication disordered population with region, gender and age specific normative data for diagnostic purposes.

Regarding the clinical utility of F0, it is to be emphasized that clinicians consider the vowel and the context while measuring the F0 of the target words/speech material. This is because, as comparing F0 of high with low vowels could lead to variations in the assessment as seen in the present study.

Formant frequencies have been clinically used extensively to study the disordered speech, emergence of vowel system, characterizing the disordered speech, in monitoring and understanding of vowel production, intelligibility and speech perception (Duggirala, 1983-84; Sumita, Ozawa, Mukohyama, Ueno, Ohyama & Taniguchi, 2002; Hedrick & Nabelek, 2004; Poissant et.al., 2006; Kertoy, Guest, Quart & Lieh-Lai, 1999; Gibson & Ohde, 2007; Kazi et.al., 2007). As all the formant frequencies (F1, F2, F3 and F4) in the current study varied with age, gender and region, clinicians can make use of this normative data to compare and differentiate the disordered from the normal population.

Vowel space is an acoustic measure for indexing the size of the vowel articulatory working space constructed using F1 and F2 of vowels /i/, /a/ and /u/. Watson et.al., (2004) reported significant differences in the vowel space among different age groups (50s, 70s and 80s). Larger vowel space and area could be indicators of clear speech and was used for judging the intelligibility of the speech (Carrell, 1984; Blomgren, Robb & Chen, 1998; Ferguson & Kewley-Port, 2007).

The vowel space in the current study was drawn using PRAAT software and considering F1 and F2 values of /i/, /a/ and /u/ of the overall data across different groups (age, gender and region) is depicted in Figures 4.3.1, 4.3.2, 4.3.3 and 4.3.4 respectively. Vowel space area calculated by using the model of Blomgren et.al., (1998), for different groups of the current study and values are given in Table 4.3.1.

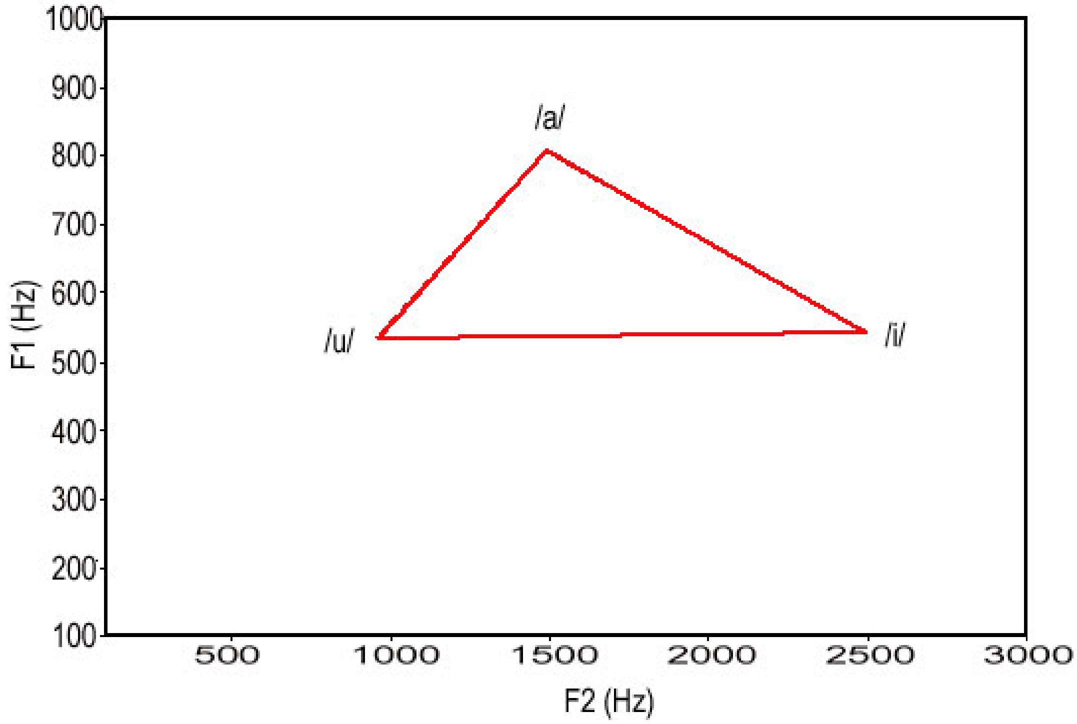


Figure 4.3.1: Vowel space for vowel /a/, /i/ and /u/

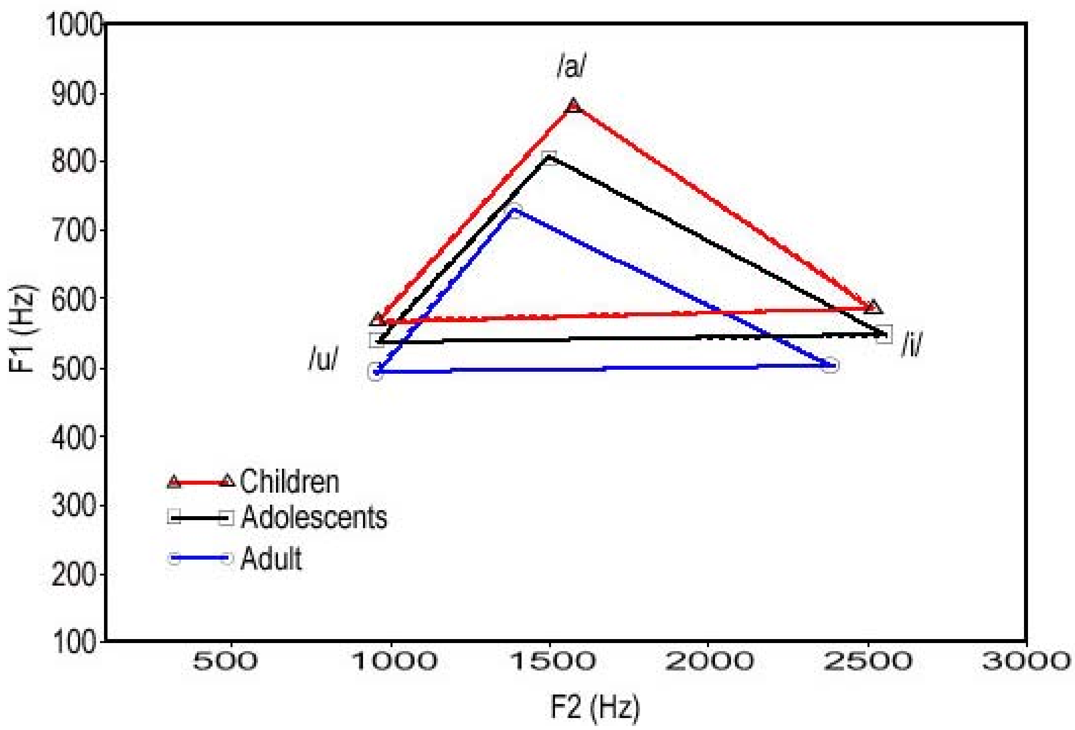


Figure 4.3.2: Vowel space for age categories

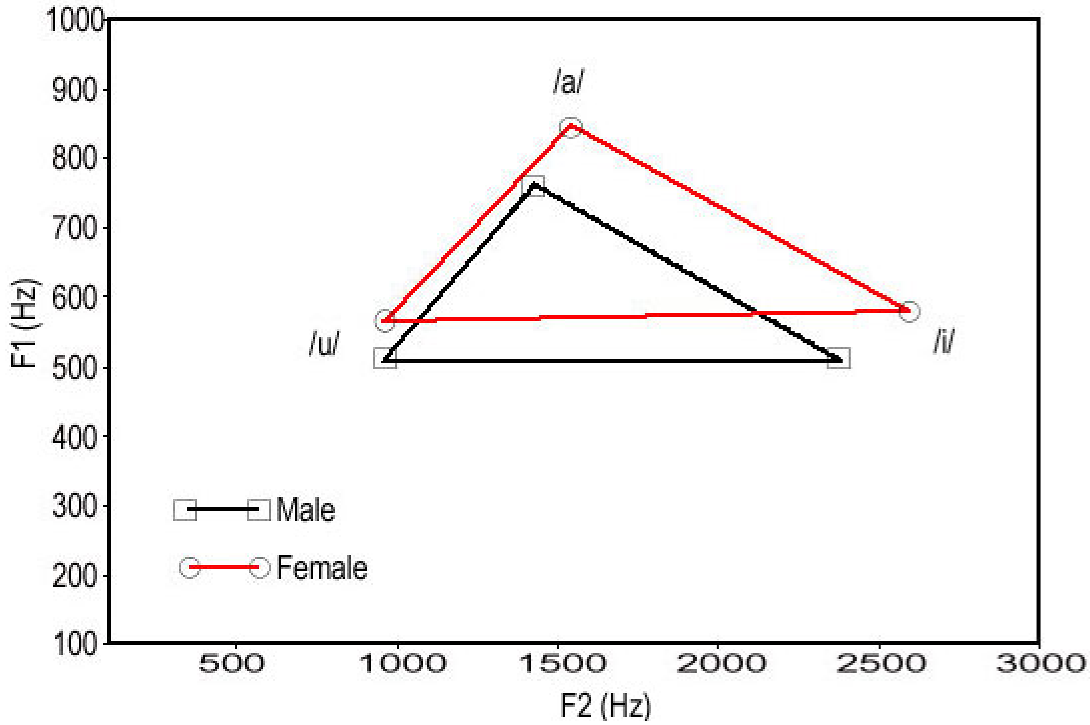


Figure 4.3.3: Vowel space for gender categories

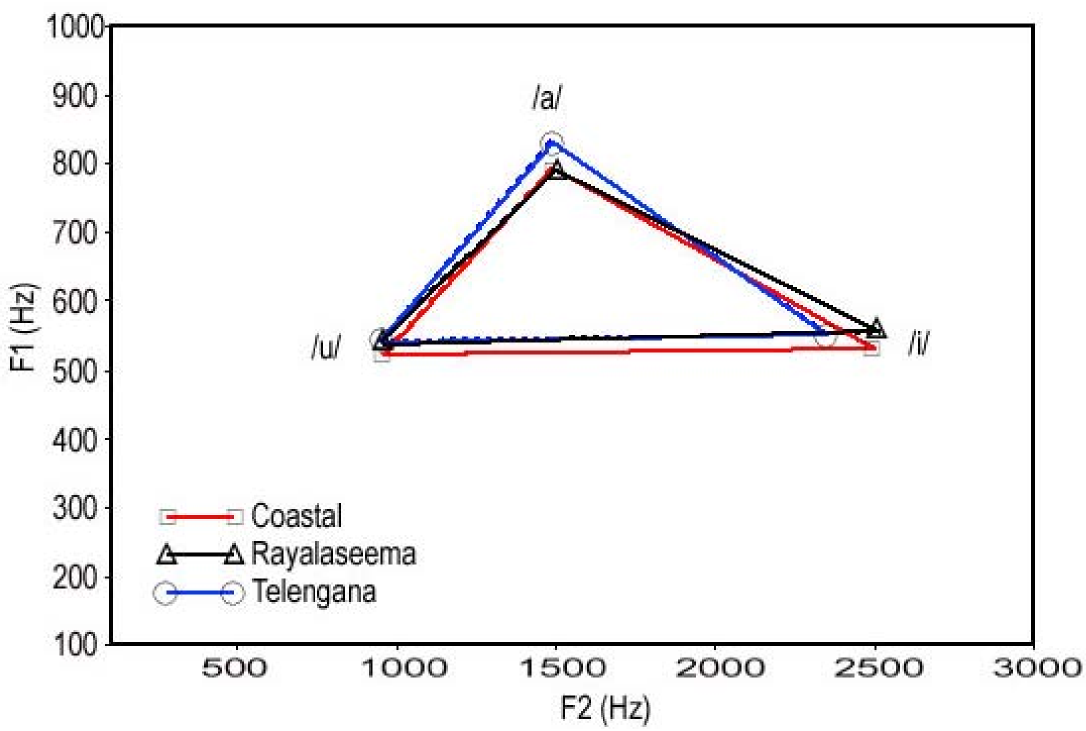


Figure 4.3.4: Vowel space for region categories

Table 4.3.1: Vowel space area in different groups

	Overall	Age			Gender		Region		
		Children	Adolescents	Adult	Female	Male	Coastal	Rayalaseema	Telengana
Area (Mz^2)	209279	242631	218412	168614	232167	186752	210019	197170	219822

From the data in Table 4.3.1 and Figures 4.3.1, 4.3.2, 4.3.3 and 4.3.4, it is observed that vowel space is different between the groups. Though age groups considered in the current study are not the same as in the quoted study (Watson et.al., 2004), age related changes in the vowel space did emerge. In the current study, smaller vowel space is noted for adults as compared to children, for males as compared to females and for speakers from Rayalaseema region as compared to Coastal or Telengana. Blomgren et.al., (1998), Klich & May (1982), Duggirala (1983-1984) and Turner, Tjaden & Weismer (1995) have used vowel space in differential diagnosis. The data obtained in this study could be used by the clinicians in differential diagnosis of various communication disorders. There are contradictory reports on association between vowel space and vowel intelligibility (Ferguson & Kewley-Port, 2007) and hence more studies on it's clinical utility are needed to substantiate it.

4.3.2 Rehabilitation/Management

The temporal and spectral data of the vowels obtained could also be used in the rehabilitation of the communication impaired in selecting appropriate training material to elicit optimum results with minimum effort. Not limiting to the areas mentioned below, information could be applied to wider areas. Clinicians can consider using vowels /e/ and /a/ in the CVC/CVCC contexts during the initial rehabilitation, long vowel words, and specific CV contexts to increase the vowel duration and thus facilitate enhanced speech intelligibility (Ferguson & Kewley-Port, 2007).

Vowels that elicit high F0 (/i/ and /u/) due to their inherent characteristics could be used to increase the pitch. Preceding consonant (nasal and fricatives) context that enhance higher F0 could also be used. Back vowels would be preferred to front and central vowels as they elicit higher F0. Based on the goal, clinicians can further compile practice material individualized to age, gender and region, as it is observed that in different groups, different vowels elicit higher or lower F0.

In the current study, it was observed that formant frequencies varied with age, gender, region and different consonant contexts. The normative data of the current study with reference to the formant frequencies as relevant to age, gender and region could help the clinician to achieve their rehabilitation goals for group appropriate vowel production and perception for their clients.

Tjaden, Rivera, Wilding & Turner (2005) had used vowel space and area to judge the recovery and improvement in dysarthria. The data (vowel space and area) of the current study could also be used by the clinicians as a reference in respective groups during rehabilitation and to judge the treatment efficacy.

Though limited, the acoustic characteristics of vowels in Telugu of the current study could be used as a reference in various communication disorder studies, speech processing strategies, speech synthesis and many more areas. The outcome of this study emphasizes that, when different co-variants and levels are considered, studying the influence of each co-variant and level would contribute significantly in understanding the influential factors.

From the results of the present study, it can be concluded that, acoustic characteristics of vowels in Telugu vary between age, gender, region and preceding consonant context groups. The influence of age, gender and consonant context on the acoustic characteristics of vowels as reported in the extensive western studies is also observed in this study. In addition, regional variations are also observed. Although linguistic variations between the region groups has been studied extensively, more studies on various anatomical and physiological factors that contribute to the variations of the acoustic characteristics of vowels in Telugu is warranted.

5

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSION

Stetson (1928) said that "speech is movement made audible". Speech, a form of verbal communication, is unique to human beings. This unique act of communication has drawn the attention of linguists, psychologists, speech scientists, speech language pathologists, audiologists, neurologists, computer scientists and other professionals involved in human communication in understanding and visualizing speech. Analysis of complex acoustic speech signal has diverse applications in phonetics, speech synthesis, automatic speech recognition, speaker identification, communication aids, speech pathology, speech perception, machine translation, hearing research, rehabilitation and assessment of communication disorders and many more.

Speech sounds consist of vowels and consonants. "Vowel is a conventional vocal sound in the production of which the speech organs offer little obstruction to the air stream and form a series of resonators above the level of the larynx" (Mosby, 2008). Vowels carry maximum energy and play a major role in speech understanding. Vowels are produced by voiced excitation of the open vocal tract. During the production of a vowel, the vocal tract normally maintains a relatively stable shape and offers minimal obstruction to the airflow. The energy thus produced can be radiated through the mouth or nasal cavity without audible friction or stoppage. Vowels are classified based on the tongue height, position of the tongue, lip position, soft palate position, phonemic length, articulators' tension and pitch. Acoustically, vowels are characterized by changing formant pattern, formant bandwidth, duration, amplitude and fundamental frequency. Among these, it is believed that formant pattern, duration and fundamental frequency play a major role in vowel perception (Pickett, 1980). Vowels play a stellar role in human communication and synthetic speech and are also influenced by developmental, linguistic, cultural, social and emotional factors (Kent & Read, 1995; Klatt, 1976; Ladefoged, 1975; Nagamma Reddy, 1998; Prahallad & Patel, 2006; Savithri, 1989; Sreenivasa Rao & Yegnanarayana, 2004). These features are also reported to play a major role in assessment, differential diagnosis and rehabilitation of communication disorders (Duggirala, 1983-1984, 1995, 2005; Edward & Valter, 2006, 2007; Hoasjoe, Martin, Doyle & Wong, 1992; Premalatha, Shenoy & Anantha, 2007).

Ladefogeds' (1975) comments that the vowels of different languages though perceived as same, with subtle acoustic differences between them, have relevance to the study of their acoustic and temporal characteristics in different languages and age groups. Information on acoustic characteristics of speech sounds will further enable understanding their articulatory nature and their perception (Pickett, 1980). Analysis of the acoustic characteristics of speech sounds of Indian languages is needed to understand their production and perception (Savithri, 1989). It will further be useful in perceptual studies, speech processing strategies, diagnosis and rehabilitation of various communication disorders.

Acoustic analysis of speech helps in early identification, (Bosma, Truby & Lind, 1965) differential diagnosis of various communication disorders (Hoasjoe, Martin, Doyle & Wong, 1992; Premalatha, Shenoy & Anantha., 2007; Tomik, Krupinski, Glodzik-Sobanska, Bala-Slodowska, Wszolek, Kusiak et.al.,, 1999; Rosen, Kent, Delaney & Duffy, 2006); laryngeal diseases (Murry & Doherty, 1980), understanding phonological process and vowel space in hearing impaired (Duggirala, 1995, 2005), assessing progress in the rehabilitation process and to improve naturalness and intelligibility of artificial speech (Nagamma Reddy, 1998).

Acoustic characteristics of vowels are generally studied based on their Fundamental Frequency, Formant Frequencies, Vowel Duration and Intensity. Acoustic studies illuminate the subtle differences in the production problems experienced not only by the hearing impaired but also in normal individuals and in different languages (Edward & Valter, 2006 & 2007; Duggirala, 1995; Ladefoged, 1975).

Telugu belongs to the South Dravidian group of languages (Krishnamurti, 2003) and is the second most widely spoken language in India (Hussain, Durrani & Gul, 2005). It has ten vowels (long and short: i, e, a, o, u) and seventeen consonants (six plosives: p, b, t, d, k, g; two retroflex stops: t_{l}, d_{l}; two affricates: tʃ, dʒ; two fricatives: s, ʃ; two nasals: m and n; one lateral: l; and two semi-vowels: /w/ and /y/) (Nagamma Reddy, 1986). Most of the studies on acoustic analysis of Telugu vowels in the literature (Kostić, Mitter & Krishnamurti, 1977; Nagamma Reddy, 1998, 1999; Prabhavathi Devi, 1990; Sreenivasa Rao, Suryakanth, Gangashetty, & Yegnanarayana, 2001) have been done only on adults or children, in limited consonant contexts, in limited sample size, selected from one region/dialect, with no comment on gender variations. However, these factors (age, dialectal variations, and consonant context) play significant role on the acoustic characteristic of vowels. The paucity of comprehensive data on the acoustic characteristics of vowels in Telugu across different age group and regions on the most essential features (vowel duration, formant frequencies, and bandwidth), has prompted the current study.

The aim of the current study was to investigate the temporal and spectral characteristics of vowels in Telugu language across different age groups. Differences in the temporal and spectral characteristics of vowels in Telugu across age groups (Group I (children): 6 to 9 years; Group II (adolescent): 13 to 15 years; Group III (adult): 20 to 30 years); between males and females; different regions in Andhra Pradesh and influence of preceding consonant context were analyzed. Clinical research implications of the data within the field of communication disorders were also discussed so as to understand/relevance of the study.

A list of 60 words consisting of ten vowels eighteen consonant and semivowel present in Telugu were used to analyze the temporal and spectral characteristics of the first vowel occurring in CVC/CVCCV context. A total of 72 randomly selected, Telugu speaking normal participants from three different regions (Coastal, Rayalaseema and Telengana) in three different age groups (Group I: 06 to 09 years; Group II: 13 – 15 years; Group III: 20 – 30 years) with equal gender ratio participated in the study.

A total of 4320 tokens of vowels from 72 participants served as the sample size for analysis. Descriptive analysis of the data was performed using SPSS 16. A three-level model was constructed with individuals as first level, consonants context as second level and vowels as third level, to evaluate the effect of age, gender and region on the response variables (vowel duration, fundamental frequency, formant frequencies and bandwidths), a multi-level approach (Quene & Bergh, 2004) was used in MlWin 1.1. Significance levels were determined with Wald test. Further to estimate the significant mean difference of each vowel between the age, region and gender groups for each response variables, one way ANOVA with Tukey HSD post hoc test and Student's *t*-test were used respectively using SPSS 16. Results obtained are as summarized below:

Vowel duration (VD):

- Vowels /e/ and /a:/ have longest vowel duration and short and long vowels /i/ have shortest vowel duration.
- Children have longer vowel duration compared to adolescents or adults.
- Females have longer vowel duration than males.
- Regional influences are seen on vowel duration. Rayalaseema speakers had longer vowel duration compared to Coastal or Telengana speakers.
- Preceding consonant's place, manner and voicing features influenced the vowel duration.
- The short and long vowel ratios observed in children was approximately 1:2, while was 1:2.2 in adolescents and 1:2.4 in adults.

Fundamental Frequency (F0):

- High vowels, /i/ and /u/ were having higher F0 and low vowel /a/ and /a:/ were having low F0
- Short vowels have higher F0 than long vowels.
- F0 was highest in children followed by adolescent and adults for all short and long vowels.
- Short and long vowel /a/ and /a:/ have lowest F0 in all age groups
- Females have higher F0 for all short and long vowels compared to males with vowel /i:/ having highest F0 in both genders.
- Short and long vowel /a/ and /a:/ have lowest F0 in both genders.
- Rayalaseema speakers have higher F0 for all short and long vowels followed by Telengana and Coastal speakers.

- Vowels when preceded by voiced consonants had lower F0 then when followed by voiceless consonants.
- Place and manner of articulation of the preceding consonant has influence on the F0 of the vowel.

Formant Frequencies (F1, F2, F3 and F4):

- Low mid vowels had the highest F1 and back high vowels had the lowest F1.
- High front vowel /i/ and /i:/ had the highest F2,F3 & F4 and back high vowel /u/ and /u:/ had the lowest F2, F3 & F4, in all age, gender and region groups.
- The long vowels had higher F2, F3 & F4 compared short vowels.
- Central vowels had higher F1 followed by front and back while Front vowels had higher F2, F3 & F4 followed by central and back.
- Children have higher formant frequencies (F1, F2, F3 & F4) followed by adolescents and adults.
- The low mid vowels have higher F1 and high back vowels have lower F1 values across age, gender and region groups.
- Females had higher formant frequencies (F1, F2, F3 & F4) values when compared to males for all vowels.
- Regional variations in formant frequencies (F1, F2, and F3) were noticed.
- Formant frequencies (F1, F2, F3 and F4) of vowels varied in different preceding consonant features such as manner, place and voicing. They seem to be contributing more than individual variations.

Bandwidths (B1, B2 & B3):

- Minimal variations in the band widths were noted among the vowels.
- Central vowels had larger bandwidth for F1 followed by back and front vowels.
- B1 reduced with increase in the phonetic length of the vowel.
- Children had larger B1 followed by adults and adolescents for all vowels except mid vowels /e/ and /o/.
- Females had larger B1 values when compared to males for all vowels.

- Speakers from Coastal region had larger B1 followed by Rayalaseema and Telengana speakers for all vowels.
- Manner and place of articulation of the preceding consonant had minimal effect on B1 of the following vowel in Telugu.

From the current study it is inferred that, vowels in Telugu follow universal criteria of vocal tract constriction and resonance characteristics, especially spectral parameters. As reported, significant variations in temporal and spectral parameters of vowels in Telugu exist between children, adolescents and adults; females and males; Coastal, Rayalaseema and Telengana speakers and the place, manner and voicing features of the preceding consonants. Hence, it is essential for speech language pathologists to apply the age, gender and region appropriate normative data to achieve appropriate speech output. From the multilevel statistical analysis, it is observed that consonants have higher contribution to the changes in formant frequencies and hence consonant contexts of the words with the target vowel should be carefully selected during comparisons of speech samples.

With the changes in formant frequencies depending on the resonant characteristics of the vocal tract and across the regions as observed in the current study, it would be interesting to further study if any anatomical variations exist between the regions which contribute to the observed variations.

The age, gender, region and preceding consonant context related data of the Telugu vowels obtained in this study would serve as a reference in the evaluation of Telugu speaking communication impaired and aid the clinicians working with this population to evolve appropriate treatment strategies.

References

REFERENCES

Alcantara, J. I., Dooley, G. J., Blamey, P. J., & Seligman, P. M. (1994). Preliminary evaluation of a formant enhancement algorithm on the perception of speech in noise for normally hearing listeners. *International Journal of Audiology, 33*(1), 15 - 27.

Ampathu, E. J. (1998). Analysis of Speech of Malayalam Speakers. Unpublished Master's Dissertation. University of Mysore.

Arehart, K. H., King, C. A., & Mclean-Mudgett, K. S. (1997). Role of fundamental frequency differences in the perceptual separation of competing vowels sounds by listeners with normal hearing and listeners with hearing loss. *Journal of Speech, Language, and Hearing Research, 40*, 1434 - 1444.

Atkinson, J. E. (1972). Intrinsic F0 in vowels: Physiological correlates. In J. J. Ohala (Ed.), *(1973) unpublished paper on Explanation for intrinsic pitch of vowels*. California: University of California.

Baker, S., Weinrich, B., Bevington, M., Schroth, K., & Schroeder, E. (2008). The effect of task type on fundamental frequency in children. *International journal of Pediatric Otorhinolaryngology, 72*(6), 885 - 889.

Balasubramanian, T. (1981). Duration of vowels in Tamil. *Journal of Phonetics, 9*, 151 - 161.

Balusu, R. (2001). *Acoustic correlates of stress and accent in Telugu*. Paper presented at the SALA XXI. from http://homepages.nyu.edu/~rb964/correlates.pdf

Baum, S. R. (1998). The role of fundamental frequency and duration in the perception of linguistic stress by individuals with brain damage. *Journal of Speech, Language, and Hearing Research, 41*, 31 - 40.

Bennett, S. (1980). Vowel formant frequency characteristics of preadolescent males and females. In S. Eguchi & I. J. Hirish (Eds.), *Development of Speech Sounds in Children*. Uppsala: Almqvist & Wiksells.

Bennett, S. (1981). Vowel formant frequency characteristics of Preadolescent males and females. *Journal of Acoustical Society of America, 67*, 231 - 238.

Bennett, S. (1983). A 3-year longitudinal study of school-aged children's fundamental frequencies. *Journal of Speech and Hearing Research, 26*, 137 - 141.

Bernstein-Ratner, N. (1985). Dissociations between vowel durations and formant frequency characteristics. *Journal of Speech and Hearing Research, 28*, 255 - 264.

Black, J. W. (1939). The Effect of the Consonant on the Vowel. *Journal of Acoustical Society of America, 10*, 203 - 205.

Black, J. W. (1949). Natural frequency, duration, and intensity of vowels in reading. *Journal of Speech and Hearing Disorder, 14*, 216 - 221.

Blomgren, M., Robb, M., & Chen, Y. (1998). A note on vowel centralization in stuttering and non stuttering individuals. *Journal of Speech, Language, and Hearing Research, 41*, 1042 - 1051.

Bosma, J. E., Truby, H. M., & Lind, J. (1965). Cry motions of the newborn infant. *Acta Paediatrica, 163*, 61 - 92.

Bradlow, A. R. (1995). A comparative acoustic study of English and Spanish vowels. *Journal of Acoustical Society of America, 97*, 1916 - 1924.

Bunch, M. (1982). *Dynamics of the singing voice*. New York: Springer-Verlag.

Bush, M. (1981). Cited in Shadle, C.H (1985), Intrinsic fundamental frequency of vowels in sentence context. *Journal of Acoustical Society of America, 78*, 1562 - 1567.

Carlson, R., & Granström, B. (1978). Experimental text-to-speech systems for the handicapped. *Journal of Acoustical Society of America, 64*, S163.

Carlson, R., Granström, B., & Klatt, D. K. (1979). Some notes on the perception of temporal patterns in speech. In B. Lindblom & S. Ohman (Eds.), *Frontiers in Speech Communication Research*. New York: Academic Press.

Carrell, T. D. (1984). *Contribution of Fundamental frequency, formant spacing, and glottal waveform to talker identification* (No. 5 Research on Speech Perception. Technical Report). Bethesda: National Institute of Health.

Cervera, T., Miralles, J. L., & Gonzalez-Alvarez, J. (2001). Acoustical analysis of Spanish vowels produced by laryngectomized subjects. *Journal of Speech, Language, and Hearing Research, 44*(5), 988 - 996.

Cheveigné, A. d. (1999). Formant Bandwidth affects the identification of competing vowels. from http://recherche.ircam.fr/equipes/pcm/cheveign/pss/1999_ICPhS.pdf

Clopper, C. G., Pisoni, D. B., & de Jong, K. (2005). Acoustic characteristics of the vowel systems of six regional varieties of American English. *Journal of Acoustical Society of America, 118*(3), 1661 - 1676.

Collins, M., Rosenbek, J. C., & Wertz, R. T. (1983). Spectrographic analysis of vowel and word duration in Apraxia of Speech. *Journal of Speech and Hearing Research, 26*, 224 - 230.

Cooper, W. E., Soares, C., Ham, A., & Damon, K. (1983). The influence of inter-and intra-speaker tempo on fundamental frequency and palatalization. *Journal of Acoustical Society of America, 73*(5), 1723 - 1730.

Coulmas. (1999). cited. In V. Duggirala (Ed.), *Development of Instructional materials for improving linguistic awareness of Telugu-speaking Hearing Impaired children* (pp. 63-79). Hyderabad: Department of Linguistics, Osmania University.

Cox, F. (2004). The acoustic characteristics of /hVd/ vowels in the speech of some Australian teenagers. Unpublished Research. Department of Linguistics, Macquarie University.

Crelin, E. (1987). *The Human Vocal Tract: Anatomy, Function, Development and Evolution*. New York: Vantage Press.

Crystal., T. H., & House., A. S. (1982). Segmental durations in connected speech signals: Preliminary results. *Journal of Acoustical Society of America, 72*(3), 705 - 716.

Daver. (1980). In F. M. Mitleb (Ed.), *Voicing effect on vowel duration is not an absolute universal* (Vol. 12, pp. 23 - 27): Journal of Phonetics.

Delattre, P. (1969). An acoustic and articulatory study of vowel reduction in four languages. In B.-R. Nan (Ed.), *Dissociations between vowel durations and formant frequency characteristics, Journal of Speech and Hearing Research* (Vol. 28, pp. 255 - 264).

Denes, P. (1955). Effect of duration on the perception of voicing. *Journal of Acoustical Society of America, 27*, 761-764.

Denes, P., & Pinson, E. (1963). *The Speech Chain: The Physics and Biology of Spoken Language*. New York: Anchor Press.

Duggirala, V. (1983-1984). Some spectrographic observations on the speech of a subject with Myositis. *Osmania Papers in Linguistics, 9,10*, 153 - 169.

Duggirala, V. (1995). Phonological space of vowel production in Telugu deaf children: A spectrographic study. *Journal of Acoustical Society of India, 23*(1), 36 - 47.

Duggirala, V. (2005). Development of Instructional materials for improving linguistic awareness of Telugu speaking Hearing Impaired children. (pp. 63 - 79). Department of Linguistics, Osmania University, Hyderabad: University Grants Commission, New Delhi.

Duggirala, V., & Barbara, D. (2007). Perceptual factors in phonological disorders: A tool for assessing input phonological processing in Telugu-English bilinguals. *Osmania Papers in Linguistics, 33*, 55-72.

Dunn, H. K. (1961). Methods of Measuring Vowel Formant Bandwidths. *Journal of Acoustical Society of America, 33*(12), 1737 - 1746.

Dyhr, N. (1990). The activity of the cricothyroid muscle and the intrinsic fundamental frequency in Danish vowels. *Phonetica, 47*((3-4)), 141 - 154.

Edward, K., & Valter, C. (2006). An Acoustic and Perceptual Study of Final Stops Produced by Profoundly Hearing Impaired Adolescents. *Journal of Speech Language and Hearing Research, 49*, 172 - 185.

Edward, K., & Valter, C. (2007). An acoustic and perceptual study of initial stops produced by profoundly hearing impaired adolescents. *Clinical Linguistics & Phonetics, 21*(1), 13 - 27.

Eguchi, S., & Hirish, I. J. (1969). *Development of Speech sounds in children* (Vol. 257). Uppsala: Almqvist & Wiksells.

Ertmer, D. J. (2001). Emergence of a vowel system in a young cochlear implant recipient. *Journal of Speech and Hearing Research, 44*(4), 803 - 813.

Ewan, W. G. (1979). Can intrinsic vowel F0 be explained by source/tract coupling? *Journal of Acoustical Society of America, 66*, 358 - 362.

Fant, G. (1960). *Acoustic Theory of Speech Production*. Mouton: The Hague.

Fant, G. (1966). A note on vocal tract size factors and nonuniform F-pattern scalings. *STL-QPSR, 4*, 22-30.

Fant, G., Stålhammar, U., & Karlsson, I. (1974). Swedish vowels in speech material of various complexity. *Speech Communication Seminar Stockholm 1974,* 139 - 147.

Ferguson, S. H., & Kewley-Port, D. (2007). Talker Differences in clear and conversational speech: Acoustic characteristics of vowels. *Journal of Speech, Language, and Hearing Research, 50*, 1241 - 1255.

Fischer-Jorgensen, E. (1964). Cited In I. Lehiste (Ed.), *Suprasegmentals*. Cambridge: MIT Press.

Fischer-Jorgensen, E. (1990). Intrinsic F0 in tense and lax vowels with special reference to German. *Phonetica, 47*, 99 - 140.

Flanagan, J. L. (1955). A Difference Limen for Vowel Formant Frequency. *Journal of the Acoustical society of America, 27*(3), 613 - 617.

Fletcher, H. (1929). *Speech and Hearing*. New York: D. Van Nostrand Company, Inc.

Fourakis, M., Botinis, A., & Katsaiti, M. (1999). Acoustic characteristics of Greek vowels. *Phonetica, 56*, 28 - 43.

Fry, D. B. (1955). Duration and intensity as physical correlates of linguistic stress. *Journal of Acoustical Society of America, 27*, 765-768.

Fry, D. B. (1979). *The physics of speech*. London: Cambridge University Press.

Gaitenby, J. (1965). The elastic word. In D. Klatt (Ed.), *The Duration of (s) in English words* (Vol. 51, pp. 51-63): Journal of Speech, Language, and Hearing Research.

Gendrot, C., & Adda-Decker, M. (2007). *Impact of duration and vowel inventory size on formant values of oral vowels: An automated formant analysis from eight languages*. Paper presented at the 16th International Conference on Phonetic Sciences. from http://www.icphs2007.de/conference/book_of_abstracts.pdf

Gibson., T., & Ohde, R. N. (2007). F2 Locus Equations: Phonetic Descriptors of Coarticulation in 17 - to 22- Month old children. *Journal of Speech, Language, and Hearing Research, 50*(1), 97 - 108.

Girija, P. N., & Sridevi, A. (1995). Duration rules for vowels in Telugu. Dept of Computer & Information sciences, AI Lab, University of Hyderabad.

Goldstein. (1980). In M. Lucie, J.-L. Schqartz & B. Louis-Jean (Eds.), *Role of vocal tract morphology in speech development: Perceptual Targets and Sensorimotor Maps for Synthesized French vowels from birth to adulthood. Journal of Speech, Language, and Hearing Research* (Vol. 47, pp. 1059 - 1080).

Goodman, P. (1911). from http://quotationsbook.com/author/2932

Gopal, H. S. (1987). Temporal aspects of tense and lax vowels in American English: Effects of speaking rate and post vocalic consonant voicing. Unpublished Dissertation. University of Texas.

Halle, M., & Stevens, K. N. (1967). Cited. In I. Lehiste (Ed.), *Suprasegmentals*. Cambridge: MIT Press.

Hasegawa-Johnson, M., Pizza, S., Alwan, A., Cha, J. S., & Hake, K. (2003). Vowel category dependence of the relationship between Palate height, Tongue height, and Oral area. *Journal of Speech, Language, and Hearing Research, 46*(3), 738 - 753.

Hedrick, M. S., & Nabelek, A. K. (2004). Effect of F2 Intensity on Identity of /u/ in Degraded Listening Conditions. *Journal of Speech, Language, and Hearing Research, 47*(5), 1012 - 1021.

Hewlett, N., Beck, J., & Beck, J. M. (2006). *An Introduction to the Science of Phonetics*: Routledge.

Hillenbrand, J., Clark, M. J., & Nearey, T. M. (2001). Effects of consonant environment on vowel formant patterns. *Journal of Acoustical Society of America, 109*, 748-763.

Hillenbrand, J., & Gayvert, R. T. (1993). Vowel classification based on fundamental frequency and formant frequencies. *Journal of Speech and Hearing Research, 36*, 694 - 700.

Hillenbrand, J., Getty, L. A., Clark, M. J., & Wheeler, K. (1995). Acoustic characteristics of American English vowels. *Journal of Acoustical Society of America, 97*, 3099 - 3111.

Hirano, M., Kurita, S., & Nakashima, T. (1981). The structure of the vocal folds. In K. N. Stevens & M. Hirano (Eds.), *Vocal fold physiology*. Tokyo: University of Tokyo Press.

Hoasjoe, D. K., Martin, G. F., Doyle, P. C., & Wong, F. S. (1992). A comparative acoustic analysis of voice production by near-total laryngectomy and normal laryngeal speakers. *Journal of Otolaryngology, 21*(1), 39-43.

Hombert, J.-M. (1977). Consonant types, vowel height and tone in Yoruba. *Studies in African Linguistics, 8*(2), 173 - 190.

Honda, K. (2004). *Physiological Factors causing tonal characteristics of speech: from global to local prosody.* Paper presented at the Speech Prosody 2004.

Honda, K., & Fujimura, O. (1991). Intrinsic vowel F0 and phase-final F0 lowering: Phonological Vs biological explanations. In J. Gauggin & B. Hammarberg (Eds.), *Vocal fold physiology: Acoustic, Perceptual and Physiological aspects of voice mechanisms* (pp. 149 - 157). San Diego, CA: Singluar Publishing group.

Hongyan, W. (2007). English as a lingua franca: Mutual intelligibility of Chinese, Dutch and American speakers of English. Unpublished LOT Dissertation Series 147. Netherlands Graduate School of Linguistics.

House, A. S. (1961). On vowel duration in English. *Journal of the Acoustical Society of America, 6*, 111 - 127.

House, A. S., & Fairbanks, G. (1953). The influence of consonant environment upon the secondary acoustical characteristics of vowels. *Journal of Acoustical Society of America, 25*, 105 - 113.

Huang, X., Acero, A., & Hon, H. W. (2001). *Spoken Language Processing*. UK: Prentice-Hall, Inc.,.

Hunyady, H. A. (2006). *The relative amplitude of vowel formants for vowels in asymmetrical consonant contexts.* The Ohio State University, Ohio.

Hussain, S., Durrani, N., & Gul, S. (2005). *Survey of Language Computing in Asia*. Lahore, Pakistan: Center for Research in Urdu Language Processing, University of Computer and Emerging Sciences.

Irwin, O. C. (1943). Speech sound elements during the 1st year of life: A review of literature. *Journal of Speech and Hearing Disorders, 8*, 109.

Jenson, P. J., & Menon, K. M. N. (1972). Physical Analysis of Linguistic Vowel duration. *Journal of Acoustical Society of America, 52*, 708 - 810.

John.W, H., Marios.S, F., Margaret.W, S., Timothy.A, H., & Laura.K, H. (1997). Effects of Formant Bandwidth on the Identification of Synthetic Vowels by Cochlear Implant Recipients. *Ear and Hearing, 18*(6), 479 - 487.

Joos. (1948). *Acoustic Phonetics - Linguistic Society of America, Language Monograph*. Baltimore: Waverly Press, Inc., 23.

Kahane, J. (1978). A morphological study of the human prepubertal and pubertal larynx. *American Journal of Anatomy, 151*, 11 - 20.

Kallail, K. J., & Emanuel, F. W. (1984). Formant - Frequency differences between isolated whispered and phonated vowel samples produced by adult female subjects. *Journal of Speech and Hearing Research, 27*, 245 - 251.

Kazi, R., Prasad, V. M. N., Kanagalingam, J., Georgalas, C., Venkitaraman, R., Nutting, C. M. C., P, et al. (2007). Analysis of formant frequencies in patients with oral or oropharyngeal cancers treated by glossectomy. *International Journal of Language Communication Disorders, 42*(5), 521 - 532.

Kent, R. D. (1976). Anatomical and Neuromucular maturation of the speech mechanism: Evidence from acoustic studies. In S. Eguchi & I. J. Hirish (Eds.), *Development of speech sounds in children* (pp. 357 - 383). Uppsala: Almquist & Wiksells.

Kent, R. D., & Ann.D, M. (1982). Acoustic features of infant vocalic utterances at 3, 6, and 9 months. In S. Eguchi & I. J. Hirish (Eds.), *Development of Speech sounds in children* (Vol. 257, pp. 402 - 414). Uppsala: Almqvist & Wiksells.

Kent, R. D., & Burkhard, R. (1981). Changes in the acoustic correlates of speech production. In D. S. Beasley & G. G. Davis (Eds.), *Aging: Communication process and disorders* (pp. 47 - 62). New York: Grune & Stratton.

Kent, R. D., & Forner, L. L. (1979). Developmental studies of vowel formant frequencies in an imitation task. *Journal of Acoustical Society of America, 65*(1), 208 - 217.

Kent, R. D., & Forner, L. L. (1980). Speech segment durations in sentence recitations by children and adults. *Journal of Phonetics, 8*, 157 - 168.

Kent, R. D., & Read, C. (1995). *The Acoustic Analysis of Speech*. New Delhi: A.I.T.B.S. Publishers & Distributors.

Kent, R. D., Weismer, G., & Kent, J. F. (1989). Toward phonetic intelligibility testing in Dysarthria. *Journal of Speech and Hearing Disorders, 54*, 482 - 499.

Kertoy, M. K., Guest, C. M., Quart, E., & Lieh-Lai, M. (1999). Speech and Phonological characteristics of Individual children with history of Tracheostomy. *Journal of Speech, Language, and Hearing Research, 42*, 621 - 635.

Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptual evidence. *Journal of Acoustical Society of America, 59*, 1208 - 1221.

Klatt, D. H. (1982). *Prediction of perceived phonetic distance from critical-bank spectra: a first step.* Paper presented at the IEEE ICASSP.

Klich, R. J., & May, G. M. (1982). Spectrographic study of vowels in stutterers' fluent speech. *Journal of Speech and Hearing Research, 25*, 364 - 370.

Koenig, W., Dunn, H. K., & Lacy, L. Y. (1946). The Sound Spectrograph. *Journal of Acoustical Society of America, 18*(1), 19 - 49.

Kostić, D., Mitter, A., & Krishnamurti, B. H. (1977). *A Short Outline of Telugu Phonetics*. Calcutta: Indian Statistical Institute.

Krause, S. E. (1982). Developmental use of vowel duration as a cue to postvocalic stop consonant voicing. *Journal of Speech and Hearing Research, 25*, 388 - 393.

Krishnamurti, B. H. (1961). *Telugu Verbal Bases: A Comparative and Descriptive study* (Vol. 24). Berkeley and Los Angeles: University of California Press.

Krishnamurti, B. H. (2003). *The Dravidian Languages*. London: Cambridge University Press.

Krishnamurti., B. H. (1998). *Language Education, and Society*. New Delhi: Sage Publications.

Ladefoged, P. (1964). Some possibilities in speech synthesis. *Language and Speech, 7*, 205 - 214.

Ladefoged, P. (1975). *A course in Phonetics*. New York: Blackwell Publishers.

Ladefoged, P. (2001). *Vowels and Consonants: An Introduction to the Sounds of Languages*: Blackwell Publishing.

Lane, H., Matthies, M., Perkell, J., Vick, J., & Zandipour, M. (2001). The effects of changes in hearing status on cochlear implant users on the acoustic vowel space and CV coarticulation. *Journal of Speech, Language, and Hearing Research, 44*, 552 563.

Langereis, M. C., Bosman, A. J., Olphen, A. F. v., & Smoorenburg, G. F. (1997). Changes in vowel quality in post-lingually deafened cochlear implant users. *Audiology, 36*(5), 279 - 297.

Lehiste, I. (1959). *An acoustic-phonetic study of internal open juncture*. Michigan: University of Michigan Speech Research Laboratory Report No. 2.

Lehiste, I. (1970). *Suprasegmentals*. Cambridge: MIT Press.

Lehiste, I., & Peterson, G. (1961). Some basic consideration in the analysis of intonation. *Journal of Acoustical Society of America, 33*, 419 - 425.

Liberman, P. (1967). Intonation, perception and language. In B.-R. Nan (Ed.), *Journal of Speech and Hearing Research* (Vol. 28, pp. 255 - 264).

Liberman, P. (1970). A study of prosodic features. In J. J. Ohala (Ed.), *(1973) unpublished paper on Explanations for the intrinsic pitch of vowels* (pp. 1 - 14). California: University of California.

Lindblom, B. (1986). Phonetic universals in vowel systems. In J. J. Ohala & J. J. Jeager (Eds.), *Experimental Phonology* (pp. 13 - 44). Orlando, FL: Academic Press.

Lisker, L. (1974). On explaining vowel duration variation glossia. *International Journal of Linguistics, 8*, 2.

Lisker, L., & Abramson, A. (1964). A cross-language study of voicing in initial stops. *Word, 20*, 384-422.

Liu, H., Wan, M., Ng, M. L., Wang, S., & Lu, C. (2006). Tonal perceptions in normal laryngeal, Esophageal, and Electrolaryngeal speech of Mandarin. *Folia Phoniatrica, 58*, 340 - 352.

Loakes, D. (2004). *Front Vowels as Speaker-Specific: Some Evidence from Australian English.* Paper presented at the 10th Australian International Conference on Speech Science & Technology, Macquarie University, Sydney.

Maddieson, I. (1993). Splitting the Mora. *UCLA Working papers in Phonetics, 83*, 9 - 18.

Man, C. Y. (2007). *An Acoustical analysis of the vowels, diphthongs and triphthongs in Hakka Chinese.* Paper presented at the 16th International Congress of Phonetic Sciences. from http://www.icphs2007.de/conference/book_of_abstracts.pdf

Manwal, L. N., Gilbert, H. R., & Lerman, J. W. (2001). Fundamental frequency, intensity, and vowel duration characteristics related to Perception of Cantonese Alaryngeal Speech. *Folia Phoniatrica et Logopaedica, 53*(1), 36 - 47.

McCrea, C. R., & Morris, R. J. (2005). The effects of fundamental frequency level on voice onset time in normal adult male speakers. *Journal of Speech, Language, and Hearing Research, 48*, 1013 - 1024.

Menard, L., Jean-Luc, S., & Boe, L.-J. (2004). Role of vocal tract morphology in speech development: Perceptual Targets and Sensorimotor Maps for Synthesized French vowels from birth to adulthood. *Journal of Speech, Language, and Hearing Research, 47*, 1059 - 1080.

Mermelstein, P. (1978). Difference limens for formant frequencies of steady-state and consonant-bound vowels. *Journal of Acoustical Society of America, 63*, 572 - 580.

Miller. (1989). Cited in Hillenbrand, J., & Gayvert, R. T. (1993). Vowel classification based on fundamental frequency and formant frequencies. *Journal of Speech and Hearing Research, 36*, 694 - 700.

Mitleb, F. M. (1984). Voicing effect on vowel duration is not an absolute universal. *Journal of Phonetics, 12*, 23 - 27.

Mohr, B. (1971). Intrinsic variations in the speech signal. *Phonetica, 23*, 65 - 93.

Monsen, R. B., & Engebretson, A. M. (1983). The Accuracy of Formant Frequency measurements: A comparison of spectrographic analysis and linear prediction. *Journal of Speech and Hearing Research, 26*, 89 - 87.

Moon, S.-J., & Lindblom, B. (1989). *Formant undershoot in clear and reference speech: a 2nd progress report*.

Mosby (Ed.) (2008) Mosby's Dental Dictionary (2nd Edition ed.). Elsevier, Inc.

Most, T., Amir, O., & Tobin, Y. (2000). The Hebrew Vowel System: Raw and Normalized Acoustic Data. *Language and Speech, 43*(3), 295 - 308.

Murry, T., & Doherty.E, T. (1980). Selected acoustic characteristics of pathologic and normal speakers. *Journal of Speech and Hearing Research, 23*, 361 - 369.

Nagamma Reddy, K. (1986). *The place of articulation of retroflex consonants in Telugu.* Paper presented at the XII All India Conference of Dravidian Linguists, Thanjavur.

Nagamma Reddy, K. (1988). The duration of Telugu speech sounds: an acoustic study. *The Journal of Institution of Electronics and Telecommunication Engineers, 34*, 1-23.

Nagamma Reddy, K. (1998). Distinctive vowel quality, quantity and nasalization in Telugu and Hindi. *Osmania papers in Linguistics, 24*, 49 - 69.

Nagamma Reddy, K. (1999). Coarticulation in Telugu: Instrumental Phonetic Evidence for and against syllable affinity. *Osmania papers in Linguistics, 25*, 1 - 24.

Nataraja, N. P., & Jagadish, A. (1984). Vowel duration and fundamental frequency. *Journal of All India Institute of Speech and Hearing, 15*, 57 - 64.

Natke, U., & Kalveram, K. T. (2001). Effect of frequency-shifted auditory feedback on fundamental frequency of long stressed and unstressed syllables. *Journal of Speech, Language, and Hearing Research, 44*, 577 - 584.

Neel, A. T. (2008). Vowel space characteristics and vowel identification accuracy. *Journal of Speech, Language, and Hearing Research, 51*, 574 - 585.

Nirmala, C. (1981). Medial consonant cluster acquisition by Telugu children. *Journal of Child Language, 8*, 63-73.

Nyquist, H. (1928, November 22, 2002). The biographies of Nyquist from http://www.geocities.com/bioelectrochemistry/nyquist.htm

Ohala, J. J. (1972). How is pitch lowered? In J. J. Ohala (Ed.), *(1973) unpublished paper on Explanations for the intrinsic pitch of vowels* (pp. 1 - 14). California: University of California.

Ohala, J. J. (1973). *Explanations for the intrinsic pitch of vowels*. Berkeley: Monthly internal memorandum, January, 9 - 26.

Oller, D. K. (1980). The emergence of the sounds of speech in infancy. In G. Yeni-Komshian, J. Kavanagh & C. A. Fegusen (Eds.), *Child Phonology* (Vol. 1). New York: Academic Press.

O'Shaughnessy, D. (1976). Cited in O'Shaughnessy, D (1981). A study of French vowel and consonant duration. *Journal of Phonetics, 9*, 385 - 405.

Pal, S. K., & Majumder, D. D. (1977). *Fuzzy sets and decision making approaches in vowel and speaker recognition.* Paper presented at the IEEE transactions on systems, man, and cybernetics.

Perkell, Lane, Svirsky, & Webster. (1992). Speech of cochlear implant patients: A longitudinal study of vowel production. *Journal of Acoustical Society of America, 91*, 2961 - 2978.

Peterson, G. E., & Barney, H. L. (1952). Control methods used in a study of the Vowels. *Journal of Acoustical Society of America, 24*(2), 175 - 184.

Peterson, G. E., & Lehiste, I. (1960). Duration of syllable nuclei in English. *Journal of the Acoustical Society of America, 32*, 693 - 703.

Pickett, J. M. (1980). *The sounds of speech communication a primer of acoustic phonetics and speech perception*. Baltimore: University Park Press.

Pickett, J. M. (1996). *The Sounds of Speech Communication - A Primer of Acoustic Phonetics and Speech Perception*. Boston: Allyn and Bacon.

Pierrehumbert, J. (1980). Cited in Shadle, C.H. (1985), Intrinsic fundamental frequency of vowels in sentence context. *Journal of Acoustical Society of America, 78*, 1562 - 1567.

Poissant, S. F., Peters, K. A., & Robb, M. P. (2006). Acoustic and perceptual appraisal of speech production in pediatric cochlear implant users. *International journal of Pediatric Otorhinolaryngology, 70*(7), 1195 - 1203.

Potter, R.K. (1946). In Koenig, W et.al., 1946 (Eds). The Sound Spectrograph. *Journal of Acoustical Society of America, 18*(1), 19 - 49.

Prabhavathi Devi, M. (1990). *Vowel length in Telugu-An Instrumental Study.* Central Institute of English & Foreign Languages, Hyderabad.

Prahallad, K., & Patel, N. (2006). SSML extensions for text to speech systems in Indian languages.from http://www.w3.org/2006/02/SSML/papers/Bhrigus/ssml_2006_iiit_bhrigus_3.0.pdf

Premalatha, M., Shenoy, A. M., & Anantha, N. (2007). Speech evaluation after near total Laryngectomy and Total Laryngectomy - A comparative acoustic analysis. *International archives of Otorihonolaryngology, 11*(2), 99.

Purcell, D. W., & Munhall, K. G. (2005). Compensation following real-time manipulation of formants in isolated vowels. *Journal of Acoustical Society of America, 119*(4), 2288 - 2297.

Qin, M. K., & Oxenham, A. J. (2005). Effects of Envelope-Vocoder Processing on F0 Discrimination and Concurrent - Vowel Identification. *Ear and Hearing, 26*(5), 451 - 460.

Quene, H., & Bergh, H. v. d. (2004). On multi-level modeling of data from repeated measures designs: a tutorial. *Speech Communication, 43*(1-2), 103-121.

Raphael, L. J. (1972). Preceding vowel duration as a cue to the perception of the voicing characteristics of word final consonants. *Journal of Acoustical Society of America, 51*, 1296 - 1303.

Rashmi, M. (1985). Acoustic aspects of speech of children. Unpublished Master's dissertation. All India Institute of Speech and Hearing, Mysore.

Riyamol, T. (2007). Acoustic Analysis of Vowels in Malayalam Speakers. Unpublished Masters dissertation. Dept of Speech and Hearing, Sri Ramachandra University, Chennai.

Robb, M. P., & Saxman, J. H. (1985). Developmental trends in vocal fundamental frequency of young children. *Journal of Speech and Hearing Research, 28*, 421 - 427.

Rosen, K. M., Kent, R. D., Delaney, A. L., & Duffy, J. R. (2006). Parametric Quantitative Acoustic Analysis of Conversation Produced by Speakers With Dysarthria and Healthy Speakers *Journal of Speech Language and Hearing Research, 49*, 395 - 411.

Rosner, B. S., & Pickering, J. B. (1994). *Vowel perception and production*. Oxford: Oxford University Press.

Russell, M. (2002). A comparison of the acoustic correlates of focus in Indian English and American English. University of Florida.

Samuel, G. (1973). A study of the fundamental frequency of voice and natural frequency of vocal tracts on an Indian population of different age ranges. Unpublished Master's dissertation. All India Institute of Speech and Hearing, Mysore.

Sashidharan, P. N. (1995). Vowel Duration in Malayalam Language. Unpublished Master's Dissertation. University of Mysore.

Savithri, S. R. (1984). Relationship between the fundamental frequency and duration. Unpublished research. All India Institute of Speech and Hearing, Mysore.

Savithri, S. R. (1986). Durational analysis of Kannada Vowels. *Journal of Acoustical Society of India, 14*(2), 34 - 31.

Savithri, S. R. (1989). Acoustic and psychological correlates of speech. *Journal of Acoustical Society of India, 17*(3,4), 41 - 48.

Scripture, E. W. (1935). Film Tracks of English Vowels. *Journal of Acoustical Society of America, 6*, 169 - 172.

Shadle, C. H. (1985). Intrinsic Fundamental Frequency of vowels in sentence context. *Journal of Acoustical Society of America, 78*(5), 1562 - 1567.

Singh, S., & Singh, K. (1979). *Phonetics: Principles and Practices*. Baltimore: University Park Press.

Sisty, N. L., & Weinberg, B. (1972). Formant frequency characteristics of Esophageal speech. *Journal of Speech and Hearing Research, 15*, 439 - 448.

Sitaramacharyulu, B. (Ed.) (2005) Sabda Ratnakaram. Vijayawada: Victory Publishers.

Smith, B. L. (1978). Temporal aspects of English speech production: A developmental perspective. *Journal of Phonetics, 6*, 37 - 67.

Sreedevi, N. (2000). *Acoustic Characteristics of Vowels in Kannda.* Unpublished Ph.D dissertation submitted to the, University of Mysore, Mysore.

Sreenivasa Rao, K., Suryakanth, V., Gangashetty, & Yegnanarayana, B. (2001). *Duration Analysis for Telugu Language*. Paper presented at the Proc. Int. Conf. Natural Language Processing, Mysore.

Sreenivasa Rao, K., & Yegnanarayana, B. (2004). *Modeling Syllable Duration in Indian Languages using neural networks.* Paper presented at the IEEE International conference Acoustics, Speech Signal Processing, Montreal, Quebec, Canada.

Stålhammar, U., Karlsson, I., & Fant, G. (1973). Contextual effects on vowel nuclei. *STL-QPSR, 14*(4), 1-18.

Stetson, H. R. (1928). In R. D. Kent & R. Charles (Eds.), *The Acoustic Analysis of Speech*. New Delhi: A.I.T.B.S Publishers and Distributors.

Stevens, N. K., & House, S. A. (1963). Perturbation of Vowel Articulations by Consonantal Context: An Acoustical Study. *Journal of Speech and Hearing Research, 6*, 111 - 127.

Strom, K., Thomson, K., Boutsen, F., & Pentz, A. (2005). *Deterioration of Vowel differentiation in Normal Aging*. Paper presented at the ASHA convention. from http://convention.asha.org/2005/handouts/293_Strom_Kaye_073999_111605030116.doc.

Sumita, Y. I., Ozawa, S., Mukohyama, H., Ueno, T., Ohyama, T., & Taniguchi, H. (2002). Digital acoustic analysis of five vowels in maxillectomy patients. *Journal of Oral Rehabilitation, 29*(7), 649 - 656.

Syrdal, A. K., & Gopal, H. S. (1986). A Perceptual model of vowel recognition based on auditory representation of American English vowels. *Journal of Acoustical Society of America, 79*, 1086 - 1100.

Taylor. (1933). The fundamental pitch of English vowels. In J. J. Ohala (Ed.), *Unpublished paper on "Explanations for the intrinsic pitch of vowels"* (pp. 1 - 14). University of California.

Thorsen, N. (1976). An acoustical investigation of Danish intonation. *Journal of Phonetics, 6*, 151 - 175.

Titze, I. R. (1989). Physiologic and acoustic differences between male and female voices. *Journal of Acoustical Society of America, 85*, 1699 - 1707.

Tjaden, K., Rivera, D., Wilding, G., & Turner, G. S. (2005). Characteristics of the Lax Vowel Space in Dysarthria. *Journal of Speech, Language, and Hearing Research, 48*(3), 554 - 566.

Tomik, B., Krupinski, J., Glodzik-Sobanska, L., Bala-Slodowska, M., Wszolek, W., Kusiak, M., et al. (1999). Acoustic analysis of dysarthria profile in ALS patients. *Journal of the Neurological Sciences, 169*(1), 35 - 48.

Turner, G. S., Tjaden, K., & Weismer, G. (1995). The influence of speaking rate on vowel space and speech intelligibility for individuals with amyotrophic lateral sclerosis. *Journal of Speech, Language, and Hearing Research, 38*, 1001 - 1014.

Udaya Shankar, P. N. (1987). The verb *undu* 'to be' in displaced Telugu dialects: A case for language contact and morphological development. *Osmania Papers in Linguistics, 13*, 73 - 84.

Umeda, N. (1981). Influence of Segmental factors on Fundamental Frequency in fluent speech. *Journal of Acoustical Society of America, 70*(2), 350 - 355.

Usha, A. A. (1978). Study of fundamental frequency of voice in an Indian population. Unpublished Master's dissertation. All India Institute of Speech and Hearing, Mysore.

Vaissière. (2007). Area functions and articulatory modeling as a tool for investigating the articulatory, acoustic and perceptual properties of sounds across languages. In C. Gendrot. & M. Adda-Decker. (Eds.), *Impact of duration and vowel inventory size on formant values of oral vowels: An automated formant analysis from eight languages.* (pp. 143). Saarbrücken:

http://www.icphs2007.de/conference/book_of_abstracts.pdf.

Velayudhan, S. (1975). *Vowel duration in Malayalam: an acoustic phonetic study.* . Paper presented at the All India Conference of Dravidian Linguists, Thiruvananthapuram.

Venkatesh, C. S. (1995). Acoustic analysis of Kannada Speech sounds. Unpublished Doctoral Thesis. University of Mysore.

Venkateswara Sastry, J. (1990-1991). Indices for standard Telugu. *Osmania Papers in Linguistics, 16-17*, 117 - 136.

Vorperian, H. K., & Kent, R. D. (2007). Vowel acoustic space development in Children: A synthesis of acoustic and anatomic data. *Journal of Speech, Language, and Hearing Research, 50*, 1510 - 1545.

Vorperian, H. K., Shubing, W., Chung, M. K., E. Michael Schimek, Reid B. Durtschi, Kent, R. D., et al. (2009). Anatomic development of the oral and pharyngeal portions of the vocal tract: An imaging study. *Journal of Acoustical Society of America, 125*(3), In press.

Watson, C. I., Palethorpe, S., & Harrington, J. (2004). *Capturing The Vowel Change In New Zealand English Over a Thirty Year Period Via A Diachronic Study.* Paper presented at the 10th Australian International Conference on Speech Science & Technology, Macquarie University, Sydney.

Whalen, D. H., & Levitt, A. G. (1995). *The Universality of intrinsic F0 of vowels* (No. SR-117/118, Jan-June). Huskins Laboratories Status Report on Speech Research, 1-14.

Whalen, D. H., Magen., H. S., Pouplier., M., Min Kang, A., & Iskarous, K. (2004). Vowel Production and Perception: Hyperarticulation without a Hyperspace Effect. *Language and Speech, 47*(2), 155 - 174.

Whitehead, A. N. (1861). from http://quotationsbook.com/author/7679

Whitehead, R. L., Schiavetti, N., Whitehead, B. H., & Metz, D. E. (1995). Temporal characteristics of speech in simultaneous communication. *Journal of Speech and Hearing Research, 38*, 1014 - 1024.

Whitehill, T. L., Ciocca, V., Chan, J., C-T., & Samman, N. (2004). Acoustic Analysis of vowels following glossectomy. *Clinical Linguistics & Phonetics, 20*(2/3), 135 - 140.

Wikimedia Foundation, I. (2008a). from http://en.wikipedia.org/wiki/Languages_of_India

Wikimedia Foundation, I. (2008b). from http://en.wikipedia.org/wiki/Origin_of_language

Wikimedia Foundation, I. (2008c). from http://en.wikipedia.org/wiki/Telugu_script

Wikimedia Foundation, I. (2008d). from http://en.wikibooks.org/wiki/Telugu/Dialects

Xue, S. A., & Hao, G. J. (2003). Changes in the Human vocal tract due to aging and the Acoustic Correlates of Speech production: A Pilot study. *Journal of Speech, Language, and Hearing Research, 46*(3), 689 - 701.

Yasojima, O., Takahashi, Y., & Tohyama, M. (2006). *Resonant Bandwidth Estimation of Vowels using Clustered-Line Spectrum Modeling for Pressure Speech Waveforms.* Paper presented at the 2006 IEEE International Symposium on Signal Processing and Information Technology, Vancouver, Canada.

Yoshiyuki, H. (1982a). Jitter and Shimmer Differences among sustained vowel phonations. *Journal of Speech and Hearing Research, 25*, 12 - 14.

Yoshiyuki, H. (1982b). Some voice fundamental frequency characteristics of oral reading and spontaneous speech by hard of hearing young women. *Journal of Speech and Hearing Research, 25*, 608 - 610.

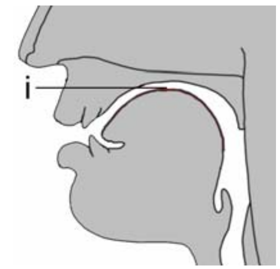
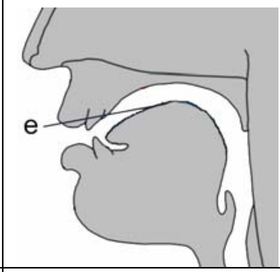
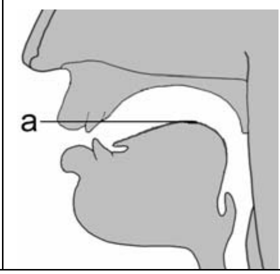
Yosida, K., Kazama, M., & Toyama, M. (2001). Signal Analysis by Clustered Line-Spectrum Modeling. *IEIC Technical Report (Institute of Electronics, Information and Communication Engineers), 101*(382(EA2001 62-73)), 31 - 36.

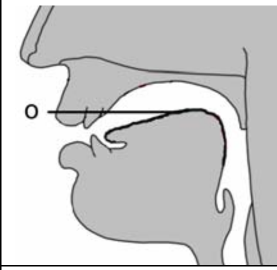
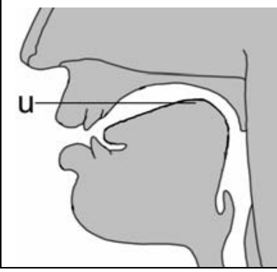
Zhi, M., & Lee, Y. L. (1990). Vowel quality contrast in Korean. Production and Perception. In Kobe (Ed.), *Proceedings of International conference on spoken language processing* (pp. 613 - 616).

Appendix

APPENDIX - I:

Description of Telugu vowels and their acoustic characteristics as described in literature.

Vowel	Grapheme	Image	Description	Vowel	Grapheme	Description
/i/	(ఇ)		• Front high vowel • Occurs in initial, medial, and final positions • F1 : 250 Hz to 350/400 Hz. • F2 : 2,500 Hz to 2,600 Hz. But seen at 2,250 Hz when F1 is at 350 – 400 Hz. • F3 : 2,700 Hz upto 3,000 Hz (is very weak)	/i:/	(ఈ)	• Front, unrounded and high vowel. • Occurs in initial, medial or final of a word • F1 : 250 Hz to 300 Hz. • F2 : 2,200 Hz to 2,600 Hz. • F3 : 2,700 Hz to 3,000 Hz. • F4 : 3,500 Hz to 3,750 Hz.
/e/	(ఎ)		• It is front half-open vowel • Occurs in initial, medial and final positions • F1 : 250 Hz to 600 Hz. • F2 : 1,500 Hz to 2,700 Hz. • F3 : 2,700 Hz to 3,000 Hz.	/e:/	(ఏ)	• It is a front vowel ranging from half-closed to half-open positions. • Occurs in initial, medial and final positions. • F1 : 370 Hz to 750 Hz. • F2 : 1,500 Hz to 2,500 Hz. • F3 : 2,750 Hz.
/a/	(అ)		• It is centralized open vowel. • Occurs in initial, medial and final positions. • F1 : 600 Hz to 750 Hz. • F2 : 1,200 Hz to 1,400 Hz. • F3 : 1,500 Hz to 3,300 Hz.	/a:/	(ఆ)	• It is open vowel • Occurs in initial, medial and final positions • F1 : 500 Hz to 800 Hz. • F2 : 1,000 Hz to 1,350 Hz. • F3 : 2,000 Hz to 3,000 Hz.

Vowel	Grapheme	Image	Description	Vowel	Grapheme	Description
/o/	(ఒ)		• It is half open back rounded vowel • Occurs in initial and medial positions • F1 : 400 Hz to 600 Hz. • F2 : 1,000 Hz to 1,250 Hz.	/o:/	(ఓ)	• It is back rounded vowel with half closed to the open variety at its end • Occurs in initial and medial positions • F1 : 400 Hz to 500 Hz. • F2 : 900 Hz to 1,100 Hz. • F3 : 2,700 Hz to 3,000 Hz.
/u/	(ଉ)		• It is high back vowel • Occurs in initial, medial and final positions • F1 : 300 Hz to 350 Hz. • F2 : 900 Hz to 1,000 Hz.	/u:/	(ଊ)	• It is high back vowel • Occurs in initial, medial and final positions • F1 : around 400 Hz • F2 : 900 Hz to 1,000 Hz.

APPENDIX - II:

The list of final 60 words in Telugu used and their meaning in English.

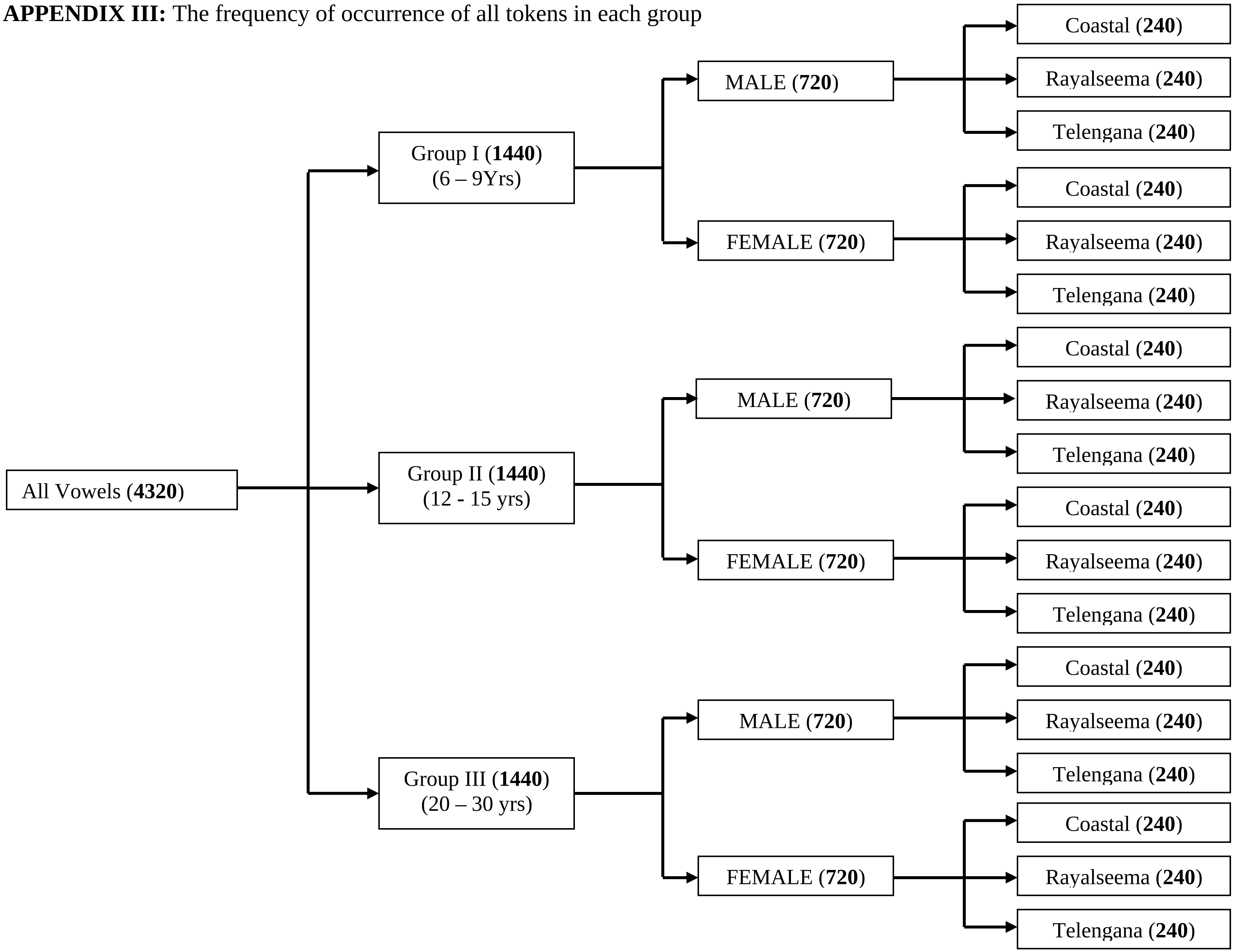
S.No.	Telugu word	Phonetic script	Meaning in English*
01.	కక్కు	/kakku/	Vomit
02.	కాకి	/ka:ki/	Crow
03.	కుక్క	/kukka/	Dog
04.	కేక	/ke:ka/	Shout
05.	గట్టు	/gat̩t̩u/	Ridge between plots of land
06.	గాటు	/ga:t̩u/	Mark or dent caused by biting
07.	గీటు	/gi:t̩u/	Make a sign by winking
08.	గేటు	/ge:t̩u/	Gate/Door
09.	చాట	/ tʃa:t̩a/	Plate made from bamboo
10.	చీటి	/tʃi:t̩i/	Slip
11.	చుట్టు	/ tʃut̩t̩u/	Go around
12.	చెట్టు	/ tʃet̩t̩u/	Tree
13.	చేటు	/ tʃe:t̩u/	Doing harm
14.	చోటు	/ tʃo:t̩u/	Place
15.	జుట్టు	/ dʃut̩t̩u/	Hair
16.	టెక్కు	/t̩ekku/	Showing off
17.	డోకు	/d̩o:ku/	Vomiting
18..	తాకు	/ta:ku/	Touch
19.	తుక్కు	/tukku/	Waste
20.	తొక్క	/tokka/	Skin of a fruit
21.	తోక	/to:ka/	Tail
22.	దాక	/da:ka/	Wide mouthed pot
23.	దిక్కు	/dikku/	Side
24.	దుక్కి	/dukki/	Plough
25.	దూకు	/du:ku/	Jump
26.	దేకు	/de:ku/	To slide along on, To creep up
27.	నక్కు	/nakku/	walk furtively, creep, crouch, hide

S.No.	Telugu word	Phonetic script	Meaning in English*
28.	నాకు	/na:ku/	For me
29.	నిక్కు	/nikku/	Erectness, Be arrogant
30.	నీకు	/ni:ku/	For you
31.	నూక	/nu:ka/	Broken rice
32.	నొక్కు	/nokku/	Press
33.	పాకి	/pa:ki/	Sweeper, Scavenger
34.	పిక్క	/pikka/	Calf of the leg
35.	పీకు	/pi:ku/	Pull
36.	పుట	/puta/	Page
37.	పూట	/pu:ta/	A period of time
38.	పెక్కు	/pekku/	Many, A good number of
39.	పేక	/pe:ka/	Playing card
40.	పొక్కు	/pokku/	Boil, Blister, Pimple
41.	పోక	/po:ka/	Piece or slice of arecanut
42.	బక్క	/bakka/	Thin
43.	బాకు	/ba:ku/	Dagger
44.	బుక్క	/bukka/	Inside of the mouth, Mouthful
45.	బొక్క	/bokka/	Hole
46.	మాకు	/ma:ku/	For us
47.	మూక	/mu:ka/	Crowd, Mob
48.	మెకు	/meku/	To eat, Swallow, Gobble up
49.	మేకు	/me:ku/	Nail
50.	మొక్క	/mokka/	Plant
51.	వక్క	/wakka/	Beatle nut
52	వెన్న	/wenna/	Butter
53.	సబ్బు	/sabbu/	Soap
54.	సుత్తి	/sutti/	Hammer
55.	రుద్దు	/ruddu/	Rub
56.	రెమ్మ	/remma/	Twig, Sub-branch of a main branch

S.No.	Telugu word	Phonetic script	Meaning in English*
57.	లక్క	/lakka/	Lacquer, A hard glossy finish applied to wooden furniture, toys, etc
58.	లెక్క	/lekka/	Money
59.	యమ	/yama/	Yama, the God of death
60.	షాపు	/ʃa:pu/	Shop

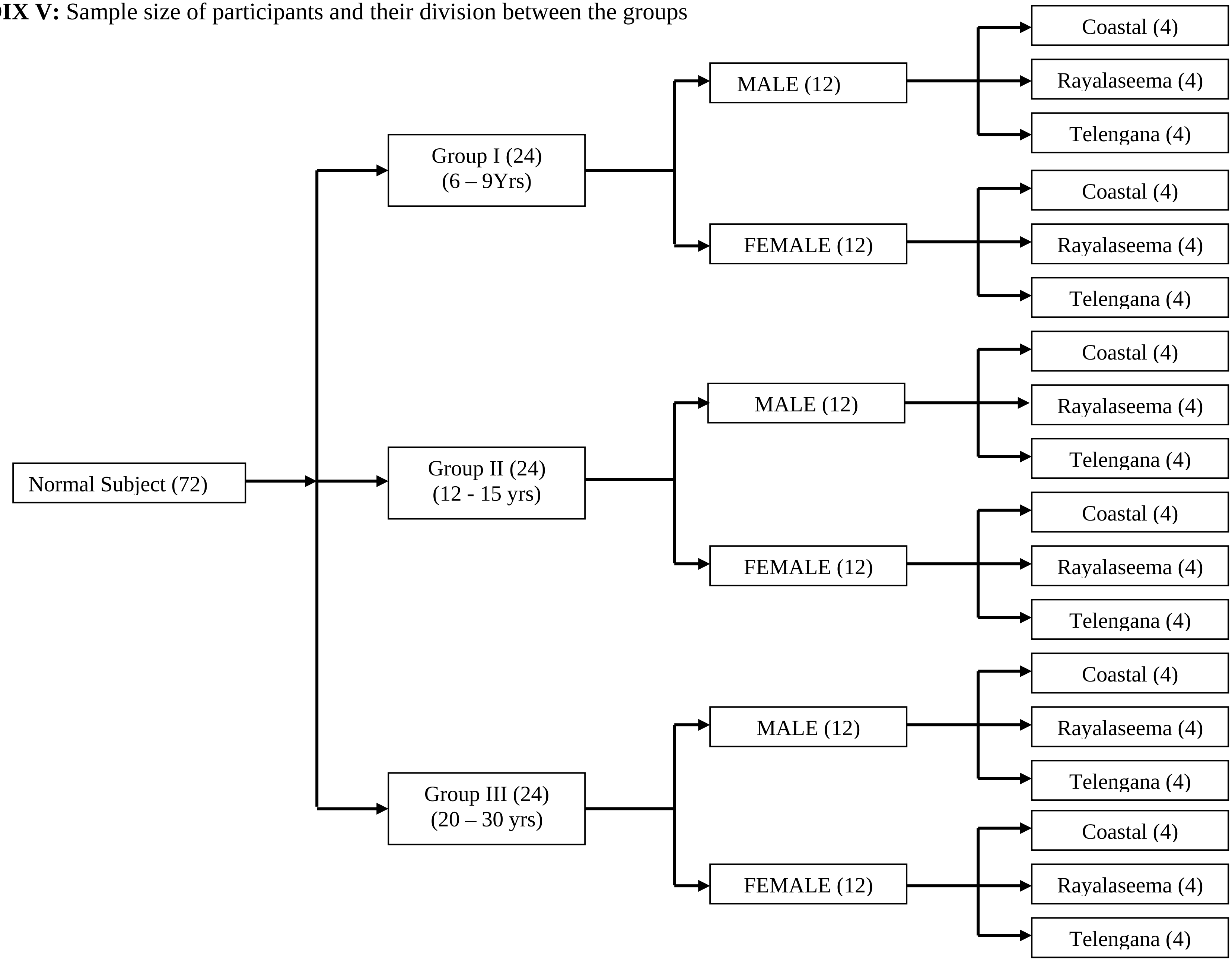
* from http://dsal.uchicago.edu/dictionaries/gwynn/.

APPENDIX III: The frequency of occurrence of all tokens in each group



APPENDIX IV: The frequency of occurrence of vowels in different groups

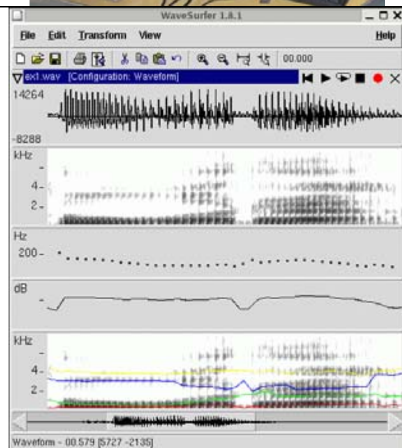
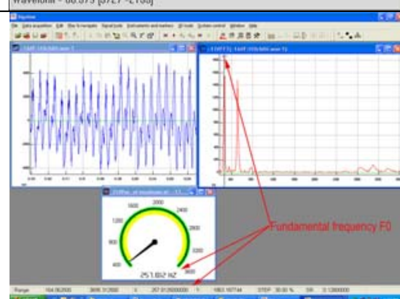
APPENDIX V: Sample size of participants and their division between the groups



APPENDIX – VI:

Equipment and software used in the study.

S.No.	Instrument/Software	Image	Technical details
1.1	Microphone		A condenser type microphone with headphone from INTEX was used for recording the speech sample. Microphone: Electret condenser type; Directivity : Omni- Directional; Magnet : Ferrite magnet; Input Impedence : 32 ohms; Frequency Response : 20 Hz - 20 KHz; Max. Input Power : 100 mW; Sensitivity : 96 dB; Connector : 3.5mm stereo plug; Cable Length : 1.8 m; Operation Voltage : 1.5 V ~ 10 V DC; Standard Operating Voltage : +3V; Current Consumption : 350 mA; Max. S/N Ratio : 40 dB or more
1.2	Computer		IBM Think pad with Inter(R) CPU, T2300 @ 1.66GHz, 504 MB of RAM with Microsoft Windows XP professional service pack 2, in built audio card was used for recording (wave surfer), editing (adobe audition 3) and analyzing fundamental frequency (sigview). HP Desktop Pentium IV computer, 1.00 GB RAM loaded with Windows XP, service pack 2, Computerized Speech Lab 4000 was used to analyze the spectral and temporal characteristics of tokens.
1.3	Adobe Audition		Adobe Audition Version 3.0, Build 7283.0 from Adobe Systems Incorporated, US was used for editing the speech sample and to extract the target word from the speech sample recorded. The extracted signal was stored in *.wav format.

S.No.	Instrument/Software	Image	Technical details
1.4	Computer Speech Lab		CSL Model 4500, Version 3.1.6 developed by STR – Speech Tech Ltd., was used for spectral and temporal analysis of the tokens. Further information can be obtained from www.kaypentax.com
1.5	Wave surfer		WaveSurfer, Version 1.7.5/0412031246 was used to record the speech sample and store in the computer. WaveSurfer is an Open Source tool for sound visualization and manipulation. It has been designed Kåre Sjölander and Jonas Beskow at the Centre for Speech Technology (CTT) at KTH in Stockholm, Sweden. It was for free downloading from the following link http://www.speech.kth.se/wavesurfer/download.html.
1.6	Sigview		Sigview (SignalLab, Goran Obradovic, 2001) was used for analyzing F0. It is a real-time signal analysis software package with wide range of powerful FFT spectral analysis tools, statistics functions and a comprehensive visualization system. It is distributed as shareware and a completely functional version free to use for 21 days is downloadable from http://www.sigview.com/download.htm. It is widely used for signal analysis in various human communications and other signal analysis.
1.7	SPSS		Version 16, Release 16.0.0 (Sep 13, 2007) developed by SPSS Inc., was used for statistical analysis of the data. Further information about the product can be obtained from http://www.spss.com.

APPENDIX -VII:

Operational definitions and measurement technique

VII.1 Vowel duration

Vowel duration is the duration from the onset of the vowel to the offset of the vowel. The onset and the offset of a vowel are determined by the presence and absence of clearly visible first two formants on the spectrogram respectively. (Krause, 1982; Gopal, 1987)

Figure 1 depicts the screen shot for vowel duration measurement. The difference between the two markers is considered as vowel duration.

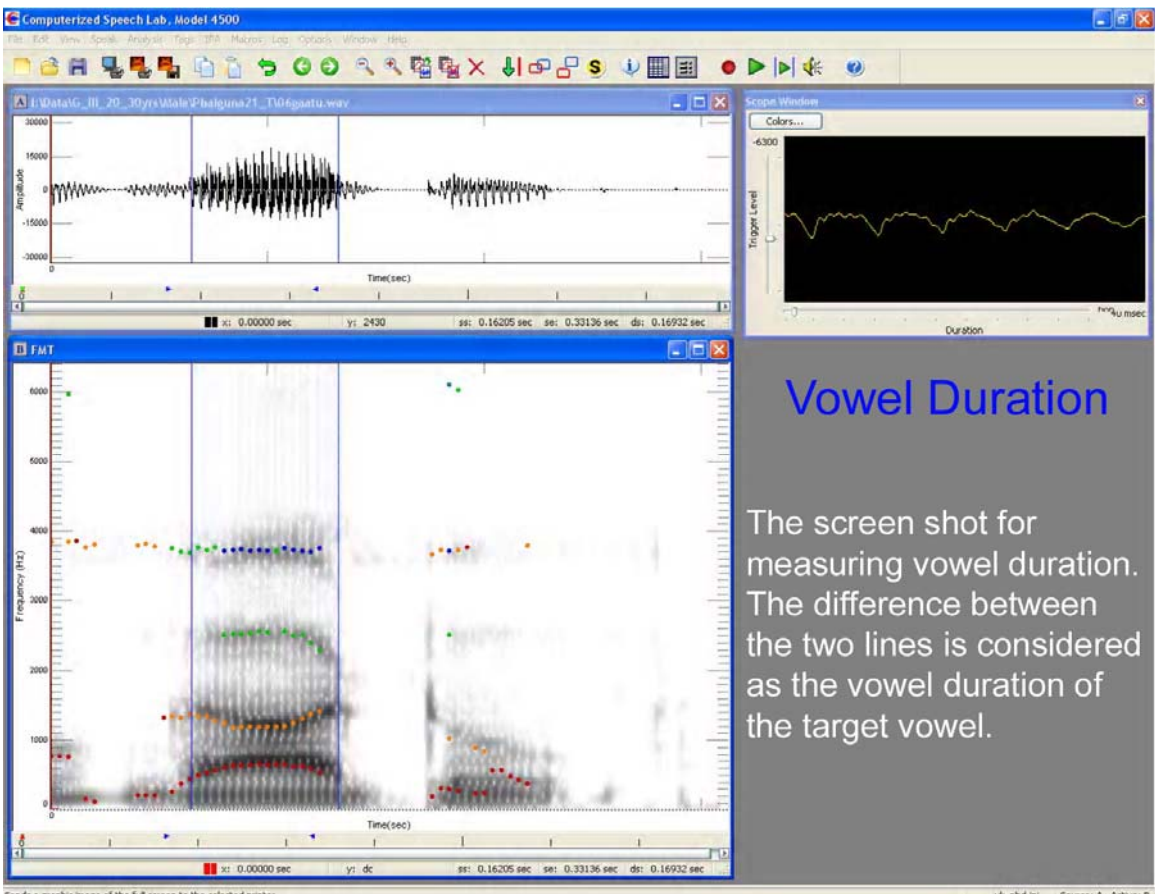


Figure 1: Screen shot of vowel duration

VII.2 Formant frequency

Formant-frequency estimates were made by measuring the mid-points of the visible dark bands of energy appropriate to the first four vowel resonances at a point within a comparatively steady-state portion of the vowel. (Sisty & Weinberg, 1972). Figure 2 is the screenshot for measuring formant frequencies. Formant frequencies plotted by the software are also done to cross check and identify the formants.

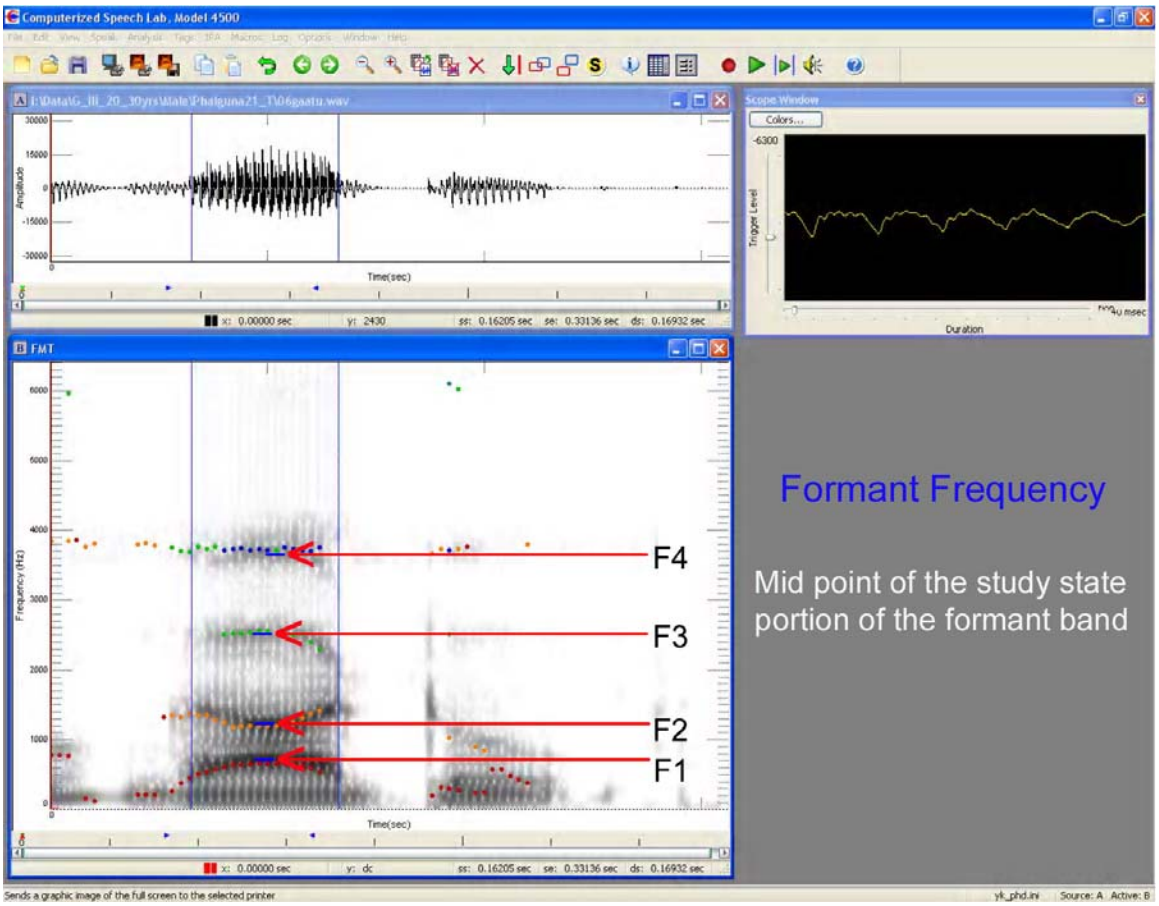


Figure 2: Screen shot of the formant frequency

VII.3 Fundamental frequency

Any voiced speech sound has a fundamental frequency. The number of glottal pulses per second determines the fundamental frequency of the sound. It is also the lowest frequency of vibration in a complex wave. Fundamental frequency of the target vowel was obtained using Sigview software. Figure 3 is the screen shot of the fundamental frequency measured.

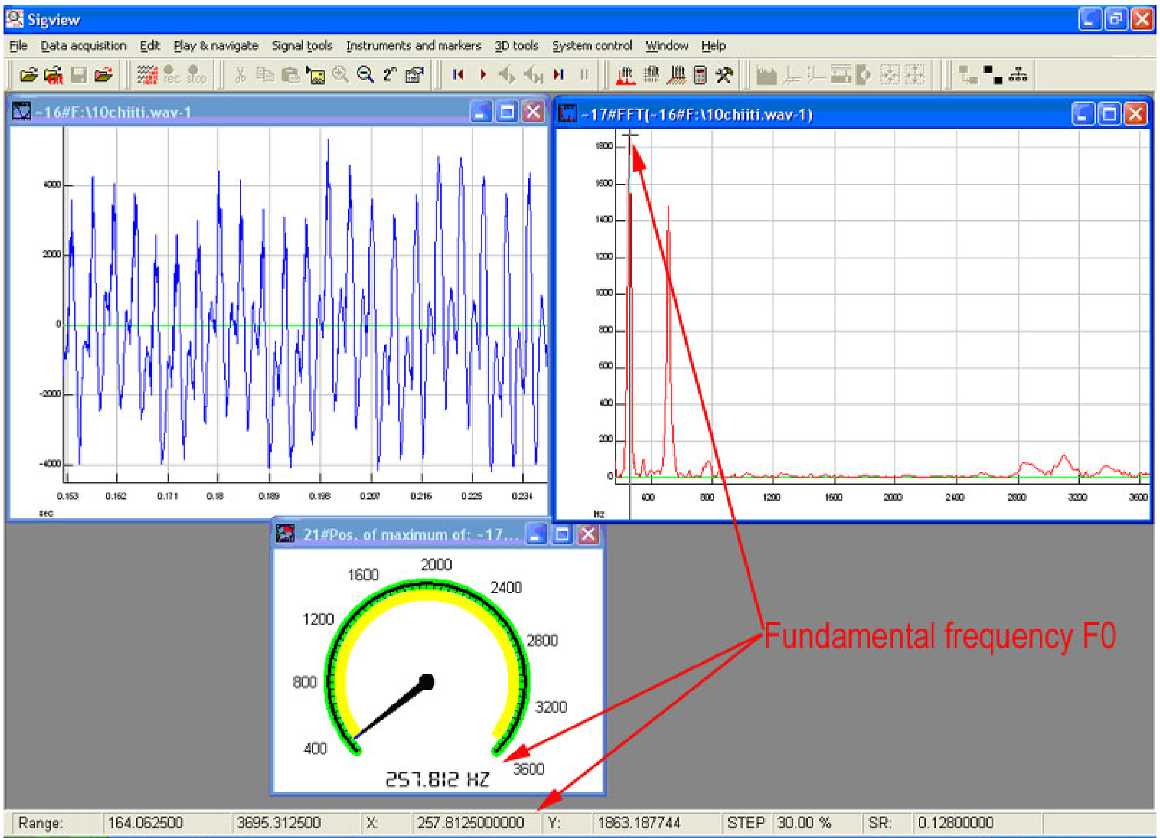


Figure 3: Screen shot of the fundamental frequency of vowel /i:/

VII.4 Formant bandwidth

Formant bandwidth, is the difference in frequency between the points on either side of the peak which have amplitude, that corresponds to 3 dB down from the peak. (Dunn,1961). Formant bandwidth values were recorded from the CSL. Figure 4 depicts the screenshot of the bandwidth for F1.

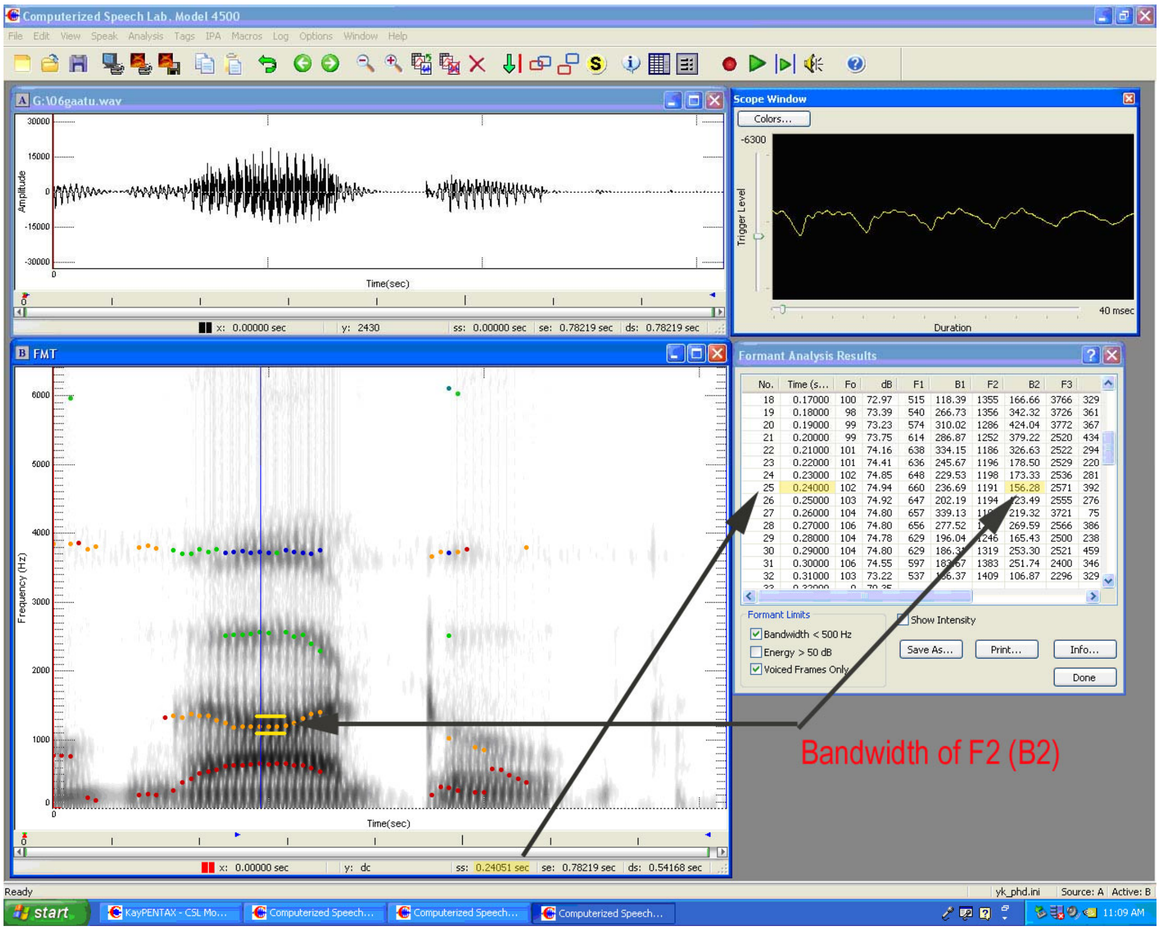


Figure 4: Screenshot of the bandwidth for F1

VII.5 Multilevel approach

Data from repeated measures experiments, such as current study, are usually analyzed with conventional ANOVA. It is known to cause problems such as the design effect (sampling hierarchy), and the requirement for complete designs and data sets. Multilevel modeling (MLM) is an alternative analysis tool for repeated measures data. MLM allows us to estimate variance and covariance components explicitly. MLM is recommended as a useful tool for analyzing repeated measures data from speech research (Quene & Bergh, 2004). Following are few terms that are commonly used in MLM.

Level	:	A component of a data hierarchy. Level I is the lowest level.
Level n variation	:	The variation of level n unit measurement about the fixed part of a model
Nesting	:	The clustering of units into a hierarchy
Cluster	:	A grouping containing ‘lower level’ elements.
Random part	:	That part of a model represented by Zu, that is the contribution of the random variables at each level
Response variable	:	Also known as a ‘dependent’ variable. Denoted by VD: Vowel duration; F0: Fundamental frequency; F1: First formant frequency; F2: Second formant frequency; F3: Third formant frequency; F4: Fourth formant frequency; B1: F1 bandwidth; B2: F2 bandwidth; B3: F3 bandwidth

In the current study a multilevel framework was constructed, in which, Level 1 is individuals differing in age, gender and region, Level 2 is consonant contexts where preceding consonant varies and Level 3 is vowels where temporal and spectral parameters are measured. As from the literature it was established that, vowels vary in their spectral and temporal characteristics in different consonant contexts and in age, gender and region individual groups. The multilevel framework of the study is depicted in Figure 3.1.

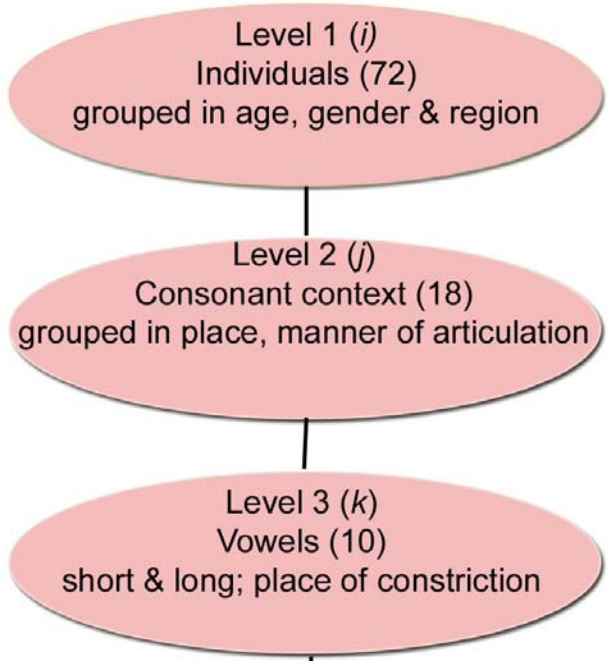


Figure 3.1: Multilevel framework considered in the study.

To evaluate the effect of age, gender, and region on spectral and temporal characteristics of vowels, it is essential to understand the variations within and between each level 1,2 and 3 influence on the response variables (in this study, vowel duration, fundamental frequency, formant frequencies, formant bandwidths).Naive analysis (ANOVA, MANOVA etc) will take care of lower level(vowel level) variations but ignores the variations in the higher level (consonant and individual level). Multilevel framework would consider these variations. Random effect model was used to study the association between response variable and set of predictors. Here, the consonant level and individual level are considered to be random effects. MLWin 1.1 was used for the analysis. Model 1, is generally used in naïve analysis and model 2 and 3 are used in MLM.

Model 1: Naïve model

$$VD_{ijk} = \beta_0 + \beta_1 age + \beta_2 gender + \beta_3 region + \varepsilon_{ijk}$$

Model 2: Random intercept model keeping consonant level as random effect

Level 2

$$VD_{ijk} = \beta_{0j} + \beta_1 age + \beta_2 gender + \beta_3 region + \varepsilon_{ijk}$$

Level 1

$$\beta_{0j} = \beta_0 + v_j$$

Model 3: Random intercept model keeping consonant level and individual level as random effect

Level 1

$$VD_{ijk} = \beta_{0ij} + \beta_1 age + \beta_2 gender + \beta_3 region + \varepsilon_{ijk}$$

Level 2

$$\beta_{0ij} = \beta_{0i} + v_j$$

Level 3

$$\beta_{0i} = \beta_0 + v_i$$

where,

VD_{ijk} = Vowel duration for i^{th} individual, j^{th} consonant and k^{th} vowel.

β_{oij} = Random intercept for level 2

β_{oi} = Random intercept for level 3

β_1 = Regression co-efficient for age

β_2 = Regression co-efficient for gender

β_3 = Regression co-efficient for region

ε_{ijk} = Random error for i^{th} individual, j^{th} consonant and k^{th} vowel.

v_j = Random effect at consonant level assumed to follow Gaussian with mean 0 and variance σ_c^2 [$v_j \approx N(0, \sigma_c^2)$]

v_i = Random effect at individual level assumed to follow Gaussian with mean 0 and variance σ_p^2 [$v_i \approx N(0, \sigma_p^2)$]

Model 3 is applied for all the other response variables (fundamental frequency, formant frequencies (F1, F2, F3, and F4), and bandwidths (B1, B2 and B3).

APPENDIX – VIII a

4.1. Vowel Duration

Table 4.1.1 Mean vowel duration (ms), SD and 95% confidence interval for all short and long vowels

N=4320

Vowel	n	Mean	SD	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
/i/	216	68.81	23.58	65.65	71.97
/e/	504	91.58	31.88	88.79	94.37
/a/	576	86.75	24.55	84.74	88.76
/o/	360	88.98	39.58	84.88	93.09
/u/	648	71.28	30.06	68.97	73.60
/i:/	288	179.82	44.23	174.69	184.95
/e:/	432	191.03	41.56	187.10	194.96
/a:/	720	196.85	38.95	194	199.70
/o:/	288	188.47	41.36	183.67	193.27
/u:/	288	182.91	44.48	177.75	188.07

Table 4.1.2: Mean vowel duration (ms), SD values and 95% confidence interval for mean for front, central and back

N=4320

Place of constriction	n	Mean	SD	95% Confidence Interval for Mean	
				Lower Bound	Upper Bound
Front	1440	135.65	63	132.38	138.92
Central	1296	147.92	64	144.43	151.41
Back	1584	116.91	64	113.73	120.08

Table 4.1.3: Ratio between short and long vowels in three age groups

	Ratio		
Vowel	Children	Adolescent	Adult
/i/ : /i:/	1: 2.4	1 : 2.6	1 : 2.8
/e/ : /e:/	1: 2.0	1 : 2.0	1 : 2.3
/a/ : /a:/	1 : 2.1	1 : 2.2	1 : 2.4
/o/ : /o:/	1: 2.0	1 : 2.0	1 : 2.4
/u/ : /u:/	1: 2.4	1 : 2.6	1 : 2.7

Table 4.1.4: Mean vowel duration (ms), SD and 95% confidence interval for mean for the three age groups

N=4320

Vowels	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	82.03	32.02	74.50	89.55	72	61.76	14.90	58.26	65.27	72	62.64	13.05	59.57	65.71
/e/	168	103.64	30.70	98.96	108.31	168	86.48	39.00	80.55	92.40	168	84.63	19.63	81.64	87.62
/a/	192	100.43	32.34	95.83	105.04	192	81.41	17.00	79.04	83.79	192	78.40	14.00	76.00	80.43
/o/	120	101.18	35.50	94.76	107.59	120	87.09	54.00	77.19	96.99	120	78.68	14.38	76.08	81.28
/u/	216	84.24	41.73	78.64	89.83	216	63.13	19.00	60.45	65.81	216	66.49	17.80	64.09	68.88
/i:/	96	194.55	48.93	184.64	204.47	96	161.42	29.00	155.49	167.34	96	183.49	45.67	174.24	192.34
/e:/	144	208.19	42.36	201.21	215.17	144	173.9	34.00	168.20	179.6	144	191.01	40.00	184.37	197.64
/a:/	240	211.27	40.63	206.10	216.43	240	182.05	31.00	178.02	186.08	240	197.25	38.44	192.36	202.13
/o:/	96	204.69	46.06	196.35	214.02	96	170.32	28.41	164.57	176.08	96	190.40	40.46	182.20	198.59
/u:/	96	200.43	51.43	190.00	210.85	96	164.78	32.25	158.25	171.32	96	183.51	40.60	175.28	191.74

Table 4.1.5: Mean vowel duration (ms), SD and 95% confidence interval for mean across gender

N=4320

Vowel	Female					Male				
	n	Mean	SD	95% CI Upper		n	Mean	SD	95% CI Lower	
				Lower	Upper				Lower	Upper
/i/	108	70.89	24.90	66.14	75.64	108	66.73	22.10	62.51	70.95
/e/	252	93.01	23.78	90.06	95.96	252	90.15	38.30	85.40	94.90
/a/	288	89.02	23.88	86.25	91.79	288	84.48	25.00	81.57	87.38
/o/	180	92.61	44.96	85.99	99.22	180	85.36	33.06	80.50	90.22
/u/	324	72.16	33.22	68.53	75.79	324	70.41	26.54	67.51	73.31
/i:/	144	180.4	46.26	172.77	188.02	144	179.24	42.25	172.28	186.20
/e:/	216	193.19	38.92	187.97	198.40	216	188.88	44.02	182.98	194.78
/a:/	360	199.01	36.62	195.22	202.81	360	194.69	41.00	190.44	198.95
/o:/	144	190.53	40.66	183.83	197.34	144	186.41	42.09	179.48	193.34
/u:/	144	181.28	43.34	174.14	188.42	144	184.53	45.68	177.00	192.05

Table 4.1.6: Mean vowel duration (ms), SD and 95% confidence interval for mean values for three regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	56.14	13.15	53.05	59.23	72	79.78	28.72	73.03	86.53	72	70.51	19.96	65.82	75.20
/e/	168	80.02	16.00	77.47	82.58	168	102.73	30.20	98.13	107.33	168	91.99	40.10	85.88	98.10
/a/	192	76.52	14.30	74.49	78.56	192	97.30	31.84	92.77	101.83	192	86.42	19.47	83.65	89.19
/o/	120	79.07	48.20	70.35	87.78	120	100.65	33.95	94.51	106.79	120	87.23	31.78	81.49	92.98
/u/	216	60.33	19.73	57.69	62.98	216	82.93	39.61	77.62	88.24	216	70.59	22.43	67.58	73.60
/i:/	96	161.09	26.12	155.80	166.39	96	206.74	48.92	196.83	216.65	96	171.62	41.00	163.32	179.93
/e:/	144	174.74	22.83	170.98	178.51	144	214.02	48.43	206.04	222.00	144	184.33	38.64	177.97	190.70
/a:/	240	178.95	23.85	175.91	181.98	240	217.32	44.59	211.65	222.99	240	194.30	35.44	189.79	198.80
/o:/	96	169.11	21.97	164.66	173.57	96	210.36	50.21	200.19	220.54	96	185.93	35.99	178.63	193.22
/u:/	96	164.15	26.97	158.68	169.61	96	208.47	48.68	198.60	218.33	96	176.10	42.63	167.47	184.74

Table 4.1.7: The mean vowel duration (ms), SD of vowels preceded by different (manner of articulation) consonants

N=4320

VOWEL	Manner of Articulation	n	Mean	Std. Deviation
/i/	Stop	144	68.04	22.804
	Nasal	72	70.35	25.164
/e/	Stop	144	90.71	44.497
	Affricate	72	89.89	26.534
	Nasal	72	91.03	23.664
	Semi vowel	72	97.15	25.875
	Lateral	72	82.01	22.205
	Trill	72	99.57	24.349
/a/	Stop	216	88.75	26.373
	Nasal	72	87.03	27.786
	Fricative	72	95.53	26.072
	Semi vowel	144	83.47	19.963
	Lateral	72	78.24	18.313
/o/	Stop	216	85.94	27.603
	Nasal	144	93.54	52.462
/u/	Stop	360	67.39	30.744
	Affricate	144	74.93	30.162
	Fricative	72	65.06	22.007
	Trill	72	89.68	25.546
/i:/	Stop	144	184.79	40.175
	Affricate	72	171.54	47.006
	Nasal	72	178.15	48.233
/e:/	Stop	288	191.89	40.262
	Affricate	72	190.93	44.761
	Nasal	72	187.69	43.752
/a:/	Stop	432	198.13	39.419
	Affricate	72	200.28	37.059
	Nasal	144	194.00	36.906
	Fricative	72	191.47	41.748
/o:/	Stop	216	189.75	40.863
	Affricate	72	184.64	42.896
/u:/	Stop	144	188.19	44.618
	Nasal	144	177.63	43.864

Table 4.1.8: The mean vowel duration (ms), SD of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	72	63.21	25.474
	Dental	72	72.88	18.738
	Alveopalatal	72	70.35	25.164
/e/	Bilabial	216	91.83	24.572
	Alveopalatal	216	90.49	25.356
	Retroflex	72	94.10	58.444
/a/	Bilabial	144	83.72	21.327
	Alveopalatal	288	86.43	23.577
	Velar	144	90.42	28.815
/o/	Bilabial	216	86.80	26.281
	Dental	72	83.43	29.751
	Alveopalatal	72	101.10	68.917
/u/	Bilabial	144	66.17	30.215
	Dental	144	69.94	34.362
	Alveopalatal	288	76.15	28.497
	Velar	72	64.72	23.214
/i:/	Bilabial	72	182.10	42.464
	Alveopalatal	144	174.85	47.572
	Velar	72	187.49	37.854
/e:/	Bilabial	144	188.49	42.321
	Dental	72	190.56	34.764
	Alveopalatal	72	190.93	44.761
	Velar	144	193.87	42.486
/a:/	Bilabial	216	195.34	38.557
	Dental	144	199.47	38.590
	Alveopalatal	216	195.15	39.146
	Velar	144	199.06	39.728
/o:/	Bilabial	72	186.47	42.167
	Dental	72	189.64	38.877
	Alveopalatal	72	184.64	42.896
	Retroflex	72	193.13	41.767
/u:/	Bilabial	144	184.42	43.826
	Dental	72	184.96	43.764
	Alveopalatal	72	177.83	46.682

Table 4.1.9: The mean vowel duration (ms), SD of vowels in different voicing feature of preceding consonants

N=4320

Vowel	Voiced consonant			Voiceless consonant		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	72	72.88	18.74	72	63.21	25.47
/e/	72	91.03	23.66	144	90.71	44.49
/a/	144	92.02	25.02	72	82.22	27.61
/o/	144	86.65	24.27	144	85.26	29.87
/u/	144	70.19	36.16	216	65.53	26.45
/i:/	72	187.50	37.85	72	182.10	42.46
/e:/	216	194.40	39.86	144	186	42.18
/a:/	288	200.70	37.78	216	193.40	40
/o:/	72	193.10	41.77	144	188.10	40.44
/u:/	144	181.20	42.51	72	191.40	45.53

APPENDIX – VIII b

4.2.1. Fundamental frequency (F0)

Table 4.2.1.1: Mean F0 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% Confidence Interval for Mean	
				Lower Bound	**Upper Bound**
/i/	215	228.53	54.3	221.23	235.83
/e/	501	220.16	52.18	215.16	224.74
/a/	574	216.17	51.81	211.92	220.41
/o/	357	220.84	51.38	215.49	226.18
/u/	643	228.6	54.21	224.40	232.80
/i:/	288	229.45	53.47	223.24	235.64
/e:/	429	219.88	52.51	214.90	224.87
/a:/	719	213.74	51.75	209.95	217.53
/o:/	287	221.93	52.14	215.87	227.98
/u:/	286	228.13	53.58	221.89	234.37

Table 4.2.1.2: Mean F0 (Hz), SD values and 95% confidence interval for mean for front, central and back

N=4320

Place of constriction	n	Mean	SD	Lower Bound	Upper Bound
Front	1433	223.2	52.99	220.45	225.95
Central	1293	214.82	51.78	211.99	217.65
Back	1573	225.54	53.15	222.91	228.17

Table 4.2.1.3: Mean F0 (Hz), SD and 95% confidence interval for mean for the three age groups

N=4320

Vowel	**Children**					**Adolescent**					**Adult**				
	n	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**	
				Lower	**Upper**				**Lower**	**Upper**				**Lower**	**Upper**
/i/	71	263.05	37.64	254.14	271.96	72	226.61	51.42	214.52	238.69	72	194.42	51.05	184.43	208.42
/e/	166	255.64	34.77	250.31	260.97	168	217.59	47.73	210.32	224.86	167	187.47	48.66	180.03	194.90
/a/	191	250.85	34.28	245.97	255.75	192	214.64	48.33	207.76	221.52	191	183.02	47.48	176.24	189.79
/o/	117	254.77	34.88	248.38	261.16	120	219.11	47.78	210.47	227.74	120	189.48	47.97	180.81	198.15
/u/	213	263.61	36.64	258.66	268.55	216	226.16	50.65	219.36	232.95	214	196.23	51.46	189.30	203.17
/i:/	96	263.14	35.63	255.92	270.36	96	227.54	48.83	217.65	237.43	96	197.65	53.29	186.91	208.40
/e:/	142	255.46	36.12	249.46	261.44	143	217.28	47.50	209.43	225.14	144	187.39	49.03	179.32	195.46
/a:/	240	249.13	36.83	244.45	253.81	240	211.63	46.24	205.75	217.51	239	180.33	46.74	174.37	186.29
/o:/	95	256.49	37.20	248.91	264.07	96	219.43	47.36	209.84	229.03	96	190.21	48.51	180.38	200.04
/u:/	95	260.87	37.11	253.31	268.43	95	226.14	50.88	215.78	236.50	96	197.70	51.70	187.23	208.18

Table 4.2.1.4: Mean F0 (Hz), SD and 95% confidence interval for mean across gender

N=4320

Vowel	Female					Male				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper
/i/	108	250.73	23.23	246.30	255.16	107	206.13	66.34	193.41	218.84
/e/	252	240.75	24.84	237.67	243.84	249	199.31	63.22	191.42	207.21
/a/	288	236.85	24.89	233.96	239.74	286	195.34	62.49	188.07	202.61
/o/	179	241.31	23.07	237.90	244.71	178	200.25	62.64	190.99	209.52
/u/	322	251.27	25.32	248.50	254.05	321	205.86	64.94	198.73	212.99
/i:/	144	251.12	22.28	247.45	254.80	144	207.77	65.54	196.96	218.56
/e:/	214	239.51	22.59	236.46	242.55	215	200.35	65.11	191.60	209.11
/a:/	360	232.49	23.02	230.10	234.87	359	194.94	64.30	188.27	201.62
/o:/	143	241.31	22.78	237.54	245.07	144	202.68	64.59	192.04	213.32
/u:/	142	249.26	23.43	245.38	253.15	144	207.29	65.55	196.49	218.09

Table 4.2.1.5: Mean F0 (Hz), SD and 95% confidence interval for mean values for three regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	208.39	57.10	194.98	221.82	72	251.14	51.57	239.02	263.25	71	226.03	45.41	215.28	236.78
/e/	166	201.60	54.47	193.26	209.95	167	239.47	49.94	231.84	247.11	168	219.29	45.01	212.43	226.14
/a/	191	197.87	52.64	190.35	205.38	192	235.07	51.07	227.79	242.33	191	215.47	44.78	209.08	221.86
/o/	119	201.14	52.95	191.53	210.76	120	241.26	49.68	232.28	250.24	118	219.92	43.26	212.04	227.82
/u/	213	211.11	57.04	203.39	218.8	215	247.4	52.77	240.31	254.49	215	227.15	46.33	220.92	233.38
/i:/	96	208.51	55.95	197.17	219.85	96	250.41	50.65	240.15	260.67	96	229.41	45.35	220.23	238.6
/e:/	142	199.65	54.26	190.65	208.65	143	239.37	50.81	230.97	247.76	144	220.49	44.75	213.11	227.86
/a:/	239	193.65	51.84	187.04	200.26	240	233.83	51.24	227.32	240.35	240	213.66	44.02	208.07	219.26
/o:/	95	200.89	53.31	190.03	211.75	96	241.71	50.81	231.41	251.99	96	222.97	44.19	214.01	231.92
/u:/	94	206.68	56.98	195.01	218.36	96	249.03	49.88	238.92	259.13	96	228.24	45.23	219.07	237.40

Table 4.2.1.6: The mean F0 (Hz), SD of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	143	228.3877	54.46906
	Nasal	72	228.8257	54.35642
/e/	Stop	144	223.5347	52.55672
	Affricate	71	224.5349	51.55168
	Nasal	72	220.3546	50.83468
	Semi vowel	71	216.4824	53.07446
	Lateral	71	214.7249	52.66622
	Trill	72	217.8697	52.95902
/a/	Stop	214	216.7581	51.96448
	Nasal	72	219.1954	53.43694
	Fricative	72	218.0085	51.94567
	Semi vowel	144	213.4271	50.90445
	Lateral	72	215.0326	52.54303
/o/	Stop	214	221.3153	51.48334
	Nasal	143	220.1226	51.40022
/u/	Stop	356	228.3239	54.57766
	Affricate	143	229.5633	54.45686
	Fricative	72	232.0042	53.76490
	Trill	72	224.6769	53.20046
/i:/	Stop	144	228.9572	53.49392
	Affricate	72	230.6626	54.16397
	Nasal	72	229.2033	53.47932
/e:/	Stop	285	219.3285	52.68074
	Affricate	72	222.4775	52.12301
	Nasal	72	219.4935	52.90972
/a:/	Stop	432	212.9971	51.95441
	Affricate	72	211.0882	52.25244
	Nasal	143	216.1022	51.34083
	Fricative	72	216.1946	51.74016
/o:/	Stop	216	221.4772	52.10107
	Affricate	71	223.2941	52.59608
/u:/	Stop	142	229.2830	53.97628
	Nasal	144	226.9942	53.33195

Table 4.2.1.7: The mean F0 (Hz), SD of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of Articulation	n	Mean	Std. Deviation
/i/	Bilabial	72	230.1472	54.92156
	Dental	71	226.6034	54.33823
	Alveopalatal	72	228.8257	54.35642
/e/	Bilabial	215	220.4112	51.97078
	Alveopalatal	214	219.0377	52.31211
	Retroflex	72	222.7275	53.04307
/a/	Bilabial	144	214.9823	51.23351
	Alveopalatal	288	216.0283	51.96258
	Velar	142	217.6562	52.41655
/o/	Bilabial	214	219.9786	51.24600
	Dental	71	222.4852	52.24016
	Alveopalatal	72	221.7660	51.59863
/u/	Bilabial	142	225.2044	53.05844
	Dental	142	230.5355	54.95257
	Alveopalatal	287	228.9498	53.84956
	Velar	72	230.1144	57.21298
/i:/	Bilabial	72	232.2051	52.89791
	Alveopalatal	144	229.9330	53.63921
	Velar	72	225.7092	54.25789
/e:/	Bilabial	144	219.9838	52.48135
	Dental	70	218.3513	51.68186
	Alveopalatal	72	222.4775	52.12301
	Velar	143	219.2301	53.64476

Vowel	Place of Articulation	n	Mean	Std. Deviation
/a:/	Bilabial	215	215.2389	51.30759
	Dental	144	212.7110	51.15730
	Alveopalatal	216	214.2582	51.82357
	Velar	144	211.7724	53.36991
/o:/	Bilabial	72	222.9665	51.92420
	Dental	72	220.1779	51.99407
	Alveopalatal	71	223.2941	52.59608
	Retroflex	72	221.2872	53.07096
/u:/	Bilabial	143	228.3010	53.56768
	Dental	71	228.0935	53.60935
	Alveopalatal	72	227.8285	54.28762

Table 4.2.1.8: Mean F0 (Hz) of vowels across voicing feature of preceding consonants

N=4320

Vowels	Voiced consonant			Voiceless consonant		
	n	Mean	SD	n	Mean	SD
/i/	71	226.6	54.34	72	230.20	54.92
/e/	72	220.4	50.84	144	223.50	52.56
/a/	144	214.5	50.95	70	221.40	54.06
/o/	142	217.5	51.32	143	223.70	51.50
/u/	142	224.6	54.21	214	230.80	54.80
/i:/	72	225.7	54.26	72	232.20	52.89
/e:/	213	218.6	52.22	144	220.50	53.46
/a:/	287	213.1	51.27	216	214.10	52.57
/o:/	72	221.3	53.07	144	221.60	51.79
/u:/	143	227.1	52.99	71	230.50	54.69

APPENDIX –VIII c

4.2.2 First Formant Frequency (F1)

Table 4.2.2.1: Mean F1 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for Mean	
				Lower	Upper
/i/	215	545.23	81.7	534.25	556.21
/e/	502	585.64	110.09	575.99	595.3
/a/	574	809.3	124.26	799.11	819.48
/o/	357	589.45	105.72	578.45	600.46
/u/	643	535.38	72.85	529.74	541.03
/i:/	288	538.44	84.32	528.66	548.22
/e:/	429	547.6	95.46	538.54	556.66
/a:/	719	866.18	104.55	858.52	873.83
/o:/	287	542.01	88.37	531.74	552.28
/u:/	286	521.49	65.31	513.88	529.09

Table 4.2.2.2: Mean F1 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels.

N=4320

Place of constriction	n	Mean	SD	95% CI for Mean	
				Lower	Upper
Front	1434	558.72	98.9	553.6	563.84
Central	1293	840.93	117.14	834.54	847.32
Back	1573	546.34	86.49	542.06	550.61

Table 4.2.2.3: Mean F1 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	71	586.82	82.87	567.21	606.44	72	546.66	72.57	529.61	563.72	72	502.77	486.98	486.98	518.56
/e/	167	637.24	111.03	620.28	654.20	168	587.38	101.25	571.96	602.80	167	532.30	518.31	518.31	546.29
/a/	191	885.76	87.61	873.26	898.27	192	811.44	112.63	795.41	827.48	191	730.67	713.76	713.76	747.58
/o/	117	630.55	106.88	610.98	650.12	120	603.35	103.19	584.70	622.00	120	535.48	520.51	520.51	550.46
/u/	213	572.45	66.48	563.47	581.43	216	538.15	69.13	528.88	547.42	214	495.70	487.39	487.39	504.02
/i:/	96	576.33	89.75	558.15	594.52	96	546.03	70.41	531.76	560.30	96	492.95	478.82	478.82	507.09
/e:/	142	600.21	95.96	584.29	616.13	143	555.92	89.91	541.06	570.78	144	487.46	477.42	477.42	497.49
/a:/	240	924.88	60.46	917.20	932.57	240	876.35	94.10	864.38	888.32	239	797.01	783.04	783.04	810.99
/o:/	95	589.97	82.05	573.25	606.68	96	561.05	80.89	544.66	577.44	96	475.51	464.10	464.10	486.91
/u:/	95	546.51	63.98	533.48	559.54	95	528.02	64.24	514.94	541.11	96	490.25	479.40	479.40	501.37

Table 4.2.2.4: Mean F1 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	Female					Male				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper
/i/	108	580.56	65.93	567.98	593.13	107	509.57	80.80	494.08	525.05
/e/	252	604.02	107.05	590.74	617.30	250	567.12	110.21	553.39	580.85
/a/	288	851.47	97.99	840.10	862.83	286	766.83	133.29	751.31	782.34
/o/	179	611.69	110.23	595.43	627.95	178	567.10	96.23	552.86	581.33
/u/	322	564.08	60.20	557.48	570.68	321	506.60	73.16	498.57	514.64
/i:/	144	574.64	69.13	563.31	586.08	144	502.19	87.72	488.56	515.81
/e:/	214	552.29	78.15	541.76	562.83	215	542.92	110.02	528.13	557.71
/a:/	360	899.31	80.17	891.00	907.62	359	832.95	115.17	821.00	844.91
/o:/	143	545.30	85.37	531.19	559.41	144	538.74	91.42	523.68	553.87
/u:/	142	542.70	52.22	534.04	551.37	144	500.56	70.17	489.01	512.12

Table 4.2.2.5: Mean F1 (Hz), SD and 95% confidence interval for mean values for three regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	530.87	81.55	511.70	550.03	72	552.71	88.38	531.95	573.48	71	552.20	73.58	534.78	569.61
/e/	167	583.90	127.07	564.49	603.31	167	587.53	107.60	571.09	603.97	168	585.5	93.78	571.22	599.79
/a/	191	797.83	129.67	779.32	816.34	192	795.29	117.13	778.62	811.96	191	834.84	122.36	817.38	852.31
/o/	119	579.73	106.95	560.31	599.14	120	587.39	96.03	570.03	604.75	118	601.36	113.36	580.69	622.03
/u/	213	525.92	77.27	515.48	536.35	215	542.56	71.97	532.88	552.23	215	537.59	68.43	528.39	546.79
/i:/	96	525.23	83.65	508.28	542.18	96	538.92	89.81	520.73	557.12	96	551.16	77.94	535.37	566.96
/e:/	142	548.00	106.07	530.41	565.60	143	544.76	96.52	528.80	560.71	144	530.02	83.17	536.32	563.72
/a:/	239	851.50	115.82	836.75	866.26	240	866.32	93.84	854.38	878.25	240	880.65	101.22	867.78	893.52
/o:/	95	534.86	100.74	514.34	555.38	96	537.36	73.66	522.43	552.28	96	553.74	88.48	535.81	571.66
/u:/	94	509.75	59.94	496.97	521.53	96	522.42	70.17	508.21	536.64	96	532.53	63.89	519.59	545.48

Table 4.2.2.6: Mean F1 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	143	542.25	82.285
	Nasal	72	551.14	80.730
/e/	Stop	144	529.32	78.542
	Affricate	72	535.51	77.358
	Nasal	72	560.91	85.508
	Semi vowel	71	664.68	126.440
	Lateral	71	648.35	112.311
	Trill	72	633.38	97.487
/a/	Stop	214	796.75	128.436
	Nasal	72	838.36	113.736
	Fricative	72	787.22	126.218
	Semi vowel	144	795.46	123.248
	Lateral	72	867.27	100.200
/o/	Stop	214	579.36	98.744
	Nasal	143	604.56	114.075
/u/	Stop	356	532.27	72.070
	Affricate	143	539.48	77.978
	Fricative	72	546.86	70.974
	Trill	72	531.17	67.740
/i:/	Stop	144	535.86	84.725
	Affricate	72	536.99	92.462
	Nasal	72	545.06	75.307
/e:/	Stop	285	538.00	84.966
	Affricate	72	522.34	72.019
	Nasal	72	610.83	125.705
/a:/	Stop	432	868.70	104.498
	Affricate	72	885.34	100.193
	Nasal	143	851.20	104.490
	Fricative	72	861.63	107.150
/o:/	Stop	216	548.42	92.509
	Affricate	71	522.49	71.447
/u:/	Stop	142	518.17	69.149
	Nasal	144	524.75	61.354

Table 4.2.2.7: Mean F1 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	72	544.58	85.354
	Dental	71	539.89	79.590
	Alveopalatal	72	551.14	80.730
/e/	Bilabial	215	584.07	112.917
	Alveopalatal	215	605.55	108.550
	Retroflex	72	530.91	85.578
/a/	Bilabial	144	805.23	123.153
	Alveopalatal	288	825.05	116.662
	Velar	142	781.48	135.497
/o/	Bilabial	214	574.22	94.443
	Dental	71	616.81	112.427
	Alveopalatal	72	607.75	122.624
/u/	Bilabial	142	522.41	65.221
	Dental	142	542.73	77.646
	Alveopalatal	287	539.25	73.755
	Velar	72	531.10	71.661
/i:/	Bilabial	72	535.02	87.389
	Alveopalatal	144	541.02	84.124
	Velar	72	536.69	82.580
/e:/	Bilabial	144	588.28	116.438
	Dental	70	514.90	64.716
	Alveopalatal	72	522.34	72.019
	Velar	143	535.36	80.666
/a:/	Bilabial	215	858.77	102.232
	Dental	144	875.19	97.367
	Alveopalatal	216	867.33	105.164
	Velar	144	866.49	113.852
/o:/	Bilabial	72	548.27	82.726
	Dental	72	576.30	106.466
	Alveopalatal	71	522.49	71.447
	Retroflex	72	520.70	78.543
/u:/	Bilabial	143	515.04	63.097
	Dental	71	525.93	67.838
	Alveopalatal	72	529.91	66.679

Table 4.2.2.8: Mean F1 (Hz) of vowels across voicing feature of preceding consonants

N=4320

Vowel	Voiced consonant			Voiceless consonant		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	71	539.89	79.590	72	544.58	85.354
/e/	72	560.91	85.508	144	529.32	78.542
/a/	144	797.17	123.510	70	795.90	138.945
/o/	142	593.50	100.655	143	576.22	100.404
/u/	142	528.94	69.810	214	534.48	73.610
/i:/	72	536.69	82.580	72	535.02	87.389
/e:/	213	549.21	100.166	144	557.84	96.932
/a:/	287	861.41	105.881	216	871.36	102.317
/o:/	72	520.70	78.543	144	562.28	96.039
/u:/	143	522.75	61.803	71	510.41	70.051

APPENDIX - VIII d

4.2.3 Second Formant Frequency (F2)

Table 4.2.3.1: Mean F2 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% Confidence Interval for Mean	
				Lower	Upper
/i/	213	2494.05	342.14	2447.84	2540.26
/e/	501	2189.68	259.07	2166.94	2212.42
/a/	573	1479.72	188.42	1464.25	1495.18
/o/	357	1124.93	171.5	1107.08	1142.78
/u/	638	947.08	80.6	940.82	953.35
/i:/	288	2507.28	326.15	2469.45	2445.11
/e:/	429	2303.32	254.92	2279.3	2327.52
/a:/	719	1480.49	197.92	1466	1494.98
/o:/	286	1135.16	174.59	1114.84	1155.47
/u:/	284	986.12	149.15	968.7	1003.54

Table 4.2.3.2: Mean F2 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels

N=4320

Place of constriction	n	Mean	SD	95% Confidence Interval for Mean	
				Lower	Upper
Front	1431	2332.98	314.74	2316.65	2349.3
Central	1292	1480.15	193.71	1469.57	1490.72
Back	1565	1029.11	161.72	1021.09	1037.13

Table 4.2.3.3: Mean F2 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	**Children**					**Adolescent**					**Adult**				
	n	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**	
				Lower	**Upper**				**Lower**	**Upper**				**Lower**	**Upper**
/i/	70	2529.8	356.53	2444.79	2614.82	71	2563.53	347.19	2481.35	2645.7	72	2390.78	300.4	2320.19	2461.37
/e/	167	2273.35	185.68	2244.98	2301.72	167	2219.62	234	2183.87	2255.37	167	2076.08	303.32	2029.74	2122.42
/a/	191	1569.16	153.47	1547.25	1595.06	192	1490.76	178.18	1465.39	1516.12	190	1378.64	182.41	1352.54	1404.75
/o/	117	1190.05	151.58	1162.29	1217.8	120	1163.1	157.96	1134.54	1191.65	120	1023.29	156.78	994.95	1051.62
/u/	211	951.12	80.19	940.24	962	214	947.29	75.14	937.16	957.41	213	942.88	86.29	931.23	954.53
/i:/	96	2423.2	363.88	2349.48	2496.93	96	2568.67	335.9	2500.61	2636.73	96	2529.97	254.29	2478.44	2581.49
/e:/	142	2301.01	262.9	2257.39	2344.63	143	2315.76	273.12	2270.62	2360.91	144	2293.25	228.04	2255.69	2330.82
/a:/	240	1616.89	154.05	1597.3	1636.48	240	1487.35	181.86	1464.23	1510.43	239	1336.63	146.75	1317.93	1355.33
/o:/	95	1229.59	144.25	1200.2	1258.97	95	1175.66	133.87	1148.38	1202.93	96	1001.63	156.67	969.88	1033.37
/u:/	94	1050.39	123.08	1029.18	1079.6	95	1019.86	137.3	991.89	1047.83	95	884.82	130.2	858.3	911.35

Table 4.2.3.4: Mean F2 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	Females					Males				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper
/i/	107	2598.3	295.78	2541.61	2654.99	106	2388.82	254.64	2320.52	2457.12
/e/	252	2305.81	169.96	2284.73	2326.90	249	2078.15	280.20	2037.18	2107.13
/a/	287	1541.05	164.17	1521.97	1560.12	286	1418.79	191.46	1395.88	1440.46
/o/	179	1184.34	164.70	1160.05	1208.63	178	1065.20	157.22	1041.94	1088.45
/u/	318	947.74	83.26	938.55	156.92	320	946.44	77.96	937.86	955.01
/i:/	144	2558.71	330.56	2504.26	2613.16	144	2455.86	314.49	2404.05	2507.66
/e:/	214	2377.09	224.44	2346.85	2407.33	215	2229.9	262.62	2194.6	2265.21
/a:/	360	1536.13	180.62	1517.41	1554.86	359	1424.69	199.02	1404.03	1445.34
/o:/	142	1165.53	167.09	1137.81	1193.25	144	1105.21	177.21	1072.02	1134.4
/u:/	141	1022.66	137.24	11.81	1045.51	143	950.08	152.09	924.94	957.06

Table 4.2.3.5: Mean F2 (Hz), SD and 95% confidence interval for mean values across regions

`

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	2501.67	326.23	2425.01	2578.33	70	2522.93	367.55	2435.29	2610.57	71	2457.85	333.45	2378.93	2536.78
/e/	167	2177.35	272.16	2135.76	2218.93	166	2207.17	265.92	2166.42	2247.92	168	2184.67	238.70	2148.31	2221.03
/a/	190	1477.67	185.51	1451.12	1504.21	192	1482.04	188.77	1455.17	1508.91	191	1479.42	192.06	1452.01	1506.83
/o/	119	1116.09	152.16	1088.47	1143.71	120	1117.00	155.80	1088.84	1145.16	118	1141.93	202.52	1105.01	1178.85
/u/	212	947.61	86.75	935.86	959.35	211	942.92	81.87	931.81	954.03	215	950.66	72.88	940.86	960.46
/i:/	96	2527.26	301.21	2466.23	2588.29	96	2503.04	365.36	2429.01	2577.07	96	2491.55	310.62	2428.61	2554.48
/e:/	142	2297.35	239.43	2257.62	2337.07	143	2300.22	283.86	2253.30	2347.15	144	2312.30	240.48	2272.69	2351.92
/a:/	239	1464.02	194.20	1439.27	1488.76	240	1470.07	180.15	1447.16	1492.98	240	1507.31	215.79	1479.87	1534.75
/o:/	95	1115.71	151.34	1084.88	1146.53	95	1116.52	145.43	1086.89	1146.14	96	1172.85	213.75	1129.54	1216.16
/u:/	94	974.44	149.92	943.73	1005.14	94	991.56	147.15	961.42	1021.70	96	992.23	151.22	961.59	1022.87

Table 4.2.3.6: Mean F2 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	142	2487.81	341.578
	Nasal	71	2506.54	345.338
/e/	Stop	144	2217.40	232.612
	Affricate	72	2165.65	275.346
	Nasal	71	2234.76	236.632
	Semi vowel	71	2186.44	255.267
	Lateral	71	2167.13	279.426
	Trill	72	2139.27	290.128
/a/	Stop	214	1503.75	175.932
	Nasal	71	1500.81	150.996
	Fricative	72	1465.20	192.509
	Semi vowel	144	1407.10	204.754
	Lateral	72	1547.23	177.922
	Total	573	1479.72	188.482
/o/	Stop	214	1115.78	161.099
	Nasal	143	1138.63	185.712
/u/	Stop	353	953.73	79.614
	Affricate	141	936.76	88.072
	Fricative	72	952.68	59.583
	Trill	72	929.13	85.034
/i:/	Stop	144	2508.71	332.766
	Affricate	72	2510.25	320.129
	Nasal	72	2501.46	323.180
/e:/	Stop	285	2302.31	266.851
	Affricate	72	2337.48	228.732
	Nasal	72	2273.18	229.033
/a:/	Stop	432	1485.71	188.553
	Affricate	72	1584.54	211.665
	Nasal	143	1419.66	184.698
	Fricative	72	1465.93	220.137
/o:/	Stop	215	1128.11	171.982
	Affricate	71	1156.49	181.824
/u:/	Stop	142	988.07	142.886
	Nasal	142	984.17	155.642

Table 4.2.3.7: Mean F2 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	71	2513.15	365.260
	Dental	71	2462.47	316.703
	Alveopalatal	71	2506.54	345.338
/e/	Bilabial	214	2220.60	232.606
	Alveopalatal	215	2157.30	280.687
	Retroflex	72	2194.50	258.472
/a/	Bilabial	144	1393.47	183.375
	Alveopalatal	287	1496.58	182.519
	Velar	142	1533.10	177.192
/o/	Bilabial	214	1086.37	151.340
	Dental	71	1191.62	165.540
	Alveopalatal	72	1173.81	200.961
/u/	Bilabial	140	949.55	88.463
	Dental	142	964.28	68.233
	Alveopalatal	285	938.85	81.200
	Velar	71	940.87	80.790
/i:/	Bilabial	72	2521.91	315.006
	Alveopalatal	144	2505.85	320.562
	Velar	72	2495.51	351.346
/e:/	Bilabial	144	2301.40	232.921
	Dental	70	2312.94	266.292
	Alveopalatal	72	2337.48	228.732
	Velar	143	2283.36	282.077
/a:/	Bilabial	215	1425.42	185.212
	Dental	144	1503.24	191.383
	Alveopalatal	216	1504.70	213.739
	Velar	144	1503.64	183.084
/o:/	Bilabial	71	1063.26	149.939
	Dental	72	1161.33	163.506
	Alveopalatal	71	1156.49	181.824
	Retroflex	72	1158.84	184.307
/u:/	Bilabial	141	941.05	134.022
	Dental	71	1039.64	139.346
	Alveopalatal	72	1021.60	161.033

Table 4.2.3.8: Mean F2 (Hz) of vowels across voicing feature of preceding consonants

N=4320

Vowels	Voiced consonant			Voiceless consonant		
	n	**mean**	**SD**	**n**	**mean**	**SD**
/i/	71	2462.47	316.7	71	2513.15	365.26
/e/	71	2234.76	236.63	144	2217.4	232.61
/a/	144	1530.16	169.77	70	1449.42	177.09
/o/	142	1105.59	150.93	143	1119.54	171.19
/u/	140	947.11	86.68	213	958.08	74.49
/i:/	72	2495.51	351.35	72	2521.91	315.01
/e:/	213	2293.95	258.8	144	2300.12	261.71
/a:/	287	1461.65	193.38	216	1481.31	185.25
/o:/	72	1158.84	184.31	143	1112.64	163.92
/u:/	141	992.98	147.36	71	936.5	127.72

APPENDIX –VIII e

4.2.4 Third Formant Frequency (F3)

Table 4.2.4.1: Mean F3 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for mean	
				Lower	Upper
/i/	214	3232.28	459.26	3170.4	3292.16
/e/	490	3115.47	444.42	3076.02	3154.92
/a/	545	3069.08	277.44	3005.74	3177.24
/o/	298	3110.41	490.65	3054.47	3166.34
/u/	492	3033.38	464.883	2992.21	3074.56
/i:/	284	3436.57	434.65	3385.8	3487.34
/e:/	427	3288.07	462.48	3244.08	3332.06
/a:/	690	3096.73	444.19	3063.53	3129.93
/o:/	265	3147.06	440.24	3093.81	3200.3
/u:/	204	3032.45	447.96	2970.61	3094.21

Table 4.2.4.2: Mean F3 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels.

N=4320

Place of constriction	n	Mean	SD	95% Confidence Interval for Mean	
				Lower	Upper
Front	1415	3249.67	464.84	3225.43	3273.91
Central	1235	3075.39	465.41	3049.66	3101.12
Back	1259	2819.75	491.23	2792.33	2847.17

Table 4.2.4.3: Mean F3 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	71	3633.13	319.48	3557.51	3708.75	71	3124.57	375.17	3035.77	3213.37	72	2943.2	369.23	2856.46	3029.99
/e/	166	3480.63	326.65	3429.95	3531.31	166	3055.36	366.32	2999.22	3111.49	162	2811.9	353.64	2757.05	2866.79
/a/	183	3463.03	272.20	3423.32	3502.72	180	3056.82	280.62	3016.82	3096.82	182	2787.3	280.08	2747.3	2820.2
/o/	104	3499.61	407.58	3415.67	3583.55	101	3094.81	429.56	3010.03	3179.59	104	2777.5	343.27	2710.77	2844.28
/u/	181	3391.60	419.04	3323.99	3459.21	161	3020.05	414.45	2955.54	3084.55	181	2748.4	320.49	2701.38	2795.39
/i:/	95	3756.20	383.65	3678.04	3834.35	94	3321.50	407.94	3237.95	3405.06	95	3230.8	312.54	3167.14	3294.47
/e:/	144	3659.81	358.07	3599.97	3719.64	143	3186.52	381.07	3123.53	3249.51	144	3027.5	392.92	2962.79	3092.24
/a:/	231	3422.34	368.19	3374.61	3470.08	230	3073.38	388.09	3022.96	3123.80	229	2791.7	326.82	2749.17	2834.28
/o:/	91	3481.54	317.19	3415.10	3547.97	91	3131.56	373.66	3053.74	3209.37	84	2805.5	342.82	2731.08	2879.87
/u:/	73	3398.44	356.65	3304.67	3492.22	73	2990.34	449.55	2885.46	3095.23	73	2783.8	300.94	2713.56	2853.99

Table 4.2.4.4: Mean F3 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	Female					Male				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper
/i/	107	3381.79	338.24	3316.96	3446.61	107	3082.78	514.09	2984.25	3181.31
/e/	251	3265.62	343.78	3222.88	3308.35	239	2957.79	482.63	2896.29	3019.29
/a/	271	3255.46	313.70	3215.46	3302.98	274	2962.76	236.59	2922.76	3012.74
/o/	146	3229.69	447.26	3156.53	3302.85	152	2995.83	504.42	2915.00	3076.67
/u/	238	3161.51	393.24	3111.30	3211.73	254	2913.33	494.62	2852.21	2974.45
/i:/	142	3538.10	338.34	3481.97	3594.23	142	3335.05	493.92	3253.11	3416.99
/e:/	213	3443.85	359.46	3395.30	3492.40	214	3133.03	500.76	3065.55	3200.50
/a:/	347	3219.96	380.31	3179.80	3260.11	343	2972.07	469.23	2922.23	3021.90
/o:/	129	3250.46	362.64	3187.28	3313.63	136	3048.98	484.16	2966.87	3131.08
/u:/	87	3192.52	390.46	3109.30	3275.74	117	2913.42	452.36	2830.59	2996.26

Table 4.2.4.5: Mean F3 (Hz), SD and 95% confidence interval for mean values across regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	3040.08	378.21	2951.2	3128.95	71	3358.10	470.37	3246.77	3469.44	71	3301.37	465.36	3191.22	3411.52
/e/	166	2976.14	373.07	2918.97	3033.31	161	3217.09	467.37	3144.35	3289.83	163	3157.00	454.76	3086.66	3227.34
/a/	182	2965.19	282.42	2925.00	3005.00	180	3209.32	289.58	3130.00	3283.30	183	3142.88	260.99	3102.00	3182.00
/o/	100	2890.33	340.74	2822.71	2957.95	103	3268.02	525.30	3165.35	3370.68	95	3171.19	506.37	3068.04	3274.35
/u/	164	2859.83	362.33	2803.96	2915.70	168	3139.19	487.14	3064.99	3213.39	160	3100.19	485.96	3024.31	3176.06
/i:/	95	3253.45	363.55	3179.39	3327.51	94	3616.99	486.63	3517.31	3716.66	95	3441.18	368.60	3366.09	3516.27
/e:/	142	3138.03	393.61	3072.73	3203.33	141	3396.08	477.57	3316.57	3475.60	144	3330.28	474.84	3252.06	3408.5
/a:/	225	2934.67	325.56	2891.90	2977.44	231	3228.52	477.60	3166.61	3290.44	234	3122.46	461.68	3062.99	3181.92
/o:/	85	2957.11	340.86	2883.59	3030.63	91	3249.07	445.85	3156.22	3341.92	89	3224.16	464.33	3126.34	3321.97
/u:/	69	2869.86	342.08	2787.68	2952.04	71	3164.98	474.61	3052.64	3277.32	64	3060.72	469.5	2943.44	3172.00

Table 4.2.4.6: Mean F3 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	142	3205.93	462.300
	Nasal	72	3284.25	451.868
/e/	Stop	142	3091.75	444.464
	Affricate	72	3067.33	467.038
	Nasal	69	3123.29	426.932
	Semi vowel	70	3204.52	454.571
	Lateral	70	3149.80	455.638
	Trill	67	3080.55	413.684
/a/	Stop	206	2448.88	280.675
	Nasal	65	2487.51	273.708
	Fricative	69	2476.86	263.918
	Semi vowel	137	2481.37	270.027
	Lateral	68	2480.00	302.642
/o/	Stop	185	3141.01	503.556
	Nasal	113	3060.31	466.622
/u/	Stop	235	3051.49	468.040
	Affricate	132	2884.05	435.349
	Fricative	63	3220.55	451.024
	Trill	62	3092.51	442.933
/i:/	Stop	142	3427.24	436.466
	Affricate	70	3411.26	413.490
	Nasal	72	3479.59	453.733
/e:/	Stop	285	3300.76	461.662
	Affricate	70	3167.92	471.585
	Nasal	72	3354.66	441.932
/a:/	Stop	423	3086.22	434.696
	Affricate	70	3071.17	474.866
	Nasal	128	3151.99	471.783
	Fricative	69	3084.55	418.018
/o:/	Stop	199	3175.48	440.744
	Affricate	66	3061.34	430.709
/u:/	Stop	107	3142.83	459.837
	Nasal	97	2910.69	402.844

Table 4.2.4.7: Mean F3 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	71	3193.44	469.871
	Dental	71	3218.43	457.604
	Alveopalatal	72	3284.25	451.868
/e/	Bilabial	209	3135.42	439.846
	Alveopalatal	209	3099.19	446.041
	Retroflex	72	3104.83	456.777
/a/	Bilabial	139	2492.46	279.146
	Alveopalatal	270	2483.84	273.981
	Velar	136	2415.88	277.649
/o/	Bilabial	169	3089.03	473.310
	Dental	66	3120.50	551.293
	Alveopalatal	63	3157.18	473.275
/u/	Bilabial	75	2937.62	443.866
	Dental	124	3141.22	449.381
	Alveopalatal	257	3016.83	462.268
	Velar	36	2979.68	526.052
/i:/	Bilabial	72	3461.63	423.131
	Alveopalatal	142	3445.91	434.178
	Velar	70	3391.87	450.062
/e:/	Bilabial	144	3317.93	446.188
	Dental	70	3282.84	426.600
	Alveopalatal	70	3167.92	471.585
	Velar	143	3319.38	485.453
/a:/	Bilabial	205	3109.64	453.508
	Dental	138	3118.50	420.636
	Alveopalatal	205	3103.98	444.221
	Velar	142	3046.47	453.692
/o:/	Bilabial	64	3204.43	459.917
	Dental	68	3153.89	454.569
	Alveopalatal	66	3061.34	430.709
	Retroflex	67	3169.75	412.027
/u:/	Bilabial	89	2992.28	419.007
	Dental	63	3185.28	461.102
	Alveopalatal	52	2916.06	437.985

Table 4.2.4.8: Mean F3 (Hz) of vowels across preceding voicing feature of consonants

N=4320

Vowels	Voiced consonant			Voiceless consonant		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	71	3218.43	457.6	71	3193.44	469.87
/e/	69	3123.29	426.93	142	3091.75	444.46
/a/	141	3063.35	277.01	65	3017.49	288.14
/o/	114	3052.96	478.22	121	3140.18	509.48
/u/	100	3132.63	435.12	135	2991.39	483.85
/i:/	70	3391.87	450.06	72	3461.63	423.13
/e:/	213	3302.4	456.78	144	3325.3	460.2
/a:/	276	3111.39	460.6	209	3070.25	422.49
/o:/	67	3169.75	412.03	132	3178.39	456.13
/u:/	108	3068.28	443.48	44	3082.07	456.37

APPENDIX - VIII f

4.2.5 Fourth Formant Frequency (F4)

Table 4.2.5.1: Mean F4 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for mean	
				Lower	Upper
/i/	186	4349.84	446.39	4285.27	4414.42
/e/	431	4256.19	410.96	4207.28	4285.1
/a/	481	4247.04	435.21	4208.05	4286.04
/o/	267	4207.54	446.09	4153.79	4261.29
/u/	409	4185.72	481.86	4138.88	4232.56
/i:/	250	4383.11	429.71	4329.58	4436.64
/e:/	380	4352.44	437.36	4308.33	4396.56
/a:/	608	4280.79	401.7	4248.8	4312.79
/o:/	252	4262.15	494.48	4200.81	4323.5
/u:/	181	4212.41	468.14	4143.75	4281.07

Table 4.2.5.2: Mean F4 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels

N=4320

Place of constriction	n	Mean	SD	95% CI for mean	
				Lower	Upper
Front	1247	4321.48	431.38	4297.51	4345.45
Central	1089	4212.06	417.94	4185.2	4234.91
Back	1109	4212.7	474.45	4184.74	4240.65

Table 4.2.5.3: Mean F4 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	52	4696.04	372.17	4592.42	4799.65	67	4322.99	389.87	4227.89	4418.08	67	4108.00	380.79	4015.13	4200.90
/e/	131	4592.27	312.21	4538.31	4636.24	148	4249.33	335.34	4194.86	4299.81	152	4017.20	397.49	3953.47	4080.87
/a/	156	4586.42	298.68	4539.18	4633.65	162	4237.93	337.95	4185.50	4290.37	163	3931.30	388.67	3871.18	3991.42
/o/	78	4574.37	306.75	4505.21	4643.53	96	4213.55	360.15	4140.58	4286.53	93	3893.70	385.94	3814.20	3973.17
/u/	117	4564.68	394.09	4492.52	4636.85	135	4201.36	378.28	4136.97	4265.75	157	3889.90	415.76	3824.31	3955.40
/i:/	76	4711.42	286.39	4645.98	4776.87	88	4337.25	377.00	4257.37	4417.13	86	4139.90	405.80	4052.90	4226.90
/e:/	116	4698.69	346.37	4634.99	4762.39	133	4313.69	358.25	4252.24	4375.14	131	4085.20	375.13	4020.33	4150.02
/a:/	205	4694.79	271.14	4657.45	4732.12	205	4292.15	527.74	4227.02	4337.28	198	3864.70	326.67	3818.87	3910.43
/o:/	84	4683.65	346.30	4608.49	4758.80	88	4275.77	317.25	4208.55	4342.98	80	3804.60	372.74	3721.66	3887.56
/u:/	49	4591.29	333.93	4495.37	4687.20	68	4267.45	389.86	4173.08	4361.81	64	3793.90	375.81	3709.99	3887.74

Table 4.2.5.4: Mean F4 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	**Female**					**Male**				
	n	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**	
				Lower	**Upper**				**Lower**	**Upper**
/i/	95	4513.49	312.58	4449.81	4577.17	91	4179.01	499.78	4074.92	4283.09
/e/	215	4409.91	310.52	4368.17	4451.65	216	4098.17	433.96	4025.03	4151.43
/a/	233	4405.51	337.19	4361.98	4449.03	248	4083.23	464.06	4020.13	4156.21
/o/	130	4380.54	327.24	4323.76	4437.33	137	4043.38	481.54	3962.03	4124.74
/u/	198	4355.54	400.17	4299.45	4411.62	211	4026.36	498.18	3958.75	4093.97
/i:/	124	4529.18	283.90	4478.72	4579.65	126	4239.35	496.51	4151.81	4326.89
/e:/	185	4522.54	348.50	4471.99	4573.09	195	4191.06	452.47	4127.15	4254.97
/a:/	291	4500.60	313.80	4454.40	4566.81	317	4114.47	440.73	4021.10	4207.84
/o:/	126	4409.84	408.11	4357.88	4481.79	126	4070.81	529.59	4001.10	4159.51
/u:/	77	4395.90	331.67	4320.62	4471.18	104	4036.56	507.95	3977.78	4165.35

Table 4.2.5.5: Mean F4 (Hz), SD and 95% confidence interval for mean values across regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	62	4255.30	427.03	4146.86	4363.75	55	4413.78	421.29	4299.88	4527.67	69	4383.83	474.32	4269.89	4497.78
/e/	152	4215.10	382.87	4276.46	4376.46	122	4354.79	413.59	4180.66	4382.92	157	4269.62	435.22	4201.01	4338.23
/a/	158	4185.56	384.06	4245.91	4345.91	156	4300.20	462.63	4227.03	4373.37	167	4255.56	449.46	4186.90	4324.23
/o/	91	4124.66	393.07	4206.52	4286.52	87	4241.08	461.64	4142.69	4339.47	89	4159.51	473.57	4059.75	4359.27
/u/	131	4087.26	428.05	4013.27	4161.25	142	4221.88	520.40	4135.55	4308.22	136	4142.80	477.89	4061.75	4323.84
/i:/	91	4329.95	385.19	4249.73	4480.17	71	4428.82	449.64	4322.39	4535.25	88	4431.20	455.35	4304.72	4497.68
/e:/	130	4307.61	380.73	4241.54	4403.68	111	4346.78	453.81	4261.42	4432.15	139	4398.88	470.73	4319.94	4477.83
/a:/	202	4199.90	356.63	4060.43	4259.38	194	4303.47	446.56	4180.23	4306.70	212	4370.98	390.02	4138.18	4393.79
/o:/	79	4182.57	420.04	4276.65	4376.65	86	4283.81	545.06	4166.94	4400.67	87	4313.02	501.07	4206.22	4419.81
/u:/	59	4099.26	432.71	3986.49	4212.02	67	4257.38	509.64	4133.07	4381.69	55	4279.01	436.97	4160.88	4397.14

Table 4.2.5.6: Mean F4 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	123	4332.35	473.666
	Nasal	63	4384.00	389.007
/e/	Stop	134	4257.18	402.616
	Affricate	67	4133.34	413.089
	Nasal	65	4186.23	387.064
	Semi vowel	59	4330.70	386.884
	Lateral	59	4368.63	431.072
	Trill	47	4198.88	423.226
/a/	Stop	192	4231.86	475.018
	Nasal	53	4240.84	395.422
	Fricative	66	4233.70	422.251
	Semi vowel	119	4247.58	415.438
	Lateral	51	4326.67	383.471
/o/	Stop	169	4233.78	447.866
	Nasal	98	4162.30	441.614
/u/	Stop	211	4212.81	473.046
	Affricate	105	4025.70	481.650
	Fricative	54	4388.98	480.031
	Trill	39	4188.49	408.081
/i:/	Stop	126	4402.94	431.559
	Affricate	60	4327.46	408.789
	Nasal	64	4396.24	447.082
/e:/	Stop	254	4382.10	450.633
	Affricate	64	4264.59	429.874
	Nasal	62	4321.60	377.685
/a:/	Stop	389	4211.66	398.819
	Affricate	57	4120.80	425.665
	Nasal	101	4112.70	398.463
	Fricative	61	4152.73	389.827
/o:/	Stop	190	4282.21	489.661
	Affricate	62	4200.70	508.067
/u:/	Stop	103	4278.04	503.595
	Nasal	78	4125.75	403.725

Table 4.2.5.7: Mean F4 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	62	4261.32	432.646
	Dental	61	4404.55	505.353
	Alveopalatal	63	4384.00	389.007
/e/	Bilabial	192	4250.64	387.766
	Alveopalatal	173	4231.39	431.902
	Retroflex	66	4272.05	424.862
/a/	Bilabial	127	4272.28	429.722
	Alveopalatal	226	4260.08	402.537
	Velar	128	4198.99	492.278
/o/	Bilabial	155	4207.20	459.236
	Dental	58	4212.78	447.254
	Alveopalatal	54	4202.90	413.205
/u/	Bilabial	63	4074.78	453.236
	Dental	118	4291.85	462.497
	Alveopalatal	198	4156.84	490.634
	Velar	30	4191.80	500.984
/i:/	Bilabial	63	4403.00	411.963
	Alveopalatal	124	4362.96	428.634
	Velar	63	4402.87	453.626
/e:/	Bilabial	127	4357.62	408.647
	Dental	67	4378.09	478.211
	Alveopalatal	64	4264.59	429.874
	Velar	122	4379.05	446.219
/a:/	Bilabial	180	4176.28	387.380
	Dental	125	4233.43	386.813
	Alveopalatal	171	4134.63	405.588
	Velar	132	4196.89	426.413
/o:/	Bilabial	61	4304.34	519.490
	Dental	65	4277.49	476.885
	Alveopalatal	62	4200.70	508.067
	Retroflex	64	4265.91	480.092
/u:/	Bilabial	79	4165.80	490.810
	Dental	59	4335.55	460.848
	Alveopalatal	43	4129.09	407.530

Table 4.2.5.8: Mean F4 (Hz) of vowels across preceding voicing feature of consonants

N=4320

Vowels	Voiced consonants			Voiceless consonants		
	n	Mean	SD	n	Mean	SD
/i/	61	4404.55	505.35	62	4261.32	432.65
/e/	65	4186.23	387.06	134	4257.18	402.62
/a/	129	4230.85	455.12	63	4233.93	517.21
/o/	101	4173.49	470.77	112	4240.5	439.91
/u/	98	4276.36	449.49	113	4157.71	487.85
/i:/	63	4402.87	453.63	63	4403	411.96
/e:/	189	4353.55	434.75	127	4395.06	441.83
/a:/	247	4185.21	407.14	190	4216.59	388.95
/o:/	64	4265.91	480.09	126	4290.49	496.14
/u:/	94	4255.9	450.77	44	4200.92	551.81

APPENDIX – VIII g

4.2.6 First Formant Bandwidth (B1)

Table 4.2.6.1: Mean B1 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for mean	
				Lower	Upper
/i/	215	58.55	18.59	56.05	61.05
/e/	502	56.39	17.04	54.9	57.89
/a/	570	57.71	20.19	56.05	59.37
/o/	355	57.78	19.05	55.79	59.77
/u/	630	56.69	19.25	55.19	58.2
/i:/	287	58.07	19.44	55.81	60.31
/e:/	429	55.51	16.95	53.9	57.12
/a:/	713	58.07	23.69	56.33	59.81
/o:/	286	56.95	19.18	54.72	59.19
/u:/	282	56.16	21.47	53.64	58.68

Table 4.2.6.2: Mean B1 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels

N=4320

Place of constriction	n	Mean	SD	95% CI for mean	
				Lower	Upper
Front	1433	56.79	17.77	55.87	57.71
Central	1283	57.91	22.19	56.69	59.12
Back	1553	56.89	19.6	55.92	57.87

Table 4.2.6.3: Mean B1 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	71	62.47	23.34	56.95	68.00	72	56.11	12.47	53.18	59.04	72	57.12	18.06	52.88	61.36
/e/	167	56.18	18.37	53.37	58.98	168	55.88	12.13	54.03	57.73	167	57.12	19.74	54.11	60.14
/a/	191	60.81	25.11	57.22	64.39	191	56.19	13.24	54.30	58.08	188	56.10	20.17	53.20	59.00
/o/	117	60.31	22.50	56.14	64.43	118	54.56	11.89	52.40	56.73	120	58.48	20.74	54.73	62.23
/u/	208	57.80	19.60	55.12	60.48	213	54.54	13.80	52.68	56.40	209	57.78	23.16	54.63	60.94
/i:/	96	60.93	22.90	56.29	65.57	95	56.15	15.74	52.94	59.35	96	57.10	18.84	53.28	60.91
/e:/	142	55.00	19.48	52.37	58.83	143	54.60	12.54	52.53	56.67	144	56.33	18.10	53.35	59.31
/a:/	237	61.92	28.95	58.21	65.62	240	54.76	14.72	52.89	56.63	236	57.58	24.73	54.40	60.75
/o:/	95	52.18	20.36	53.98	62.27	96	54.15	13.99	51.32	56.98	95	57.62	22.16	54.10	63.13
/u:/	93	60.15	26.98	54.55	65.71	95	54.75	17.30	51.23	58.28	94	53.63	18.59	49.83	57.44

Table 4.2.6.4: Mean B1 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	**Female**					**Male**				
	n	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**	
				Lower	**Upper**				**Lower**	**Upper**
/i/	108	60.46	17.64	57.10	63.83	107	56.62	19.39	52.90	60.33
/e/	252	56.83	16.72	54.76	58.91	250	55.95	17.38	53.79	58.12
/a/	286	60.28	23.10	57.59	62.97	284	55.12	16.39	53.20	57.03
/o/	179	59.90	21.64	56.71	63.09	176	55.63	15.77	53.28	57.97
/u/	318	57.67	19.28	55.55	59.80	312	55.69	19.19	53.56	57.83
/i:/	143	58.43	18.72	55.33	61.52	144	57.71	20.18	54.38	61.03
/e:/	214	55.01	15.32	52.95	57.08	215	56.01	18.44	53.53	58.49
/a:/	355	59.34	24.99	56.73	61.95	358	56.82	22.29	54.50	59.13
/o:/	142	57.68	17.55	54.77	60.59	144	56.23	20.71	52.82	59.64
/u:/	140	57.56	22.40	53.82	61.31	142	54.78	20.49	51.38	58.18

Table 4.2.6.5: Mean B1 (Hz), SD and 95% confidence interval for mean values across regions

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	60.42	19.61	55.81	65.02	72	61.29	23.78	55.70	66.88	71	53.87	7.75	52.04	55.71
/e/	167	61.35	19.59	58.35	64.34	167	56.51	19.05	53.60	59.43	168	51.35	8.87	50.00	52.70
/a/	188	60.09	20.33	57.17	63.02	191	62.74	25.77	59.07	66.42	191	50.32	7.95	49.18	51.45
/o/	119	61.86	19.79	58.27	65.45	118	60.65	23.28	56.41	64.90	118	50.79	9.31	49.10	52.49
/u/	210	61.61	22.84	58.51	64.72	207	57.37	21.49	54.43	60.32	213	51.18	9.00	49.97	52.40
/i:/	95	62.48	18.12	58.79	66.17	96	59.05	25.74	53.83	64.26	96	52.72	10.03	50.69	54.75
/e:/	142	60.41	17.87	57.45	63.38	143	55.13	20.36	51.76	58.49	144	51.06	9.44	49.51	52.62
/a:/	236	60.27	24.52	57.12	63.41	237	64.11	30.31	60.23	67.98	240	49.96	8.14	48.92	50.99
/o:/	94	62.43	21.15	58.09	66.76	96	58.20	22.52	53.64	62.77	96	50.34	9.11	48.50	52.19
/u:/	92	57.96	19.58	53.90	62.02	94	60.23	29.84	54.12	66.34	96	50.45	8.46	48.74	52.17

Table 4.2.6.6: Mean B1 (Hz) and SD of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	143	58.99	19.504
	Nasal	72	57.67	16.732
/e/	Stop	144	57.55	16.208
	Affricate	72	54.10	15.015
	Nasal	72	58.12	18.686
	Semi vowel	71	57.90	15.643
	Lateral	71	52.04	13.016
	Trill	72	57.45	22.428
/a/	Stop	211	58.96	22.696
	Nasal	71	58.94	21.214
	Fricative	72	55.91	15.792
	Semi vowel	144	55.93	18.390
	Lateral	72	58.16	18.757
/o/	Stop	212	57.61	18.930
	Nasal	143	58.04	19.288
/u/	Stop	347	56.52	19.993
	Affricate	142	58.38	19.394
	Fricative	69	55.72	16.711
	Trill	72	55.10	17.594
/i:/	Stop	143	57.97	18.635
	Affricate	72	54.25	15.755
	Nasal	72	62.08	23.405
/e:/	Stop	285	54.71	15.342
	Affricate	72	54.47	17.723
	Nasal	72	59.74	21.295
/a:/	Stop	429	58.80	24.643
	Affricate	71	57.27	24.145
	Nasal	141	56.68	21.637
	Fricative	72	57.24	21.454
/o:/	Stop	216	56.99	18.582
	Affricate	70	56.83	21.067
/u:/	Stop	140	55.06	20.442
	Nasal	142	57.25	22.449

Table 4.2.6.7: Mean B1 (Hz) and SD of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	72	59.21	19.741
	Dental	71	58.77	19.398
	Alveopalatal	72	57.67	16.732
/e/	Bilabial	215	57.41	16.328
	Alveopalatal	215	54.54	17.381
	Retroflex	72	58.87	17.738
/a/	Bilabial	141	56.99	20.948
	Alveopalatal	287	56.94	17.611
	Velar	142	59.96	23.934
/o/	Bilabial	213	57.49	18.179
	Dental	70	58.17	20.653
	Alveopalatal	72	58.27	20.181
/u/	Bilabial	137	56.93	21.184
	Dental	140	55.44	18.232
	Alveopalatal	283	56.90	18.320
	Velar	70	57.89	21.113
/i:/	Bilabial	72	57.33	17.576
	Alveopalatal	144	58.17	20.264
	Velar	71	58.61	19.755
/e:/	Bilabial	144	56.25	18.188
	Dental	70	52.90	13.366
	Alveopalatal	72	54.47	17.723
	Velar	143	56.58	16.818
/a:/	Bilabial	214	57.47	23.536
	Dental	144	58.34	23.260
	Alveopalatal	213	56.97	22.231
	Velar	142	60.36	26.408
/o:/	Bilabial	72	58.05	19.601
	Dental	72	58.45	20.032
	Alveopalatal	70	56.83	21.067
	Retroflex	72	54.48	15.825
/u:/	Bilabial	142	56.84	21.482
	Dental	70	52.99	19.916
	Alveopalatal	70	57.96	22.858

Table 4.2.6.8: Mean B1 (Hz) of vowels across preceding voicing feature of consonants

N=4320

Vowels	Voiced consonants			Voiceless consonants		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	71	58.77	19.398	72	59.21	19.741
/e/	72	58.12	18.686	144	57.55	16.208
/a/	141	57.56	18.995	70	61.80	28.695
/o/	141	57.77	19.038	142	57.54	18.598
/u/	139	55.78	20.466	208	57.02	19.705
/i:/	71	58.61	19.755	72	57.33	17.576
/e:/	213	55.65	17.668	144	55.83	15.491
/a:/	287	58.91	24.661	213	58.05	23.829
/o:/	72	54.48	15.825	144	58.25	19.749
/u:/	142	54.79	21.097	70	57.13	20.892

APPENDIX – VIII h

4.2.7 Second Formant Bandwidth (B2)

Table 4.2.7.1: Mean B2 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for mean	
				Lower	Upper
/i/	212	133.97	17.53	131.6	136.35
/e/	496	137.73	16.04	136.32	139.15
/a/	566	137.11	15.04	135.87	138.35
/o/	351	134.75	16.48	133.02	136.48
/u/	608	136.9	17.1	135.53	138.26
/i:/	287	134.07	17	132.1	136.04
/e:/	428	137.63	17	136.01	139.24
/a:/	714	137.57	16.04	136.39	138.75
/o:/	282	136.12	18.42	133.96	138.28
/u:/	273	134.67	15.27	132.85	136.49

Table 4.2.7.2: Mean B2 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels

N=4320

Place of constriction	n	Mean	SD	95% CI for mean	
				Lower	Upper
Front	1423	136.4	16.82	135.53	137.28
Central	1280	137.37	15.6	136.51	138.22
Back	1514	135.85	16.91	135	136.7

Table 4.2.7.3: Mean B2 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	69	134.94	14.22	131.52	138.35	71	136.46	16.39	132.59	140.34	72	130.60	20.88	125.69	135.50
/e/	163	140.22	18.69	137.33	143.11	166	136.62	12.39	134.73	138.52	167	136.40	16.27	133.92	138.89
/a/	190	136.65	17.81	134.10	139.20	191	136.90	13.10	135.03	138.77	185	137.80	13.82	135.80	139.81
/o/	117	133.10	17.23	129.25	136.25	118	133.91	16.71	130.86	136.96	116	137.27	15.30	134.45	140.08
/u/	205	135.11	17.55	132.69	137.53	200	137.63	16.16	135.38	139.89	203	137.97	17.47	135.56	140.39
/i:/	96	137.08	15.82	133.87	140.28	95	132.71	16.31	129.39	136.03	96	132.42	18.40	128.69	136.15
/e:/	141	140.66	20.94	137.17	144.14	143	137.13	13.00	134.98	139.29	144	135.15	15.80	132.55	137.75
/a:/	238	136.35	19.30	133.88	138.81	238	137.76	12.85	136.12	139.41	238	138.59	15.29	136.64	140.55
/o:/	94	132.45	18.50	128.66	136.24	95	135.91	16.67	132.52	139.31	93	140.05	19.42	136.05	144.05
/u:/	88	132.86	19.31	128.77	136.95	94	133.88	11.79	131.46	136.29	91	137.23	13.81	134.35	140.10

Table 4.2.7.4: Mean B2 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	**Female**					**Male**				
	n	**Mean**	**SD**	**95% CI for mean**		**n**	**Mean**	**SD**	**95% CI for mean**	
				Lower	**Upper**				**Lower**	**Upper**
/i/	107	135.60	15.12	132.70	138.50	105	132.32	19.61	128.52	136.12
/e/	249	138.55	17.34	136.39	140.71	247	136.91	14.60	135.08	138.74
/a/	284	138.85	16.27	136.95	140.75	282	135.36	13.50	133.77	136.94
/o/	178	134.80	16.23	132.40	137.20	173	134.69	16.79	132.17	137.21
/u/	305	136.60	16.60	134.73	138.47	303	137.20	17.61	135.21	139.19
/i:/	143	136.10	15.69	133.51	138.70	144	132.06	17.97	129.10	135.01
/e:/	213	138.47	18.56	135.97	140.98	215	136.79	15.29	134.73	138.84
/a:/	357	138.41	18.47	136.49	140.33	357	136.73	13.15	135.36	138.10
/o:/	140	136.98	17.45	134.07	139.90	142	135.27	19.36	132.06	138.48
/u:/	132	135.67	14.46	133.18	138.16	141	133.73	15.99	131.07	136.39

Table 4.2.7.5: Mean B2 (Hz), SD and 95% confidence interval for mean values across region

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	72	133.57	18.17	129.31	137.84	69	133.89	16.49	129.93	137.86	71	134.46	18.08	130.18	138.74
/e/	166	138.27	16.27	135.77	140.76	162	140.43	17.47	137.72	143.15	168	134.60	13.76	132.50	136.70
/a/	185	136.67	13.37	134.73	138.61	190	139.72	18.34	137.09	142.34	191	134.94	12.38	133.17	136.70
/o/	117	134.62	16.15	131.66	137.58	117	135.09	19.00	131.61	138.57	117	134.54	14.08	131.96	137.11
/u/	203	137.71	17.05	135.35	140.07	194	138.14	17.99	135.59	140.68	211	134.97	16.19	132.78	137.17
/i:/	95	129.00	17.46	125.44	132.56	96	138.69	19.20	134.80	142.59	96	134.47	12.16	132.01	136.94
/e:/	142	135.92	15.83	133.29	138.55	142	142.82	20.75	139.38	146.26	144	134.19	12.24	132.17	136.20
/a:/	238	138.27	16.01	136.23	140.32	236	139.30	19.12	136.85	141.75	240	135.17	12.03	133.64	136.69
/o:/	93	137.30	19.36	133.31	141.29	94	133.99	18.14	130.28	137.71	95	137.08	17.74	133.46	140.69
/u:/	92	133.85	13.42	131.07	136.63	88	135.62	15.20	132.40	138.84	93	134.57	17.08	131.06	138.09

Table 4.2.7.6: Mean B2 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	141	134.13	15.064
	Nasal	71	133.67	21.725
/e/	Stop	141	137.60	16.280
	Affricate	72	137.04	14.305
	Nasal	70	136.99	11.871
	Semi vowel	71	140.41	19.015
	Lateral	70	136.50	19.239
	Trill	72	137.97	14.270
/a/	Stop	212	138.74	16.063
	Nasal	71	136.54	15.542
	Fricative	71	137.36	13.948
	Semi vowel	142	134.47	13.848
	Lateral	70	137.83	14.332
/o/	Stop	210	134.20	17.509
	Nasal	141	135.57	14.856
/u/	Stop	334	136.89	16.489
	Affricate	137	138.56	17.485
	Fricative	66	136.85	21.999
	Trill	71	133.79	13.498
/i:/	Stop	143	133.59	18.553
	Affricate	72	135.82	15.847
	Nasal	72	133.28	14.637
/e:/	Stop	285	138.02	18.193
	Affricate	71	135.31	13.603
	Nasal	72	138.35	14.979
/a:/	Stop	429	137.73	13.880
	Affricate	72	138.27	16.578
	Nasal	143	136.06	15.671
	Fricative	70	138.95	25.850
/o:/	Stop	213	135.87	17.361
	Affricate	69	136.88	21.483
/u:/	Stop	136	134.48	14.655
	Nasal	137	134.85	15.915

Table 4.2.7.7: Mean B2 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	71	134.16	16.852
	Dental	70	134.09	13.126
	Alveopalatal	71	133.67	21.725
/e/	Bilabial	213	138.88	16.133
	Alveopalatal	214	137.17	16.011
	Retroflex	69	135.92	15.814
/a/	Bilabial	141	135.87	16.773
	Alveopalatal	284	136.46	14.155
	Velar	141	139.66	14.748
/o/	Bilabial	210	133.68	17.773
	Dental	70	136.08	15.107
	Alveopalatal	71	136.61	13.499
/u/	Bilabial	128	136.59	14.820
	Dental	138	138.54	17.105
	Alveopalatal	274	136.91	17.837
	Velar	68	134.08	17.970
/i:/	Bilabial	72	132.50	17.306
	Alveopalatal	144	134.55	15.254
	Velar	71	134.70	19.798
/e:/	Bilabial	144	139.78	17.684
	Dental	70	136.80	18.511
	Alveopalatal	71	135.31	13.603
	Velar	143	137.01	16.967
/a:/	Bilabial	214	136.47	14.189
	Dental	143	137.74	14.999
	Alveopalatal	214	138.28	19.921
	Velar	143	137.99	12.921
/o:/	Bilabial	70	132.60	12.559
	Dental	72	137.90	16.574
	Alveopalatal	69	136.88	21.483
	Retroflex	71	137.06	21.501
/u:/	Bilabial	133	134.27	17.013
	Dental	70	135.89	14.411
	Alveopalatal	70	134.20	12.497

Table 4.2.7.8: Mean B2 (Hz) of vowels across preceding voicing feature of consonants

N=4320

Vowels	**Voiced consonants**			**Voiceless consonants**		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	70	134.09	13.126	71	134.16	16.852
/e/	70	136.99	11.871	141	137.60	16.280
/a/	143	137.90	16.301	69	140.50	15.525
/o/	140	133.06	17.488	140	135.50	16.781
/u/	131	136.71	16.006	203	137.00	16.831
/i:/	71	134.70	19.798	72	132.50	17.306
/e:/	213	137.37	16.074	144	139.15	19.592
/a:/	286	137.32	13.793	214	137.19	14.464
/o:/	71	137.06	21.501	142	135.28	14.919
/u:/	137	135.71	16.703	66	132.99	14.875

APPENDIX - VIII i

4.2.8 Third Formant Bandwidth (B3)

Table 4.2.8.1: Mean B3 (Hz), SD and 95% confidence interval for mean of all short and long vowels

N=4320

Vowel	n	Mean	SD	95% CI for mean	
				Lower	Upper
/i/	205	229.9	18.54	227.35	232.46
/e/	469	230.26	17.62	228.66	231.86
/a/	498	228.3	17.84	226.73	229.87
/o/	274	230.37	16.63	228.39	232.35
/u/	420	229.98	19.34	228.12	231.83
/i:/	271	229.93	14.58	228.19	231.68
/e:/	419	231.93	17.44	230.26	233.61
/a:/	649	228.91	17.95	227.53	230.29
/o:/	250	227.36	20.06	224.86	229.86
/u:/	177	229.81	17.9	227.16	232.47

Table 4.2.8.2: Mean B3 (Hz), SD and 95% confidence interval for mean values for front, central and back vowels

N=4320

Place of constriction	n	Mean	SD	95% CI or mean	
				Lower	Upper
Front	1364	230.66	17.15	229.74	231.57
Center	1147	228.65	17.89	227.61	229.68
Back	1121	229.47	18.67	228.37	230.56

Table 4.2.8.3: Mean B3 (Hz), SD and 95% confidence interval for mean for three age groups

N=4320

Vowel	Children					Adolescent					Adult				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	68	229.33	15.83	225.5	233.17	68	227.96	16.29	224.02	231.9	69	232.38	22.64	226.94	237.81
/e/	154	231.22	15.44	228.77	233.68	157	228.61	18.08	225.76	231.45	158	230.97	19.09	227.97	233.98
/a/	175	226.34	17.77	223.69	228.99	166	227.94	17.56	225.25	230.63	157	230.87	18	228.03	233.71
/o/	89	231.12	18.31	227.26	234.98	94	227.38	15.31	224.25	230.52	91	232.73	15.93	229.41	236.05
/u/	133	227.63	20.47	224.12	231.14	123	229.49	17.11	226.43	232.54	164	232.25	19.82	229.19	235.31
/i:/	91	231.11	15.17	227.95	234.27	89	228.45	14.29	225.44	231.46	91	230.21	14.3	227.23	233.19
/e:/	137	231.29	19.18	228.05	234.53	140	232.47	12.34	230.41	234.53	142	232.03	19.89	228.73	235.33
/a:/	220	227.87	18	225.48	230.26	216	229.36	14.9	227.37	231.36	213	229.52	20.58	226.74	232.3
/o:/	90	224.39	23.39	219.49	229.29	83	228.02	13.69	225.03	231.01	77	230.13	21.39	225.28	234.99
/u:/	49	231.98	16.74	227.17	236.79	63	227.85	17.42	223.46	232.23	65	230.08	19.22	225.32	234.84

Table 4.2.8.4: Mean B3 (Hz), SD and 95% confidence interval for mean values across gender

N=4320

Vowel	Female					Male				
	n	**Mean**	**SD**	**Lower**	**Upper**	**n**	**Mean**	**SD**	**Lower**	**Upper**
/i/	102	227.67	18.17	224.10	231.24	103	232.11	18.72	228.45	235.77
/e/	240	231.13	14.77	229.25	233.01	229	229.36	20.18	226.73	231.98
/a/	242	227.26	17.07	225.10	229.43	256	229.00	18.51	227.01	231.56
/o/	134	228.57	17.58	225.57	231.57	140	232.10	15.55	229.50	234.70
/u/	199	226.85	18.97	224.20	229.50	221	232.79	19.27	230.24	235.35
/i:/	130	231.36	12.25	229.24	233.49	141	228.61	16.37	225.89	231.34
/e:/	206	231.67	16.72	229.37	233.97	213	232.19	18.14	229.74	234.64
/a:/	319	228.04	16.53	226.21	229.86	330	229.76	19.21	227.68	231.84
/o:/	122	227.15	20.82	223.42	230.88	128	227.57	19.39	224.18	230.96
/u:/	73	230.09	16.38	226.27	233.91	104	229.62	18.97	225.93	233.30

Table 4.2.8.5: Mean B3 (Hz), SD and 95% confidence interval for mean values across region

N=4320

Vowel	Coastal					Rayalaseema					Telengana				
	n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean		n	Mean	SD	95% CI for mean	
				Lower	Upper				Lower	Upper				Lower	Upper
/i/	69	227.31	16.34	223.39	231.24	66	229.76	20.77	224.66	234.87	70	232.59	18.24	228.24	236.94
/e/	161	228.51	17.46	225.79	231.22	153	231.51	20.89	228.17	234.85	155	230.86	13.83	228.66	233.05
/a/	159	229.04	16.70	226.43	231.66	173	227.42	21.23	224.24	230.61	166	228.51	14.82	226.24	230.78
/o/	89	229.36	15.92	226.01	232.71	96	231.83	20.37	227.70	235.95	89	229.82	12.37	227.21	232.42
/u/	131	228.50	20.31	224.99	232.01	145	232.15	21.86	228.57	235.74	144	229.13	15.23	226.63	231.64
/i:/	91	229.15	14.42	226.15	232.15	86	231.18	18.67	227.18	235.19	94	229.55	9.75	227.55	231.54
/e:/	139	230.06	18.36	226.99	233.14	138	234.11	19.81	230.77	237.44	142	231.65	13.48	229.41	233.88
/a:/	209	226.93	19.61	224.26	229.61	216	230.55	20.78	227.76	233.34	224	229.17	12.44	227.54	230.81
/o:/	80	224.06	19.10	219.81	228.31	88	229.09	24.75	223.80	234.28	82	228.79	14.42	225.62	231.96
/u:/	59	229.25	19.10	224.28	234.23	64	229.24	20.48	224.13	234.36	54	231.09	12.82	227.59	234.59

Table 4.2.8.6: Mean B3 (Hz) of vowels preceded by different (manner of articulation) consonants

N=4320

Vowel	Manner of articulation	n	Mean	Std. Deviation
/i/	Stop	137	229.48	19.940
	Nasal	68	230.75	15.435
/e/	Stop	136	228.63	24.019
	Affricate	66	230.32	14.277
	Nasal	66	232.25	13.996
	Semi vowel	67	231.02	14.932
	Lateral	68	230.94	14.179
	Trill	66	230.11	13.916
/a/	Stop	187	228.39	18.007
	Nasal	59	228.33	16.830
	Fricative	62	223.94	20.099
	Semi vowel	127	230.43	15.377
	Lateral	63	228.03	20.145
/o/	Stop	167	230.56	17.522
	Nasal	107	230.08	15.215
/u/	Stop	201	229.68	19.981
	Affricate	106	232.12	18.536
	Fricative	54	228.86	16.775
	Trill	59	228.16	20.780
/i:/	Stop	135	228.38	15.225
	Affricate	65	230.49	14.731
	Nasal	71	232.38	12.913
/e:/	Stop	279	231.93	17.795
	Affricate	70	232.30	17.463
	Nasal	70	231.58	16.147
/a:/	Stop	402	228.70	17.907
	Affricate	66	229.34	22.156
	Nasal	118	228.31	17.240
	Fricative	63	230.89	14.565
/o:/	Stop	191	226.85	21.516
	Affricate	59	229.02	14.420
/u:/	Stop	97	231.50	16.701
	Nasal	80	227.77	19.158

Table 4.2.8.7: Mean B3 (Hz) of vowels preceded by different (place of articulation) consonants

N=4320

Vowel	Place of articulation	n	Mean	Std. Deviation
/i/	Bilabial	70	229.53	21.428
	Dental	67	229.43	18.420
	Alveopalatal	68	230.75	15.435
/e/	Bilabial	200	230.50	17.099
	Alveopalatal	200	230.46	14.059
	Retroflex	69	229.00	26.482
/a/	Bilabial	123	230.13	16.716
	Alveopalatal	250	227.41	17.761
	Velar	125	228.30	19.017
/o/	Bilabial	154	231.45	17.545
	Dental	61	230.40	16.274
	Alveopalatal	59	227.52	14.309
/u/	Bilabial	60	230.61	23.195
	Dental	109	228.05	18.263
	Alveopalatal	219	230.25	18.766
	Velar	32	233.51	19.072
/i:/	Bilabial	69	231.39	13.375
	Alveopalatal	136	231.48	13.793
	Velar	66	225.23	16.463
/e:/	Bilabial	140	232.79	17.970
	Dental	70	229.15	17.101
	Alveopalatal	70	232.30	17.463
	Velar	139	232.29	17.090
/a:/	Bilabial	189	226.54	18.487
	Dental	133	230.09	19.018
	Alveopalatal	191	230.35	17.992
	Velar	136	229.04	15.775
/o:/	Bilabial	62	226.99	27.519
	Dental	66	225.41	19.782
	Alveopalatal	59	229.02	14.420
	Retroflex	63	228.23	16.100
/u:/	Bilabial	74	228.61	16.857
	Dental	60	232.64	17.652
	Alveopalatal	43	227.92	19.829

Table 4.2.8.8: Mean B3 (Hz) of vowels across preceding voicing feature of consonants

N=4320

Vowels	Voiced consonants			Voiceless consonants		
	n	**Mean**	**SD**	**n**	**Mean**	**SD**
/i/	67	229.43	18.420	70	229.53	21.428
/e/	66	232.25	13.996	136	228.63	24.019
/a/	128	229.26	17.031	59	226.51	19.988
/o/	103	233.55	14.292	112	228.95	19.234
/u/	86	228.27	16.443	115	230.74	22.276
/i:/	66	225.23	16.463	69	231.39	13.375
/e:/	208	230.51	16.887	141	233.85	18.139
/a:/	262	228.24	17.636	196	228.40	18.327
/o:/	63	228.23	16.100	128	226.17	23.762
/u:/	97	230.71	18.099	37	229.64	15.079

APPENDIX – IX :

Letter seeking administrative permission

Manipal College of Allied Health Sciences
A constituent college of Manipal University

Manipal
7th February, 2005

permitted
07/02/2005
Dean & HoD

DEAN
Manipal College of Allied Health Sciences
Manipal University, MANIPAL - 576 104

To
The Dean
Manipal College of Allied Health Sciences
MAHE, Manipal

Through
The HoD
Department of Speech and Hearing
Manipal College of Allied Health Sciences
MAHE, Manipal

Dear Sir,

Sub: Permission to conduct the study

I would like to request you to permit me to conduct my PhD research project titled "Acoustic characteristics of vowels in Telugu" at department of Speech and Hearing, MCOAHS.

As a part of this study, I will be visiting different schools and institutions to record speech sample from the participants after obtaining their consent. I request you to kindly introduce me to concerned head of the institutions. Your kind help is much appreciated.

Thanking you

Yours sincerely

Y. Krishna

Krishna. Y
Sr. Grade Lecturer
Dept., of Speech and Hearing
MCOAHS, Manipal

Manipal – 576 104, Karnataka, India. Phone : 91 820 2922704, 2922705, 2922771 Fax: 91 820 2571915
Email: office.coahs@manipal.edu Website: www.manipal.edu

APPENDIX – IX :
Consent form for participants of the study

Consent form for participants of the study (English)

I ___________________________________ (participants name) agree to participate in the research project on “Acoustic characteristics of vowels in Telugu” being conducted by Mr. Krishna. Y, who is PhD student and faculty of Manipal College of Allied Health Sciences, Manipal University, Manipal.

I understand the purpose of this study is to investigate the acoustic characteristics of vowels in Telugu language. This will help in obtaining normative data across the age, gender and regions. This will be achieved by analyzing the speech sample recorded.

I understand that my participation in this research will involve 10 to 15 minutes for recording the speech sample. I also understand that this will not cause any risk or harm to me or to my work.

I am aware that I can contact Mr. Krishna. Y (@ 0820 2922748) if I have any concerns about the research. I also understand that I am free to withdraw my participation my participation from this research project at any time I wish and without giving a reason.

I agree that the research data gathered from this project may be published in form that does not identify me any way.

______________________________ __________
Signature of Participant/Guardian Date

Consent form for participants of the study (TELUGU)

నేను ___________________________ (పేరు) మనిపాల్ కాలేజ్ ఆఫ్ అల్లైడ్ హెల్త్ సైన్స్ లో పని చేస్తున్న శ్రీ క్రిష్ణ గారు చేస్తున్న రీసర్చ్ లో పాల్గొనడానికి సమ్మతిస్తున్నాను.

నాకు ఈ రీసర్చ్ గురించి అవగతము అయింది. తెలుగు వోవల్స్ యొక్క అకోస్టిక్ పలితలను, వాటిని రికార్డు చేసి అనలసిస్ చేయడము వలన లభ్యమగును.

నేను శ్రీ క్రిష్ణ గారిని (0820 2922748) ఫోను ద్వరా ఎప్పుడైన ఈ రీసర్చి గురించి మాట్లాడ వచ్చున్. నేను ఈ రీసర్చినించి ఏ కారణములేకుండా బయటకు రావచ్చును.

ఈ రీసర్చి ద్వార వచ్చిన ఫలితాలను నా యొక్క అనన్యతను తెలుపకుండా ముద్రణ చేయడానికీ వొప్పుకోంటున్నాను.

______________________________ __________
Signature of Participant/Guardian Date