FORMANT FREQUENCIES OF VOWELS

IN TULU

Manisha Hegde

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

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ALL INDIA INSTITUTE OF SPEECH AND HEARING

MANASAGANGOTHRI, MYSORE-570 006

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CERTIFICATE

This is to certify that this dissertation entitled ***"Formant Frequencies of Vowels in Tulu"*** is a bonafide work submitted in part fulfilment for degree of Master of Science (Speech-Language Pathology) of the student Registration Number: 13SLP014. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore
May, 2015

Prof. S.R. Savithri
Director
All India Institute Of Speech and Hearing
Manasagangothri, Mysore-570006

CERTIFICATE

This is to certify that this dissertation entitled ***"Formant Frequencies of Vowels in Tulu"*** has been prepared under my supervision and guidance. It is also been certified that this dissertation has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore

May, 2015

Guide

Prof. S.R. Savithri

Director

All India Institute Of Speech and Hearing

Manasagangothri, Mysore-570006

DECLARATION

This is to certify that this dissertation entitled ***"Formant Frequencies of Vowels in Tulu"*** is the result of my own study under the guidance of Prof. S.R. Savithri, Director, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier to any other University for the award of any other Diploma or Degree.

Mysore, ***Registration No. 13SLP014***

May, 2015

Dedicated to,

Sujatha Hegde (Amma), Kishore Hegde (Poppa),

Anudeep Hegde (Anna)

And

Savithri Ma'am

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CHAPTER I

INTRODUCTION

Speech is a unique form of communication in which the speech waves in the form of acoustic energy transmits the information. The interaction of one or more source with the vocal tract filter system results in speech waveforms (Fant, 1960). Speech sounds are most commonly divided into vowels and consonants. A vowel sound is usually formed as sound energy from the vibrating vocal folds escapes through a relatively open vocal tract of a particular shape. Each vowel has a specific, characteristic vocal tract shape which is determined by the position of-the tongue, jaw, and lips. Vowels can be distinguished from consonants based on the patterns of acoustic energy they exhibit. Vowels demonstrate at least two formant areas, as they are highly resonant. Thus, vowels are more intense compared to consonants (Ladefoged & Johnson, 2010; Buaman-Waengler, 2012).

Acoustically, vowels can be classified based on the formant pattern, shape of the vocal tract, spectrum, and duration. The peaks of the sound spectrum are called as formants. The frequencies of such peaks are termed formant frequencies. Formant frequencies of vowels are dependent on tongue height or tongue advancement. As the height of the tongue increases, the frequency of the first formant (F_1) decreases, and the second formant frequency (F_2) is directly related to the tongue advancement/position (Fant, 1960). The oral cavity would be roughly divided into two cavities during the production of vowels - front cavity and back cavity. The space in the oral cavity space in front of the articulatory constriction is referred to as front cavity and the space behind the articulatory constriction is referred to as back cavity. Though erroneously, to a large extent, F_1 depends on the volume of the back cavity and F_2 largely depends on the front cavity volume (Fant, 1960). Thus, one would expect a high first formant frequency if the tongue is positioned low at the back of the oral tract. Also, high formant frequencies can be expected in oral tracts that are smaller in size.

The vowels of English can be categorized in a number of ways: with respect to tongue position (Front, back, central, high, mid and low); with respect to lip rounding (rounded or unrounded); with respect to tenseness (tense vowels-longer in duration and involves greater degree of muscular tension and lax vowels-relatively short and involves less muscular effort). In standard production, vowels are voiced and non-nasal. However, vowels are sometimes devoiced, as in whispered speech and nasalized, when they precede or follow nasal consonants (Bernthal & Bankson, 1993).

All the languages of the world include the primary cardinal vowels that are the simplest to describe and analyze acoustically. The development of the speech articulators involved in the production of speech sounds occur gradually over the period of life span, and there are anatomical differences among different ages, genders and races, which contribute in producing various vocal quality. Along with the structural variations, the phonological, linguistic and syntactic rules of each language further adds on to the speech sound complexity. A number of studies (Mermelstein, 1967; Fitch & Giedd, 1999; Vorperian & Kent, 2005; Mugitani & Hiroya, 2012) have been conducted to investigate the development of speech motor control, vocal tract configuration and vocal tract development. Acoustic analysis of speech sounds is a non-invasive and indirect technique to study the changes in anatomy, motor control and phonological functions (Baken & Orlikoff, 2007). Vowels in different languages, even though different, are sometimes perceived as same (Ladefoged, 1975). The subtle differences can be studied by acoustic analysis of speech sounds of different languages.

During production of a vowel, the vocal tract behaves like a tube open at one end (the lips) and closed at the other end (the glottis, during vocal fold adduction) with uniform diameter. The lowest frequency at which such a tube resonates will have a wavelength 4 times the length of tube. The tube resonates at every odd multiple of that frequency. The maximum velocity of air molecules is at the lips. At the glottis, pressure is high but velocity is at a minimum. In general, constrictions at points of maximum pressure increase the resonant frequency and constrictions at the point of maximum velocity decrease the resonant frequency. Frequencies of lower resonances in the vocal tract or formants are the most affected by the changes in mouth opening. Speech sounds produced with small mouth openings have low first formant frequency. The second formant is most affected by the changes in size of the oral cavity. The third formant is affected by the front versus back constriction. The vocal tract is a variable resonator and changes the frequency of formants owing to changes in its shape due to changes in placement of articulator, and thus produces a variety of sounds.

Previous studies (Peterson & Barney, 1952; Busby & Plant, 1995; Chen & Wang, 2011, among others) on vowels have shown that the formant frequencies of vowels vary due to a number of variables, such as: gender, age, context, and influence of other known languages. Peterson and Barney (1952) studied English vowels in adults and children and reported that acoustic values vary markedly with age and gender characteristics of speakers. Busby and Plant (1995) studied the frequencies of first three formants (F_1, F_2, and F_3) and fundamental frequency of 11 non-diphthong vowels of Australian English produced by 40 preadolescents. The results indicated that, the F0 values decreased as age increased, but there was no difference between females and males. Formant frequencies (F_1, F_2, and F_3) decreased as the age increased, and the values for females were higher than those for males. Chen and Wang (2011) measured and analyzed first two formant frequencies of Chinese (Mandarin) and English vowels and concluded that American English and Chinese English are different in terms of vowel height and frontness. The authors concluded that, Chinese English and Foreign Language students pronounce Chinese vowels and English vowels in the similar way. These students had a tendency to move vowels closer to the front positions and higher.

Acoustic characteristics of vowels are also studied in many Indian languages. Khan, Gupta and Rizvi (1994) analyzed formant frequencies of Hindi vowels in /hVd/and C1VC2 contexts in three subjects and it was observed that the vowel formant variations were not significant for both contexts and speakers. The vowel consistency for the female speaker was better than the vowel consistency for the male speakers. Sreedevi (2000) reported higher F_1 in boys and girls compared to adult and adolescent males in Kannada. Krishna (2009) studied the acoustic characteristics (spectral and temporal) of vowels in Telugu language and found that in the context of different consonant features (place, manner and voicing and regional variations) the formant frequencies showed a lot of variation. He also reported that children had higher formant frequencies followed by adolescents and adults and higher formant frequencies were noticed in females compared to males. Narang, Misra and Kakoti (2013) studied the acoustic features (duration and formant frequency) of Kashmiri vowels and the results indicated that formant frequencies are also qualitatively different in contrasting long and short vowel.

With latest advances in the management of various communication disorders, knowledge about the acoustic characteristics of speech sounds in every language, dialects, age group, and gender will help the professionals in assessment, diagnosis and management of individuals with impaired communication. There is dearth of literature and scarcity of comprehensive data describing the acoustic characteristics of vowels in Tulu language ["Tulu language is considered as one of the five Dravidian languages; other four being Telugu, Tamil, Kannada and Malayalam. It is spoken in Udupi district and Dakshina Kannada district of Karnataka state and also spoken in the northern part of Kerala state. In India, 1.72 million people speak it as their native language, which is increased by 10 percent over the 1991 census (census 2001)]. There is no literature which explains about the changes in formant frequencies across gender and age in Tulu language. Hence the present study aimed at analyzing the frequencies of first two formants of 10 vowels in Tulu and measured the main effect of age and gender. The objectives of the study were to (a) investigate the frequencies of first two formants of Tulu vowels, (b) determine the effect of age (4-5years, 7-8years, 18-20 years) on frequencies of first two formants of Tulu vowels, (c) determine the effect of gender (males and females) on frequencies of first two formants of Tulu vowels, and (d) determine the effect of position and length on the frequencies of the first two formants of Tulu vowels.

CHAPTER II

REVIEW OF LITERATURE

The review will be discussed under the following headings:

1) Speech sounds and vowel classification
2) Developmental changes in the vocal tract
3) Tulu language and its sound system
4) Frequencies of Formants of vowels
5) Clinical relevance of formant frequencies

1) Speech sounds and vowel classification

Humans use speech as their primary mode of communication. Most of the reasons relate to the fact that speech was selectively advantageous in the evolutionary history of *Homo sapiens.* Efficient and redundant speech is produced by the human vocal tract. Speech is efficient due to the conveyance of information more quickly as compared to other channels of communication and is redundant, because speech signals allow listeners to understand messages even when they are not completely heard. Speech sounds are broadly classified as vowels and consonants. Vowels are most commonly described based on relative position of constriction in the oral cavity, height of the tongue, lip rounding, position of soft palate, length, tenseness of articulator, and relative pitch as follows:

1. Front, Back, Central –depending on relative position of the constriction in the oral cavity
2. High, Low, Mid – depending on relative height of the tongue

3. Rounded, Spread, Unrounded –depending on the relative position of the lips
4. Nasal and Oral – depending on the position of the soft palate
5. Long and Short– depending on the phonemic length of the vowel
6. Tense and Lax – depending on the tenseness of the articulator
7. High, Low, Mid– depending on the relative pitch of the vowel.

Fant (1960) explained the vowel production using the source filter theory, according to which, filtering action of the vocal tract on the pulses of air produced by the glottis results in vowels. The vowels produced are complex acoustic signals with both frequency and amplitude information. Thus the vowels can be depicted in the form of a spectrum

Acoustically, vowels are usually described by its formant pattern, spectrum, fundamental frequency, duration, bandwidth, and amplitude. Among these, the parameters that are believed to help in the vowel perception are formant pattern, fundamental frequency and duration (Pickett, 1980). In most of the languages low mid vowel /a/ has the highest F_1, front high vowel /i/ has the highest F_2 and back high rounded vowel /u/ has the lowest F_2.

2) Developmental changes in the vocal tract

Human vocal tract evolves over a period of lifespan, that is, from the time of birth to adulthood. It is a known fact that, vocal tract of an infant is not simply a miniature form of vocal tract of an adult (Negus, 1949). Therefore, there will be no uniformity in the developmental trajectory and each vocal tract segment is expected to grow in a different way at different timing and between genders with male laryngeal structures larger than that of female (Kahane, 1978; Vorperian & Kent, 2009). The most apparent difference between the vocal tract of a child and an adult is the length. The vocal tract length ranges from about 8 cm in newborns to about 17 cm in adults. The soft palate and the epiglottis are in very close proximity each other. During postnatal development, larynx along with hyoid bone descends slowly and the bend at the oropharyngeal channel forms a right angle. Between the age of 3 to 5 years, the structural development of speech articulators occurs most rapidly and then, the development of larynx is slow until puberty (Eguchi & Hirish, 1969).

In humans, from the commencement of babbling until adulthood, substantial modifications appear in the speech production system. As a result of the overall development, the ratio of the horizontal oral cavity length versus the vertical pharynx length changes from 2:1 in infancy to approximately 1:1 in adulthood (Goldstein, 1980). Structural changes, and refinement in motor control, produce varied acoustic patterns. The formant frequencies in children differ by virtue of sexual dissimilarity in jaw opening, pharynx size, and larynx position (Bennett, 1981). The quality of vowel is determined by the shape of the cavities of the mouth, nose, pharynx, and position of tongue, lips and soft palate. For different vowels, the length of the vocal tract varies and brings about variation in the resonance frequencies. Longer the vocal tract, lower the resonance frequencies and shorter the vocal tract, higher the resonance frequencies.

The morphology of the ‘‘vocal tract’’ is of crucial importance in the production of human speech, because the shape of the vocal tract decides the different articulatory possibilities, and thus, likely formant patterns in speech (Chiba & Kajiyama, 1941; Stevens & House, 1955; Fant, 1960; Lieberman &

Blumstein, 1988; Titze, 1994). Traditionally, radiographic techniques studies were conducted to find out the interaction between vocal tract shape and speech acoustics (e.g., Fant, 1960; Perkell, 1969; Holbrook and Carmody, 1937). But the potential health hazards of exposure to ionizing radiation have typically restricted these investigations to small sample sizes, both in terms of articulatory positions and subjects. Figure 1 shows the vocal tract of an infant and an adult male.

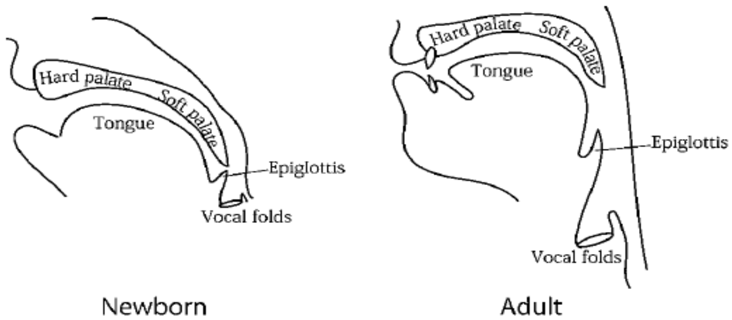


Figure 1: Vocal tracts of a newborn and an adult male (Source: Fitch & Giedd, 1999).

Fitch and Giedd, (1999) attempted to study the morphology and vocal tract development using Magnetic resonance imaging in 129 normal humans, (53 females and 76 males) aged between 2–25 years. Exclusion criteria for this study were congenital anomalies, or history of speech delay or language impairment, in the subject or first degree relatives of the subject. The subjects were instructed to lie motionless and to breathe quietly during the scanning procedure. Using computer graphic techniques, morphometric data, including midsagittal vocal tract shape, length, and proportions, were collected. Results reveal significant positive correlation between the length of the vocal tract and body size (height or weight). The authors reported that lip, tongue blade, tongue dorsum, and velum segments increase in size by an average of 12% between childhood and puberty, and only upto 5% between puberty and adulthood, whereas the pharynx length increases by 22% between childhood and puberty and by 25% between puberty and adulthood. There were clear differences in morphology of male and female vocal tract, including changes in overall length of vocal tract and the relative proportions of the oral and pharyngeal cavity. These gender differences were not apparent in children, but emerged at puberty, implying that they were part of the vocal remodelling process that appears during puberty in males. The findings of this study have implications in speech forensics, speech recognition, and the evolution of the human speech system.

Literature is well stocked with studies conducted on the developmental variations occurring in vocalization of human beings throughout the life span. During the first year of life, infant's vocalization is mostly vowel production. Vowels are the first sounds to be learned by the infants, and they acquire majority of the vowels during the second quarter of the first year. In a study done on English speaking American individuals, to know the age related changes in vocal tract and its effects on acoustic parameters. The length of the oral cavity and its volume in elderly individuals has been found to be considerably increased as compared to younger individuals (Xue & Hao, 2003).

"From literature, it may be inferred that establishment of a language-relevant acoustic delegation can be expressed from vowel development. Formants (F1-F3) are highly sensitive to variation, with respect to age and gender; slow decrease in formant frequencies; decrease in F1-F2 area; reduction in variability of formant frequency. By 4 years of age, there is a appearance of variation in formant frequencies between genders, which becomes more evident by 8 years and distinct by 16 years of age. There is also decline in fundamental frequency following first year of life, with quick decline during childhood (birth to 3 years) and adolescence" (Vorperian & Kent, 2007).

3) Tulu language and its sound system

Tulu language is one among the Dravidian language and came into existence about 3000 years ago. It is spoken in Udupi district, Dakshina Kannada district of Karnataka state and also spoken in the northern part of Kerala state. Tulu has a script of its own and it has originated from Aryezhuttu. Malayalam and Tulu script has a common origin and thus, the scripts of the two languages bear similarity (http://en.wikipedia.org/wiki/Tulu_language). There are four different dialects of Tulu language, which are largely similar, with little variations. The dialects are:

1. **Common Tulu**: Spoken by most of the people. This dialect is used primarily for inter-community communication.
2. **Brahmin Tulu**: Used by Tulu Brahmins and is influenced by Sanskrit.
3. **Jain Dialect**: Used by the Tulu Jains. It is a dialect where the letter 'H' replaces the initial letters 'S and 'T'.
4. **Harijan Dialect**: Used by the Tribal classes and Harijan.

Tulu has a rich vocabulary and many linguists consider it as a highly developed language with 34 consonants and 14 vowels (/a/, /a:/, /i/, /i:/, /u/,

/u:/, /e/, /e:/, /ai/, /o/, /o:/, /au/) constituting the phonemic system of Tulu (Ullal, 2012). Tulu has /æ/ or /ɛ/ like vowel, usually occurring in the word-final position. Neither Tulu script nor Kannada script has a symbol to explicitly represent this particular vowel, which is usually written as /e/. For instance, the first person singular and the third person singular masculine form of a verb are spelled similarly in all the three tenses (ending in /e/) but are pronounced differently. Especially in nouns, when /e/ occurs in the final position, it is pronounced as /æ/. Additionally, Tulu has an schwa /ə/ (/ɯ/-like vowel). In the Kannada script, Brigel (1872), used a vira:ma (halant), ್, represent this vowel.

4) Frequencies of Formants of vowels

The word formant has its origin in the German language, which was first introduced in the 19th Century, by Physicist Hermann. According to Singh & Singh (1979), a formant frequency is the significantly amplified frequency region for a extended period of time. The physical properties of the vocal tract are displayed by the peaks in the spectrum. The formants of a speech sound are called as the F1 (first formant), F2 (second formant), F3 (third formant) and so on.

Formant frequencies are affected by the configuration of the vocal tract. It has been assumed from past research that the first formant is concerned with the back cavity and the second formant is concerned with the front cavity of the mouth, though erroneously (Joos, 1948). Usually, frequency of all the formants decreases as the vocal tract length increases. There is a decrease in formant frequencies as the lip constriction increases. First formant decreases and the second formant increases with the elevation of the anterior part of the tongue. Elevation of the back of the tongue reduces the second formant. First formant frequency increases with narrowing of pharynx. Formant frequencies of oral vowel are higher than that of nasal vowels, and females have higher formant frequencies than males. Constriction in the anterior end of the vocal tract contributes to lower F_1 and higher F_2, and constriction in the posterior end of the vocal tract contributes to lower F_1 and moderate F_2.

A number of studies have been conducted to study the formant frequencies in different languages of the world. Initial attempt was made by Peterson and Barney, in 1952, which has been considered as the classic study. For any of the vowels, there is no set of absolute values for the formant frequency. This is because vocal tracts of different size and length resonate to different frequencies. Peterson and Barney, measured the formant frequencies of 76 American English speakers (33 men, 28 women and 15 children). A list of ten monosyllabic words each beginning with /h/ and ending with /d/ and differing only in the vowel was presented to the speaker and the utterances were recorded with a magnetic tape recorder. The words were analyzed using sound spectrograph. Frequency and amplitude of the first three formants and fundamental frequency were measured. The average formant frequencies for the three groups are shown in table 1.

		I	I	E	æ	A	ɔ	U	u	ʌ	ɝ
Fundamental	**M**	**136**	**135**	**130**	**127**	**124**	**129**	**137**	**141**	**130**	**133**
Frequencies	**W**	**235**	**232**	**223**	**210**	**212**	**216**	**232**	**231**	**221**	**218**
(CPS)	**Ch**	**272**	**269**	**260**	**251**	**256**	**263**	**276**	**274**	**261**	**261**
Formant Frequencies (cps)	**M**	**270**	**390**	**530**	**660**	**730**	**570**	**440**	**300**	**640**	**490**
F_1	**W**	**310**	**430**	**610**	**860**	**850**	**590**	**470**	**370**	**760**	**500**
	Ch	**370**	**530**	**690**	**1010**	**1030**	**680**	**560**	**430**	**830**	**560**
F_2	**M**	**2290**	**1990**	**1840**	**1720**	**1090**	**840**	**1020**	**870**	**1190**	**1350**
	W	**2790**	**2480**	**2330**	**2050**	**1220**	**920**	**1160**	**950**	**1400**	**1640**
	Ch	**3200**	**2700**	**2610**	**2320**	**1370**	**1060**	**1410**	**1170**	**1590**	**1820**
F_3	**M**	**3010**	**2550**	**2480**	**2410**	**2440**	**2410**	**2240**	**2240**	**2390**	**1690**
	W	**3310**	**3070**	**2990**	**2850**	**2810**	**2710**	**2680**	**2670**	**2780**	**1960**
	Ch	**3730**	**3600**	**3570**	**3320**	**3170**	**3180**	**3310**	**3260**	**3360**	**2160**

Table 1: Averages of Formant frequencies of vowels (Source: Peterson &Barney, 1952)

The results revealed that, there are significant differences in frequencies of the first three formant, among the groups for each vowel. Nonetheless, vowels are remarkably similar in relative positions, in an F1 by F2 formant plot. Figure 2 shows the F1 by F2 formant plot.

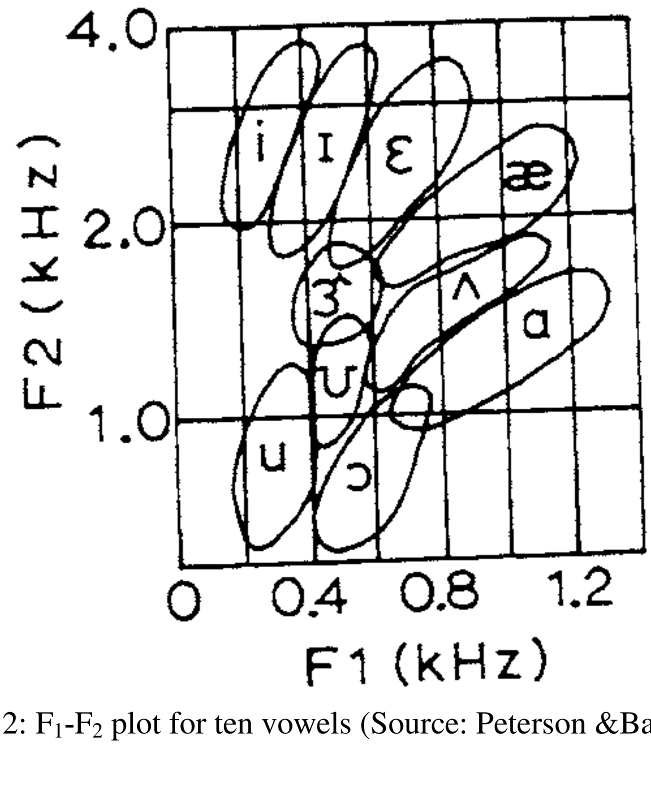


Figure 2: F_1-F_2 plot for ten vowels (Source: Peterson &Barney, 1952)

As expected, lower resonant frequencies were produced by larger vocal tracts than the smaller ones. Thus, children have the highest formant frequencies and men have lowest formant frequencies, whereas women have intermediate values. The differences in formant frequency, are not simply attributed to the differences in overall dimensions of the vocal tract, but to the fact that women and children have a relatively smaller ratio of pharyngeal area to oral cavity compared with those of the men.

Stevens and House (1963) investigated the formant of American English Vowels. Words with 8 common American English vowels embedded between 14 consonants were used in the study. The formant frequencies were extracted using Spectrum – matching procedure. Results revealed that, the first formant shifts are quite small. For front vowels, there is a downward shift in F2 due to the consonantal environments and the shift is noticed to a larger extent for lax (short vowels) compared to tense vowels. The consonantal environment surrounding the vowels also brought about considerable differences in the vowel formant frequencies between speakers. The authors found that different consonantal contexts affected the formant frequencies of vowels and that they varied significantly from one to another. Yet another observation was that, the consonantal context causes orderly shifts in the formant frequencies based on the place of articulation, manner of articulation, and voicing characteristics of the consonant.

Majewski and Hollien (1967) analyzed formant frequencies of six polish vowels (/i, i•, e, a, o, and u/) and these vowels were produced in two ways: (a) sustained vowels for approximately 1 second and (b) in CVC contexts, vowels embedded within /b/ and /t/ consonants. Meaningful words were chosen as the stimuli and there were 28 samples of each vowel produced by the subjects. The subjects were native speakers of Polish and there were seven men and 7 women. None of them exhibited any speech or voice disorders. The subjects were adults and the mean age for males was 40 years and mean age for females was 32years. The samples were analyzed spectrographically and the formant frequencies (first two formants) were determined. The results revealed some differences among talkers and for the different types of vowel production but the differences were not significant. Another method was employed wherein, the formant frequency regions were determined for synthetic vowels that were classified by the polish listeners. 69 synthetic vowels were presented twice to the listeners and they were instructed to write the symbol for the vowel that was perceptually similar to one of the Polish vowels. The listeners consisted of same group of people who took part in the previous experiment. The comparisons between the formant frequencies obtained using two methods showed good agreement. A reasonably good agreement was noted between the formant frequency values for Polish vowels and the analogous American English vowels. Authors concluded that the data provided by this study, and its relation to other similar studies, gives a reasonably accurate identification of the first two formants of the six vowels in the Polish language.

Eguchi and Hirish (1969), analyzed the first and second formant frequencies of English vowels across age groups and reported that, the first two formants decreased rapidly from 3 years to 5 years of age. Decrease in second formant frequency was greater than the first formant frequency. First formant did not vary much with respect to age. Anterior cavity development had greater effect as compared to posterior cavity development. Structural and psycho-physiological development had a great influence on the variations in frequencies of the formant.

Kent (1976) reported that, the formant frequency values of children are higher than that of the values obtained for adult females. Adult males have the lowest formant frequency values as compared to that of children and adult females.

Purcell (1979) examined formant frequencies of Russian vowels in two males and two females. The subjects were native speakers of Russian and the stimuli consisted of 150 nonsense words consisting of the six vowels in all combinations, followed by one of /b/, /d/,d /g/ or their palatized counterparts followed by the six vowels. The resulting 150 words were read twice by the subjects and they were instructed to read both the vowels in each utterance as unreduced and not to place any special stress on either vowel. The frequencies of the first two formants were measured at four different points:

1. In the steady state portion of the first vowel.
2. At the transition from vowel to consonant of the first vowel.
3. At the transition from the consonant to vowel of the second vowel.
4. In the steady state portion of the second vowel.

The formant frequencies were estimated using the linear prediction algorithms. The results indicated that for the first formant frequencies, the vowel height of second vowel does not affect the first formant transition at TV1 but the vowel height of first vowel affects the value of the first formant at TV1. For the second formant frequencies, the vowel opposite to the transition has no effect, only the vowel adjacent to the transition has an effect.

Busby & Plant (1995) conducted a study to investigate the age and gender related differences in formant frequencies of Australian English vowels produced by preadolescent girls and boys. Forty native speakers of Australian English each were considered in four age groups. Each subject was instructed to produce 11 test words containing vowels of Australian English. F1, F2 and F3 were estimated using digital sonograph which was then adjusted to produce spectrograms. The authors reported that there is a systematic decrease in F1 and F2 values with advancing age for most of the vowels and were more marked in younger age groups. The F3 values decreases with increase in age and girls have higher values than boys. There were gender differences recorded for lower vowels.

Hillenbrand, Getty, Clark, and Wheeler (1995) designed a study to replicate one of the initial attempts to study vowel acoustics conducted by Peterson and Barney in 1952. Recordings were made in /hVd/ context spoken by 45 men, 48 women and 46 children. The subjects were native speakers of American English and they were screened for dialectical variations. The subjects were instructed to read the words containing 12 vowels. The measurement of formant frequencies, fundamental frequency, vowel duration and steady state duration was done using the Linear Prediction Curve and the gray scale spectrogram. Vowel identification task was also carried out where 20 undergraduate and graduate students were chosen as listeners. They were presented with words that were low pass filtered at 7.2kHz and were instructed to identify. The results obtained were in good agreement with that of the study conducted by Peterson and Barney (1952). They authors concluded that vowel cannot be separated well only on the basis of single sample of F1 and F2 patterns. Adding vowel duration to the formant patterns improves the classification accuracy of vowels to a modest level.

Significant gender differences in F1 and F2 were noted in few studies. In English, around the age of 11 the gender difference in formant frequency and fundamental frequency patterns begin and is complete by the age of 15; however, this trend was not observed in Hebrew language (Most. et al., 2000).

Watson, Palethrope and Harrington (2004) studied the vowels in New Zealand English and they reported that, there is lowering of first formant over the age. Speech of individuals changes over a period of time in agreement with general population. The researchers attributed these changes due to structural variations in the vocal tract.

Hawkins and Midgley (2005) studied the effect of pronunciation on changes in the spectral characteristics (formant frequencies). This study targeted the RP accent which has been changing over a period of time. The authors studied the formant frequencies of vowels in stressed monosyllables. Five subjects were chosen in four different age groups (20-25years, 35-40years, 50-55years, 65-73years) who were RP speakers (standard British accent). To bring about vocal tract normalization, only male speakers were chosen for this study. The RP vowels were placed in the /hVd/ context to produce words and the speakers were instructed to read them aloud with a short pause between words and in a falling intonation. The target words were randomized with other filler words to encourage natural pronunciation. The first two formants were measured at steady state of each vowel using acoustical analysis. Measurement of the formant frequencies of vowels highlight a progressive trend for F1 to be high in /ε/ and /æ/, and for F2 to be high in /u:/ and /ʊ/. No change in formant frequency can be attributed to differences in a single articulatory parameter on the basis of only acoustic measurements.

Butcher (2006) studied speech samples of 92 females (natives of South Australia) were collected over a period of 5 years with a mean age of 22.3years. The vowels, both monophthongs and diphthongs were embedded in the /h-d/ context and the subjects were asked to read three token of each vowel from randomized lists. The first two formants were extracted from the LPC display (measurement points displayed by the spectrograms). The results were then compared with another study done by Cox, 2006 in the New South Wales state, East Australia. It seems likely that SA speakers are more traditional (fronting of two monophthongs, /u/ and /ɜ/ and the raising of /e/) when it comes to articulation as compared to NSW speakers. Among the diphthongs, there appears to be a common trend for closer articulations (lower F1 values). The other differences are that, the four vowels in SA are closer to a greater degree than in NSW, but the variations are so large that they probably should not be attributed to the general trend of (phonetically) closer articulation, but rather to (phonologically) different targets.

Man (2007), studied formant patterns in the vowels, diphthongs and triphthongs in Meixican Hakka Chinese language in male and female speakers. The first and second formant frequency values produced by females were higher than that of male speakers. The results suggested that vowel /i/ is more variable. The authors also suggested that the relative distance between the high vowels and mid vowels is larger for females as compared to the male speakers in the vowel ellipses.

Lee & Iverson (2008), studied the developmental variations of formant frequencies in Korean vowels produced by female and male children (5 and 10 years of age). The results revealed that formant frequencies decrease with increasing age and there was a significant difference in formant frequency values between males and females. The comparison of the data with the English data revealed that, the formant values varied for vowel /a/ among the different age groups, which was similar to that of English. Thus, suggests a more universal developmental pattern in production of vowel.

Chen, Cheng and Hsu (2013), conducted a longitudinal study to investigate the developmental changes. Two Mandarin speaking children, a boy and a girl, were audio recorded during daily natural conversation and picture naming task, from birth to 9 years, once every three months. The first two formant frequencies were measured using FFT, LPC, narrow and wide band spectrogram. The results revealed that the male subject had lower formant frequencies as compared to the female subject. There was a continuous decrease in frequency of the two formants till 9 years of age. In the female subject, an obvious decrease of frequency of the formants was observed. The F1 values were more stable as compared to the F2 values in both the subjects. Hence it was inferred that the tongue movements are acquired earlier than the jaw movements. F2 values of /i/ and /u/ vowels displayed high variability till 9 years of age.

There have been a lot of studies in Indian languages. Jensen and Menon (1972) studied formant frequencies of vowels in Malayalam and reported that the F1 and F2 formants showed relatively small variation between the long and the short vowel pairs. They also reported a systematic relationship between /a/ versus /a:/ and /u/ versus /u:/ vowel pairs only and not among other vowel pairs.

Kushalraj (1983), conducted a study in Kannada language in children in four different age ranges between 4-12yrs to investigate the speech development. The results revealed that there were no significant gender differences in terms of formant frequencies. Vowel /a/ had the highest F_1 among all vowels and vowels /i/ and /u/ had the highest F_2 and F_3 frequency. No systematic variations were noticed in formant frequencies of all the vowels with increase in age.

Khan, Gupta and Rizvi (1994) investigated the formant frequencies of ten Hindi vowels in /hVḍ/ and C1VC2 contexts. Twenty words were recorded from two male and one female speaker through a reading task. First four formant frequencies of the vowels were determined using the broadband spectrograms. Authors reported that formant frequency variations were similar in both the contexts. There were no significantly large variations for any of the speakers. They also noticed that the vowel consistency of male speakers were poor compared to that of the female speaker.

Tiku (1994), studied the acoustic characteristics of 29 vowels in Kashmiri language. Five males and five females were considered for the study in the age range of 18-25 years. The subjects were instructed to read the meaningful words (CVC combination) embedded in a carrier phrase. The first four formant frequencies of target vowels were extracted from the speech spectrogram. The results revealed that females had higher formant frequency values as compared to that of males. The long and short vowels in Kashmiri were significantly different and the nasal vowels had lower formants compared to oral vowels.

Ampathu (1998), in her study, including a wide age range (7-8yrs, 40-45yrs, 20-25yrs, 70-80yrs), reported that in children, the formant frequency values were higher and word duration were longer as compared to adults in Malayalam language. The formant frequency values reduced and word duration increased in the geriatric population.

Reddy (1999) studied the coarticultion in Telugu language and reported that quality of vowel and formant frequencies changed based on the nature of vowel in the next adjacent vowel. The F1 and F2 of the /a/ vowel decreased when followed by the vowel /i/ and decreased even more with /u/ compared to vowel /a/. F3 decreased when followed by the vowel /i/ and increased when followed by the vowel /u/. The variations in the formant frequency values were dependent on the backness and height of the first vowel.

Sreedevi (2000) studied the Kannada vowels and reported that female children had significantly lower F1 (3% lower) than male children. Adolescent females had 7% higher F1 and adult females had 11% higher compared to males. F2 in female speakers was markedly higher than males across age ranges. She reported a linear decrease in F3 with age (children to adults) and significant decrease in adults in both the genders. It was also reported that, with increase in age the formant frequency values decreased and it was not attributed only to the structural variations but also to pharyngeal to oral cavity area.

Riyamol (2007), studied vowels spoken by Malayalam adult speakers and reported that males had lower formant frequency values as compared to that of females which is in correspondence with the Peterson and Barney (1952) study done in English. She reported that, low vowels have higher F1 frequency and the high vowels have lower F1 frequency. Low back and high back vowels have lower F2 compared to front vowels.

Krishna (2009) studied acoustic characteristics of Telugu vowels from a list of 60 disyllabic words with CVCCV and CVCV syllables. All ten short and long vowels were included in the study and the first four formant frequencies were extracted. The results suggested that the formant frequencies in children were higher as compared to that of adolescents and adults. Females had higher formant frequency values for all the vowels. The author reported that the formant frequencies varied in the contexts of different consonant features such as manner, place and voicing. Regional or dialectical variations in the formant frequency values were noticed.

5) Clinical relevance of Formant Frequencies

The iso-vowel lines (F1-F2 plot and F2-F3 plot) developed Kent and Forner (1979), attempts to provide a good solution to compare and contrast the data of disordered individuals with that of the normal speakers. The technique provides a graphical representation of formant structure which helps in the evaluation. It also helps in obtaining a developmental pattern of formant variations (Duggirala, 1983-1984).

Formants frequencies can be used to study the development of the vowel system, intelligibility of speech, developmental variations in co-articulation in children with Cochlear implants (Ertmer, 2001; Poissant et al., 2006; Gibson & Ohde, 2007). Formant frequency measurements can also help in predicting the speech intelligibility. There have been many studies investigating the formant frequencies in individuals with Maxillectomy and glossectomy. Authors have reported lower F2 for all vowels and higher F1 in individuals with maxillectomy for vowel /i/ compared to normal speakers (Sumita et al.2002). In glossectomy patients, lower F2 value and a restricted range for vowel /i/ was reported. which correlated with poor speech intelligibility (Whitehill, Ciocca, Chan & Samman (2004). From both the studies it can be inferred that the F2 could be very sensitive measure for vowel intelligibility.

Formant frequencies have also been studied in individuals with esophageal and tracheoesophageal speech. In Spanish language it has been reported that these spekers hae higher F1 and F2 values as compared to control speakers (Cervera, Miralles & Álvarez, 2001).

The review of literature discussed clearly indicates that the formant frequency values vary with respect to age, gender, context, languages and its regional variations and in disordered speech. Extensive research has been conducted to investigate the formant frequencies in different languages across the world and the cross linguistic studies have revealed differences in the formant patterns. With the progress in assessment, diagnosis and management of communication disorders, there is a need for the professionals to understand the acoustic features of vowels of each language. Thus there is an increased need to investigate the formant structure in different Indian languages. Tulu language has a paucity of studies that describes the acoustic characteristics of its vowel system; hence, this study was warranted. It analyzed the frequencies of first two formants of 10 vowels in Tulu and measured the main effect of age and gender. The objectives of the study were to (a) investigate the frequencies of first two formants of Tulu vowels, (b) determine the effect of age (4-5years, 7-8years, 18-20 years) on frequencies of first two formants of Tulu vowels, (c) determine the effect of gender (males and females) on frequencies of first two formants of Tulu vowels, and (d) determine the effect of position and length on the frequencies of the first two formants of Tulu vowels.

CHAPTER III

METHOD

Participants: Thirty native Tulu speakers (15 males and 15 females) each in the age range of 4-5 years, 7-8 years and 18-20 years participated in this study. The mean age of males in the 4-5 years age group was 4.8 and that of females was 4.73; mean age of males in 7-8years was 7.46 and that of females was 7; mean age of males in 18-20 years group was 18.53 and that of females was 19.26. These 90 subjects were selected on the criteria that they:

- were natives and residents of Mangalore or Udupi,
- had Tulu as the mother tongue and dominant language. However all the subjects were bilinguals or multilinguals with exposure to Kannada and/or English, and
- had no history of speech, language, and hearing disorders,

The participants were screened informally for normal speech, language skills. Ling test was used to screen them for normal hearing sensitivity. Adults were interviewed directly whereas for children, the teachers or parents were interviewed regarding speech, language and hearing problems or any other relevant history.

Stimuli/Material: According to Ullal (2012) there are 14 vowels (including 2 diphthongs) in Tulu language. The vowels intended to be analyzed were: /a/ (low central short), /a:/ (low central long), /i/ (high front short), /i:/ (high front long), /u/ (back high rounded short), /u:/ (back high rounded long), /e/ (mid high front short), /e:/ (mid high front long), /o/ (mid back high rounded short), /o:/ (mid back high rounded long). Twenty-five words with ten primary vowels of Tulu language were considered for the study (as mentioned above). The stimuli consisted of a set of pictures depicting meaningful, simple and common Tulu words (which can be named by the children too) with each of the test vowels in the initial, medial, and final position.

The words were selected by the investigator, in the /VCV/ or /CVC/ or /CVCV/ contexts. /CVCVCV/ or /CV/ or /VCVCV/ context was considered due to the unavailability of words in the required environments. Fricative and affricate word contexts were avoided to aid during the analysis by avoiding the obscurity of formant frequencies by the noise components. Table 2 shows the material used in the study.

Vowel	Word-Initial Position	Word-Medial Position	Word-final Position
/a/	/**a**ri/	/bad**a**næ/	/mar**a**/
/a:/	/**a:**næ/	/n**a:**ji/	
/i/	/**i**re/	/p**i**li/	/ko:r**i**/
/i:/	/**i:**roɭu/	/m**i:**nƏ/	
/u/	/**u**milƏ/	/k**u**ri/	/maip**u**/
/u:/	/**u:**dubatti/	/m**u:**ʤi/	/t**u:**/
/e/	/**e**li/	/k**e**bi/	/a:m**e**/
/e:/	/**e:**ḍƏ/	/p**e:**rƏ/	
/o/	/**o**nʈæ/	/k**o**ḍæ/	
/o:/	/**o:**ḍu/	/l**o:**ʈæ/	

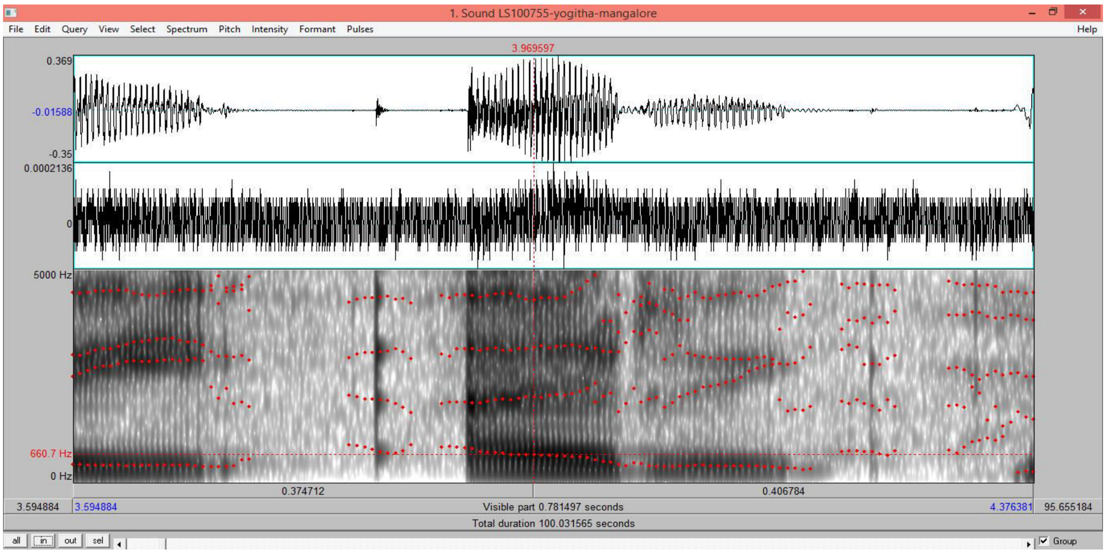
Table 2: Material used in the study.

Pictures for the target words were selected. Appropriate sized, clear, colored and real pictures with white background were chosen. These pictures were arranged randomly in a power-point presentation with one picture per slide.

Procedure: Written consent was obtained from the participants (for younger children from parents or teachers). Participants were tested individually. They were seated comfortably in a room with minimum interference from the background noise and the participant was instructed to name the pictures presented visually on a laptop screen thrice. The participant was prompted if he/she was not able to name the picture. Each picture was presented in random order at a gap of 3-5 seconds. The speech sample was audio recorded using a digital voice recorder (Olumpus LS-10 linear PCM digital voice recorder, Sampling frequency-44.1kHz), with the microphone positioned 10 cm away from the mouth.

Perceptual Analysis: The speech samples were played to two Speech-Language Pathologists (native speaker of Tulu) to judge the correctness of production of vowel. The judges were presented the samples through headphones and were asked to mark 0 for the wrong production and 1 for right production on the response sheet provided for all the three trials. The best out of the 3 trials (which is considered as the most correct) was selected for acoustic analysis. That is, on visual inspection of the spectrogram, the target vowel with clear and stable formant structure was chosen for analyses. Most of the times the 2^{nd} trial was considered as it had the stable formant structure and without interference by the rising and falling pitch at the beginning and the end of the three repetitions for each target word.

Acoustic Analysis: PRAAT (Boersma & Weinik, 2011) software was used for the acoustic analysis. The speech Sample was depicted as spectrogram (wide band bar type). Frequencies of the first two formants of the vowels were extracted by placing the cursor in the steady state of the formant of the vowel. The formant frequency values were tabulated. Figure 3 depicts extraction of formant frequencies.



661 Hertz (nearest F_1 to CURSOR)

Figure 3: Extraction of formant frequency (F_1) of vowel /a/ (cursor at extraction).

Statistical Analysis: A commercially available SPSS was used for statistical analysis. Initially, Shapiro Wilk's test of normality was done and majority of the parameters were normal within each age group. Mean and standard deviation of formant frequencies in three age groups were calculated. Mixed ANOVA was done to determine the main effects and interaction between the within subject and between subject variables on the formant frequencies. The variables included age, gender, position, and length of vowels. Post hoc Bonferroni, and 3-way repeated measures ANOVA were done to determine the significance. T-test was done to find significant difference between frequencies of formants in various positions and length.

CHAPTER IV

RESULTS

The results are discussed under the following headings.

(1) Frequencies of the first two formants of vowels.

(2) Effect of age, gender, position, length and vowel on frequencies of the first two formants of vowels.

(1) Frequencies of the first two formants of vowels

Frequency of the First formant (F_1)

Short vowels: F_1 of all short vowels in both genders in word initial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_1 was observed in vowel /a/ in all the age groups and genders.*** This was followed by F_1 of /o/, /e/, /u/ and /i/ in all age groups and genders, except in males in the age range of 18-20years. Table 3 shows mean and SD of F_1 of short vowels in the word-initial position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.02: 1.11 to 1:1.34:1.55. On an average it was 1:1.19: 1.32 and 1:1.11:1.19 in males and females, respectively. Table 4 shows the scaling of F_1 word-initial position.

	MALE					FEMALE				
Age	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**
4-5	1090	561	582	625	664	1110	560	581	599	660
S.D	114.71	59.40	61.26	70.98	82.50	112.68	56.48	61.26	68.77	63.80
7-8	940	498	530	592	616	1045	510	558	574	606
S.D	165.55	82.31	63.70	44.32	73.35	155.71	46.69	43.54	34.09	69.60
18-20	703	439	479	453	574	922	443	502	499	593
S.D	78.013	53.89	59.39	43.31	59.04	81.87	54.98	58.28	43.22	76.95

Table 3: Mean (Hz) and SD of F_1 for short vowels in word- initial position.

Vowel/ Age Group	MALE					FEMALE				
	/a/	/i/	/u/	/e/	/o/	/a/	/i/	/u/	/e/	/o/
7-8	1.34	1.13	1.11	1.31	1.07	1.13	1.15	1.11	1.15	1.02
4-5	1.55	1.28	1.22	1.38	1.16	1.20	1.26	1.16	1.20	1.11

Table 4: Scaling of F_1 in word-initial position (Reference is 18-20 years).

F_1 of all short vowels in both genders in word-medial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_1 was observed in vowel /a/ in all the age groups and genders.*** This was followed by F_1 of /o/, /e/, /u/ and /i/ in all age groups and genders, except in males in the age range of 18-20 years. Table 5 shows mean and SD of F_1 of short vowels in the word-medial position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.02: 1.16:1.16 to 1:1.34:1.40. On an average it was 1:1.16: 1.8 and 1:1.40:1.21 in males and females, respectively. Table 6 shows the scaling of F_1 in word-medial position.

	MALE					FEMALE				
Age	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**
4-5	826	542	585	622	697	871	538	578	614	654
S.D	109.23	66.46	68.21	67.37	84.97	104.21	74.92	63.80	71.2	70.81
7-8	756	477	558	596	685	842	530	538	579	622
S.D	138.88	52.65	48.28	53.02	67.99	139.39	43.93	57.12	28.8	63.77
18-20	631	466	439	444	571	717	424	472	497	582
SD	74.71	151.55	36.87	39.72	49.09	76.61	64.32	34.88	42.43	83.44

Table 5: Mean (Hz) and SD of F_1 of short vowels in the word-medial position.

Vowel/ Age Group	MALE					FEMALE				
	/a/	/i/	/u/	/e/	/o/	/a/	/i/	/u/	/e/	/o/
7-8	1.19	1.02	1.27	1.64	1.19	1.17	1.25	1.14	1.16	1.06
4-5	1.30	1.16	1.33	1.40	1.22	1.21	1.27	1.22	1.23	1.12

Table 6: Scaling of F_1 in word-medial position (Reference is 18-20 years).

F_1 of all short vowels in both genders in word-final position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_1 was observed in vowel /a/ in all the age groups and genders.*** This was followed by F_1 of /e/, /u/ and /i/ in all age groups and genders. Table 7 shows mean and SD of F_1 of short vowels (except vowel /o/) in the word-final position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.11:1.18 to 1:1.37:1.57 . On an average it was 1:1.26:1.42 and 1:1.18:1.27 in males and females, respectively. Table 8 shows the scaling of F_1 in word-final position.

	MALE				FEMALE			
Age	**/a/**	**/i/**	**/u/**	**/e/**	**/a/**	**/i/**	**/u/**	**/e/**
4-5	1123	558	574	867	1069	552	583	956
S.D	123.02	65.65	69.34	145.31	129.61	69.19	72.41	217.96
7-8	979	492	544	754	1040	503	549	872
S.D	151.05	54.81	87.16	198.70	150.64	34.58	37.87	143.27
18-20	713	398	459	591	864	417	493	713
S.D	79.43	52.77	58.73	129.25	77.97	67.79	63.59	141.22

Table 7: Mean (Hz) and SD of F_1 of short vowels in the word-final position.

Vowel/ Age Group	**MALE**				**FEMALE**			
	/a/	**/i/**	**/u/**	**/e/**	**/a/**	**/i/**	**/u/**	**/e/**
7-8	1.37	1.24	1.18	1.27	1.20	1.21	1.11	1.22
4-5	1.57	1.40	1.25	1.47	1.24	1.32	1.18	1.34

Table 8: Scaling of F_1 in word-final position (Reference is 18-20 years).

Long vowels: F_1 of all long vowels in both genders in word-initial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_1 was observed in vowel /a:/ in all the age groups and genders.*** This was followed by F_1 of /o:/, /e:/, /u:/ and /i:/ in all age groups and genders. Table 9 shows mean and SD of F_1 of long vowels in the word-initial position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.05:1.10 to 1:1.29:1.37. On an average it was 1:1.22:1.33 and 1:1.16:1.18 in males and females, respectively. Table 10 shows the scaling of F_1 in word-initial position.

	MALE					FEMALE				
Age	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**
4-5	1019	519	583	626	646	1078	512	572	626	618
S.D	229.8	79.2	71.5	75.50	83.7	248.10	75.2	65.0	73.6	60.8
7-8	889	483	555	594	595	1026	497	543	577	580
S.D	254.3	72.4	60.5	54.50	67.6	284.5	48.5	34.1	38.9	41.5
18-20	757	383	457	457	500	977	416	484	486	511
SD	92.62	49.6	49.73	45.10	55.8	167.67	71.94	54.09	41.18	47.8

Table 9: Mean (Hz) and SD of F_1 for long vowels in word-initial position.

Vowel/ Age Group	MALE					FEMALE				
	/a:/	/i:/	/u:/	/e:/	/o:/	/a:/	/i:/	/u:/	/e:/	/o:/
7-8	1.17	1.26	1.21	1.29	1.19	1.05	1.19	1.22	1.19	1.13
4-5	1.35	1.35	1.27	1.37	1.29	1.10	1.23	1.18	1.29	1.21

Table 10: Scaling of F_1 in word-initial position (Reference is 18-20 years).

F_1 of all long vowels in both genders in word-medial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_1 was observed in vowel /a:/ in all the age groups and genders.*** This was followed by F_1 of /o:/, /e:/, /u:/ and /i:/ in all age groups and genders, except in males in the age range of 18-20 years. Table 11 shows mean and SD of F_1 of long vowels in the word-medial position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.06: 1.14 to 1:1.34:1.35. On an average it was 1:1.17:1.28 and 1:1.16:1.20 in males and females, respectively. Table 12 shows the scaling of F_1 in word-medial position.

	MALE					FEMALE				
Age	/a:/	/i:/	/u:/	/e:/	/o:/	/a:/	/i:/	/u:/	/e:/	/o:/
4-5	1000	552	576	622	728	1058	560	573	626	638
S.D	278.9	59.9	61.55	67.14	129.9	242.98	60.70	71.84	65.03	78.9
7-8	793	524	546	621	669	1038	528	558	579	656
S.D	258.7	70.6	71.04	58.78	69.75	286.81	58.64	50.90	48.63	69.9
18-20	750	438	485	462	574	926	435	485	487	569
S.D	89.10	59.9	86.49	36.13	57.80	138.11	79.72	80.58	83.31	80.45

Table 11: Mean (Hz) and SD of F_1 for long vowels in word-medial position.

Vowel/ Age Group	MALE					FEMALE				
	/a:/	/i:/	/u:/	/e:/	/o:/	/a:/	/i:/	/u:/	/e:/	/o:/
7-8	1.06	1.19	1.12	1.34	1.16	1.12	1.21	1.15	1.19	1.15
4-5	1.33	1.26	1.19	1.65	1.27	1.14	1.29	1.18	1.28	1.12

Table 12: Scaling of F_1 in word-medial position (Reference is 18-20 years).

Frequency of F1 of long vowel /u:/ in both genders in word- final position increased from 18-20 years to 7-8 years to 4-5 years. Table 13 shows mean and

SD of F_1 of long vowel /u:/ in the word-final position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years was 1:1.23:1.30 for males and1:1.21:1.22 for females.

	MALE	FEMALE
Age	**/u:/**	**/u:/**
4-5	558	559
S.D	73.52	68.12
7-8	527	551
S.D	61.02	46.74
18-20	429	456
S.D	67.16	66.24

Table 13: Mean (Hz) and SD of F_1 for long vowels in word-final position.

Vowel/ Age Group	MALE /u:/	FEMALE /u:/
7-8	1.23	1.21
4-5	1.30	1.22

Table 14: Scaling of F_1 in word-final position (Reference is 18-20 years).

To summarize, results indicated higher F_1 on vowel /a/, in all age groups, and in females.

Frequency of Second formant (F_2)

Short Vowels: F_2 of all short vowels in both genders in word- initial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_2 was observed in vowel /i/ in all the age groups and genders.*** This was followed by F_2 of /e/, /a/, /o/ and /u/ in all age groups and genders, except in females in the age range of 4-5 years. Table 14 shows mean and SD of F_2 of short vowels in word-initial position. The scaling of F_2 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.09:1.12 to 1:1.47:1.47. On an average it was 1:1.27:1.32 and 1:1.19:1.24 in males and females, respectively. Table 15 shows the scaling of F_2 in word-initial position.

	MALE					FEMALE				
Age	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**
4-5	2146	3191	1275	3033	1377	2151	3413	1420	3186	1304
S.D	153.1	269.6	175.0	250.3	155.5	130.9	282.0	564.8	241.4	176
7-8	1983	317	1213	2851	13762	2172	3399	1230	3163	1277
S.D	259.4	247.9	131.3	217.8	51.4	236.3	212.0	161.7	243.1	183
18-20	1595	21621	1091	2120	1140	1749	2706	1061	2576	1163
S.D	118.9	51.6	85.61	107.7	130.3	118.9	134.1	140.6	136.5	113.4

Table 15: Mean (Hz) and SD of F_2 of short vowels in word-initial position.

Vowel/ Age Group	**MALE**					**FEMALE**				
	/a/	**/i/**	**/u/**	**/e/**	**/o/**	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**
7-8	1.24	1.47	1.11	1.34	1.21	1.24	1.26	1.16	1.23	1.09
4-5	1.34	1.47	1.17	1.43	1.21	1.23	1.26	1.34	1.24	1.12

Table 16: Scaling of F_2 in word-initial position (Reference is 18-20 years).

F_2 of all short vowels in both genders in word-medial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_2 was observed in vowel /i/ in all the age groups and genders except for vowel /u/ in males.*** This was followed by F_2 of /e/, /a/, /o/ and /u/ in two groups and genders, except in the age range of 18-20 years. Table 16 shows mean and SD of F_2 of short vowels in word-medial position. The scaling of F_2 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1:1 to 1:1.49:1.48. On an average it was 1:1.25:1.29 and 1:1.16:1.16 in males and females, respectively. Table 17 shows the scaling of F_2 in word-medial position. Table 17 shows the scaling of F_2 in word-medial position.

	MALE					FEMALE				
Age	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**	**/a/**	**/i/**	**/u/**	**/e/**	**/o/**
4-5	2342	3110	1341	3109	1421	2365	3276	1281	3159	1311
S.D	240.2	223.3	165.2	245.7	129.5	132.2	220.5	160.1	174.9	160.9
7-8	2142	3133	1319	2865	1384	2373	3249	1310	3116	1365
S.D	341.8	199.6	265.5	172.4	192.4	318.5	221.8	203.1	225.1	182.5
18-20	1697	2107	1341	2100	1238	1991	2639	1291	2488	1215
S.D	108.9	109.9	107.6	119.8	113.9	85.10	455.1	181.9	99.64	92.21

Table 17: Mean (Hz) and SD of F_2 of short vowels in word-medial position.

Vowel/ Age Group	MALE					FEMALE				
	/a/	/i/	/u/	/e/	/o/	/a/	/i/	/u/	/e/	/o/
7-8	1.26	1.49	1.00	1.36	1.12	1.19	1.23	1.01	1.25	1.12
4-5	1.38	1.48	1.00	1.48	1.15	1.19	1.24	1.00	1.27	1.08

Table 18: Scaling of F_2 in word-medial position (Reference is 18-20 years).

F_2 of all short vowels in both genders in word-final position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_2 was observed in vowel /i/ in all the age groups and genders.*** This was followed by F_2 of /e/, /a/, and /u/ in two groups and genders. Table 18 shows mean and SD of F_2 of short vowels in word-final position. The scaling of F_2 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.13:1.04 to 1:1.47:1.46. On an average it was 1:1.31:1.34 and 1:1.20:1.19 in males and females, respectively. Table 19 shows the scaling of F_2 in word-medial position. Table 19 shows the scaling of F_2 in word-final position.

	MALE				FEMALE			
Age	/a/	/i/	/u/	/e/	/a/	/i/	/u/	/e/
4-5	2089	3149	1228	2467	2127	3288	1137	2639
S.D	184.29	288.56	172.62	301.87	145.40	170.62	126.00	133.09
7-8	1952	3160	1223	2391	2130	3350	1236	2545
S.D	197.68	211.38	187.80	221.78	236.18	235.01	145.59	158.31
18-20	1459	2152	1075	1840	1616	2721	1094	2226
S.D	94.08	193.25	131.65	185.32	111.96	201.23	115.94	170.78

Table 19: Mean (Hz) and SD of F_2 of short vowels in word-final position.

Vowel/ Age Group	MALE				FEMALE			
	/a/	/i/	/u/	/e/	/a/	/i/	/u/	/e/
7-8	1.34	1.47	1.14	1.29	1.32	1.23	1.13	1.14
4-5	1.43	1.46	1.14	1.34	1.32	1.21	1.04	1.18

Table 20: Scaling of F_2 in word-final position (Reference is 18-20 years).

Long Vowels: F_2 of all long vowels in both genders in word-initial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_2 was observed in vowel /i/ in all the age groups and genders.*** This was followed by F_2 of /e/, /a/, /u/ and /o/ in two groups and genders. Table 20 shows mean and SD of F_2 of long vowels in word-final position. The scaling of F_2 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.1:1.07 to 1:1.46:1.48. On an average it was 1:1.25:1.32 and 1:1.19:1.12 in males and females, respectively. Table 20 shows the scaling of F_2 in word-medial position. Table 21 shows the scaling of F_2 in word-final position.

	MALE					FEMALE				
Age	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**
4-5	2007	3244	1264	3010	1226	2005	3457	1256	3215	1178
S.D	228.4	225.1	157.3	164.7	140.2	135.4	215.7	99.79	257.6	115.1
7-8	1773	3192	1273	2843	1144	1980	3402	1198	3094	1160
S.D	229.7	125.9	208.3	369.2	140.2	278.8	221.5	132.4	124.4	98.49
18-20	1448	2184	1148	2122	1023	1561	2655	1177	2572	984
S.D	102.1	162.8	146.4	106.1	103.2	114.4	184.2	182.4	128.3	86.15

Table 21: Mean (Hz) and SD of F_2 of long vowels in word-initial position.

Vowel/ Age Group	MALE					FEMALE				
	/a:/	/i:/	/u:/	/e:/	/o:/	/a:/	/i:/	/u:/	/e:/	/o:/
7-8	1.22	1.46	1.11	1.34	1.12	1.27	1.28	1.02	1.20	1.18
4-5	1.39	1.48	1.10	1.42	1.19	1.28	1.30	1.07	1.25	1.19

Table 22: Scaling of F_2 in word-initial position (Reference is 18-20 years).

F2 of all long vowels in both genders in word-medial position increased from 18-20 years to 7-8 years to 4-5 years. ***Highest F_2 was observed in vowel /i/ in all the age groups and genders.*** This was followed by F_2 of /e:/, /a:/, /o:/ and /u:/ in all groups and genders. Table 22 shows mean and SD of F_2 of long vowels in the word-medial position. The scaling of F_1 between 18-20 years, 7-8 years, and 4-5 years ranged from 1:1.05:1.07 to 1:1.4:1.45. On an average it was 1:1.23:1.29 and 1:1.19:1.16 in males and females, respectively. Table 23 shows the scaling of F_2 in word-medial position.

	MALE					FEMALE				
Age	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**
4-5 **S.D**	2036 223.1	3323 238.1	1260 118.5	3003 173.4	1432 223.6	1998 194.7	3437 238.7	1208 198.5	3118 208.0	1317 119.8
7-8 **S.D**	1717 254.3	3260 139.8	1220 205.1	2920 298.4	1433 209.8	2078 213.7	3423 174.9	1180 346.1	3127 272.4	1459 152.4
18- **20** **S.D**	1579 109.9	2345 184.6	1108 156.0	2064 128.9	1241 78.02	1702 107.4	2878 160.1	1123 188.6	2439 346.3	1219 128.5

Table 23: Mean (Hz) and SD of F_2 for long vowels in word-medial position.

Vowel/ Age Group	MALE					FEM ALE				
	/a:/	**/i:/**	**/u:/**	**/e:/**	**/o:/**	**/a:/**	**/i:/**	**/u:/**	**/e:/**	**/o:/**
7-8	1.23	1.39	1.10	1.41	1.15	1.22	1.19	1.05	1.28	1.19
4-5	1.29	1.42	1.14	1.45	1.15	1.17	1.19	1.07	1.28	1.08

Table 24: Scaling of F_2 in word-medial position (Reference is 18-20 years).

Frequency of F2 of long vowel /u:/ in both genders in word- final position increased from 18-20 years to 7-8 years to 4-5 years. Table 24 shows the F_2 of long vowel /u:/ in the word-final position. 18-20 years, 7-8 years, and 4-5 years was 1:1.08:1.16 for males and 1:1.03:1.03 for females. Table 25 shows the scaling of F_2 in word-final position.

	MALE	FEMALE
Age	**/u:/**	**/u:/**
4-5 **S.D**	1258 168.43	1117 78.62
7-8 **S.D**	1162 167.25	1177 135.09
18-20 **S.D**	1079 115.36	1080 148.37

Table 25: Mean (Hz) and SD of F_2 for long vowels in word-final position.

Vowel/ Age Group	**MALE**	**FEMALE**
	/u:/	**/u:/**
7-8	1.08	1.03
4-5	1.16	1.03

Table 26: Scaling of F_2 in word-final position (Reference is 18-20 years).

It was observed that the F_1 and F_2 of short and long vowel /i/ and /e/ were overlapping. Similarly, those of short and long vowel /u/ and /o/ were overlapping. Figures 4 and 5 show the F_1 - F_2 plot of all the short and long vowels, respectively.

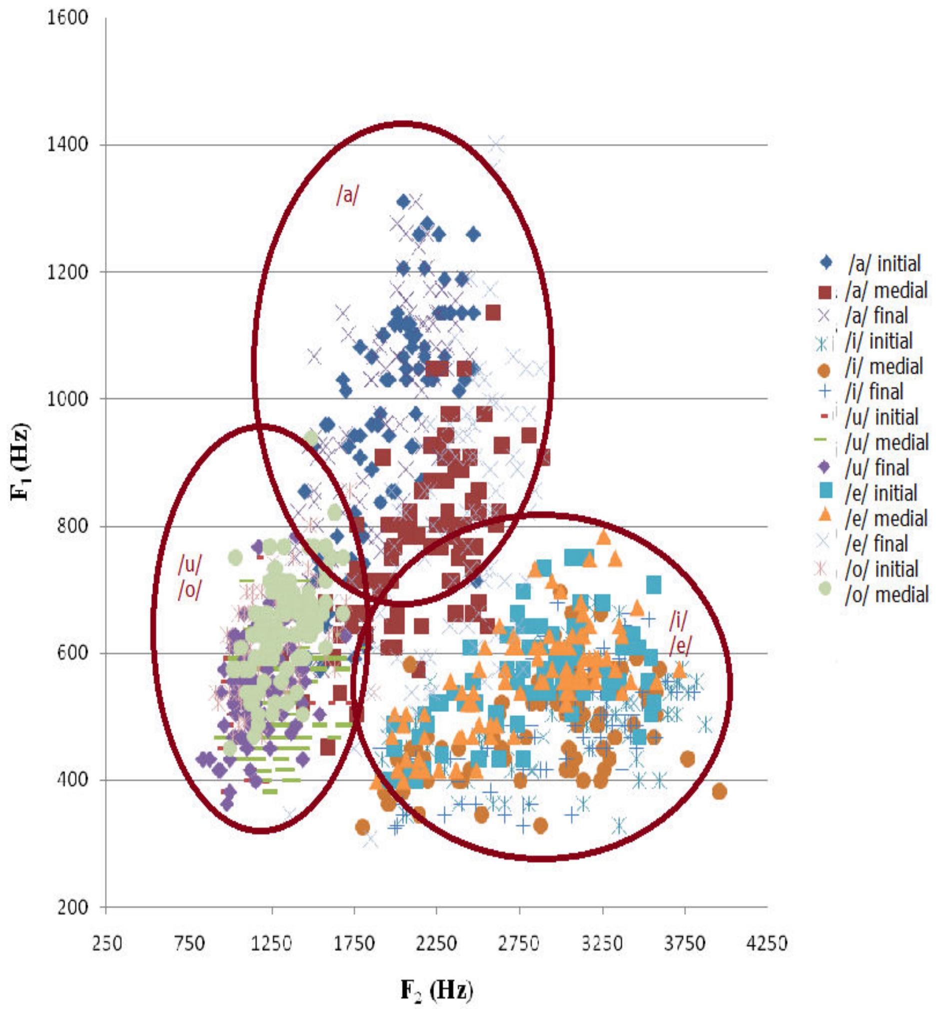


Figure 4: F_1-F_2 plot of short vowels in word-initial, medial and final positions.

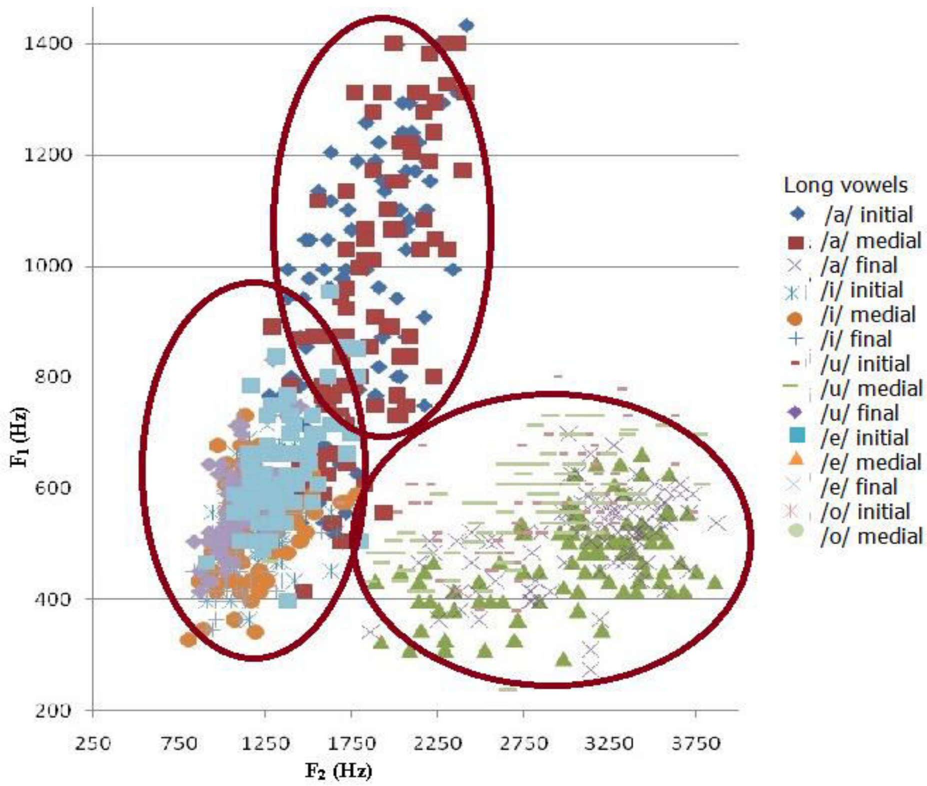


Figure 5: F_1-F_2 plot of long vowels in word-initial, medial and final positions.

The isovowel lines of long and short vowel /a/ in word-initial position were similar. However, that of vowel /a:/ had F_1 above 1400 Hz. Figures 6 and 7 show the isovowel lines of short and long vowel /a/ in word-initial position.

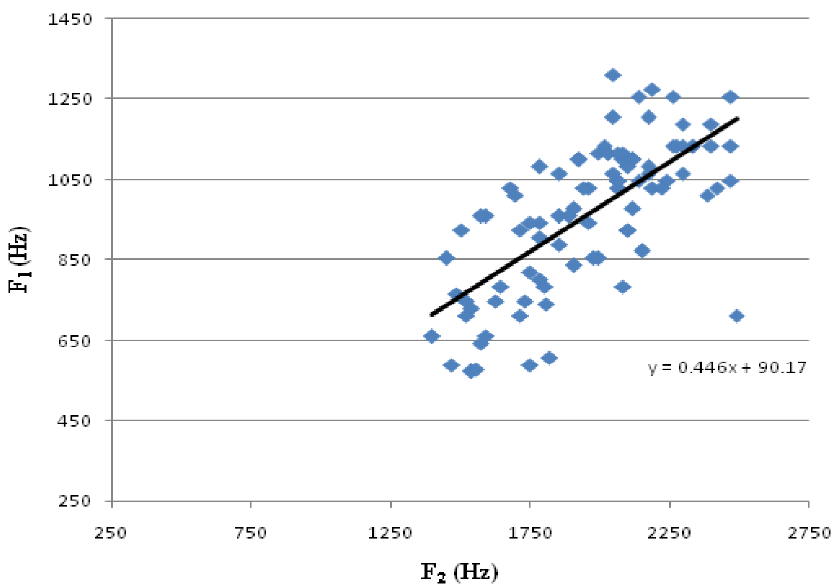


Figure 6: Isovowel line of vowel /a/ in word initial position

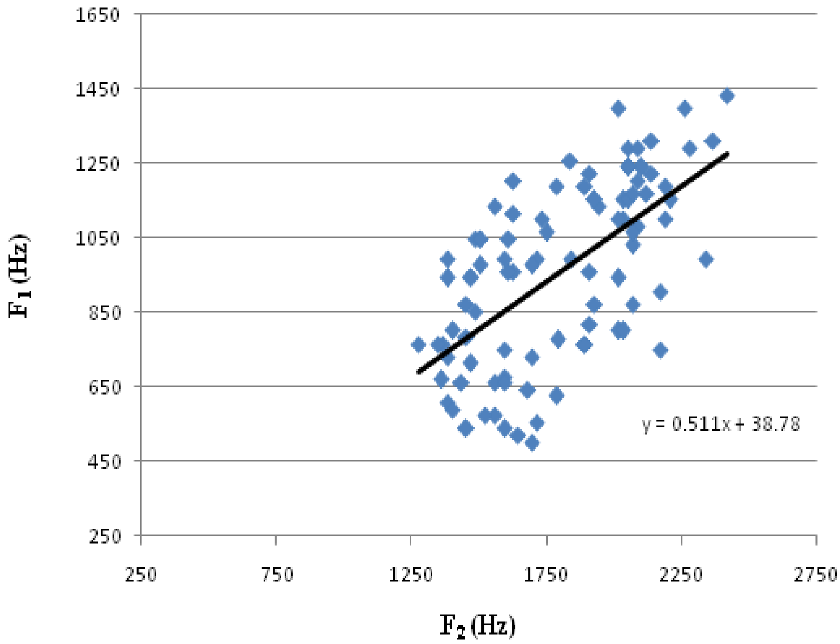


Figure 7: Isovowel line of /a:/ in word-initial position.

The isovowel lines of long and short vowel /a/ in word-medial position were similar. However, that of vowel /a:/ had F_1 above 1400 Hz. Figures 8 and 9 show the isovowel lines of short and long vowel /a/ in word-initial position.

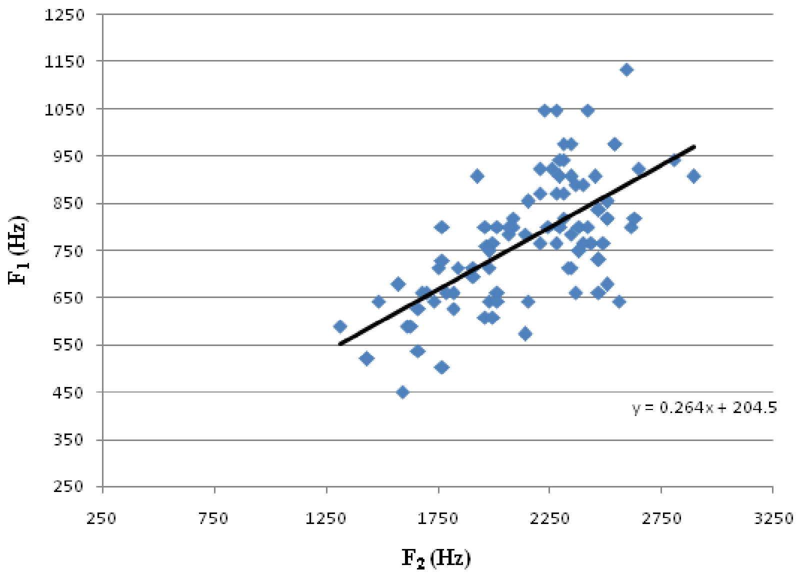


Figure 8: Isovowel line of /a/ in word medial position.

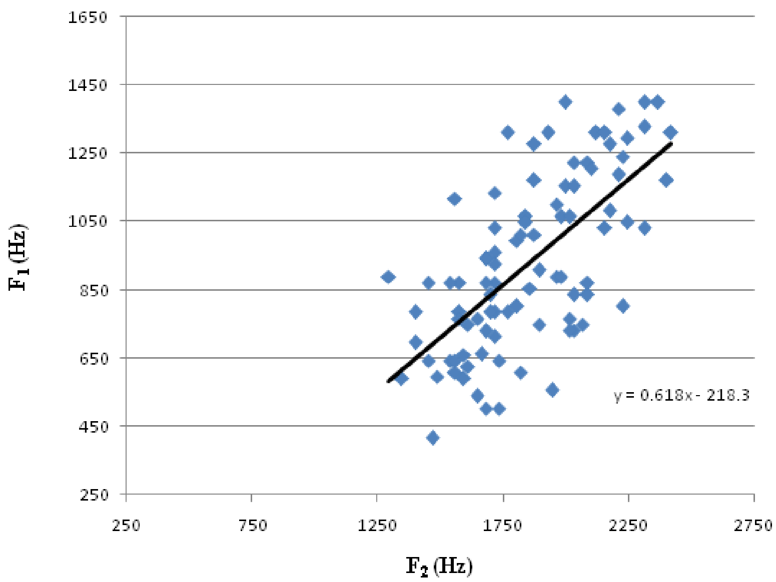


Figure 9: Isovowel line of /a:/ in word-medial position.

The isovowel line of short vowel /a/ in word-final position is in figure 10.

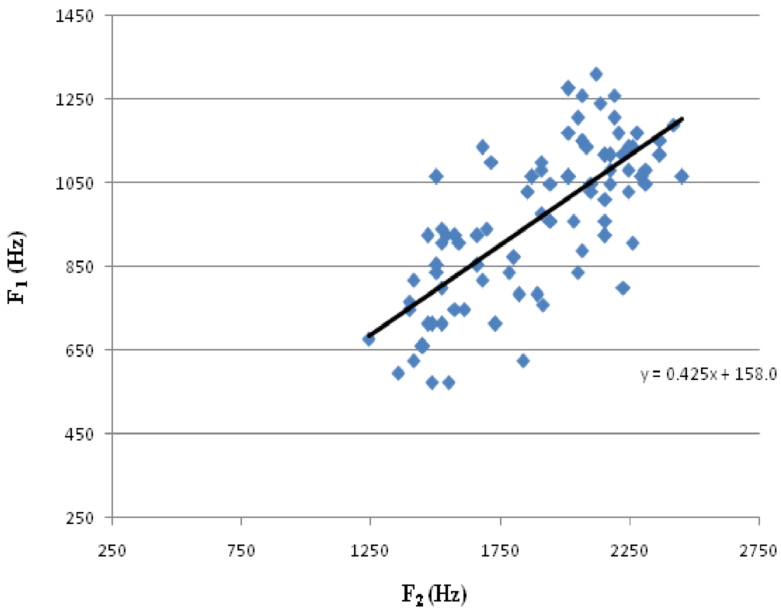


Figure 10: Isovowel line of /a/ in word-final position.

Figure 11 shows the isovowel lines of vowel /i/ in all positions (initial, medial and final). Figure 12 shows the isovowel lines of vowel /i:/ in all positions (initial and medial). Figures 13 and 14 show the isovowel lines of vowel /u/ and /u:/ in all positions (initial, medial and final).

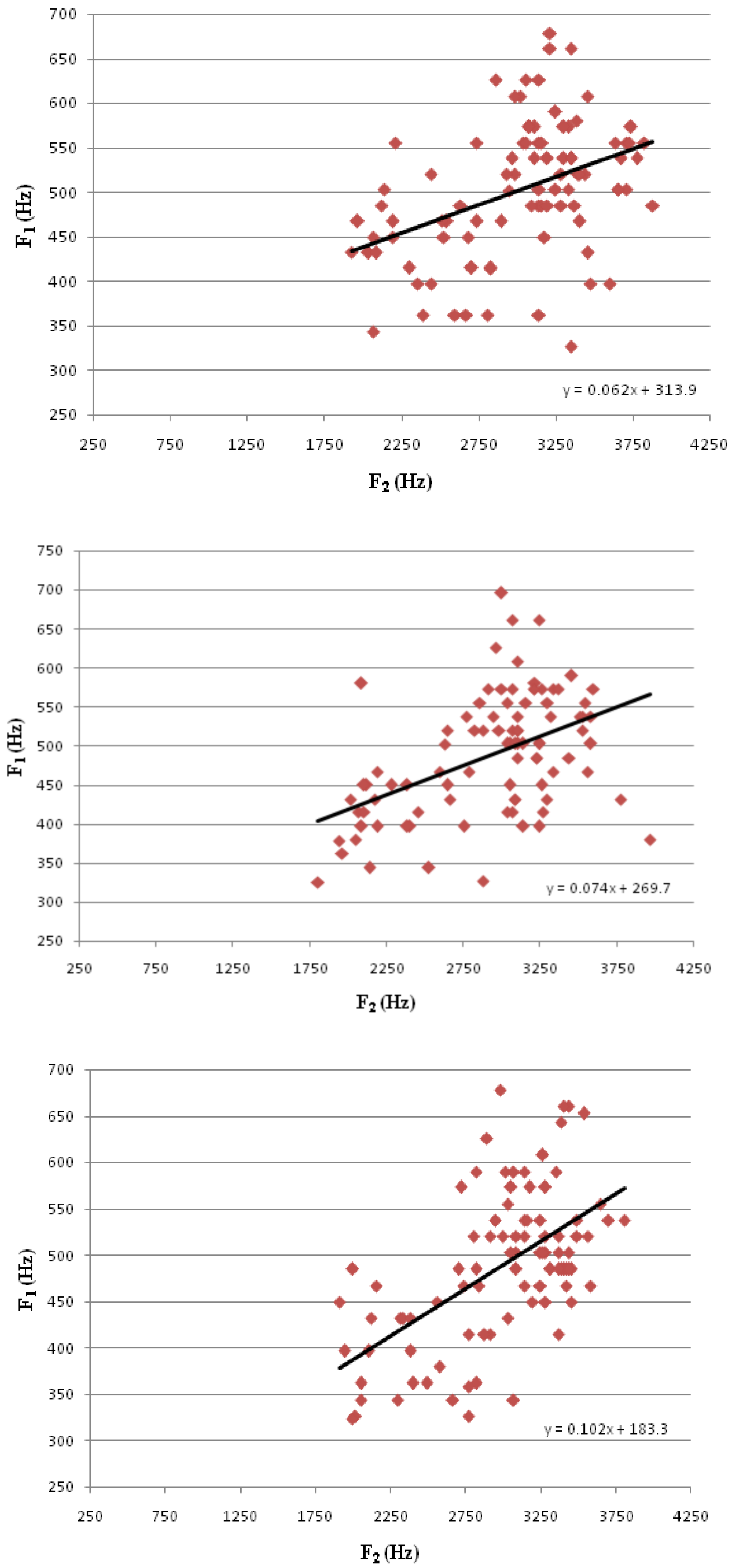


Figure 11: Isovowel line of /i/ in all positions

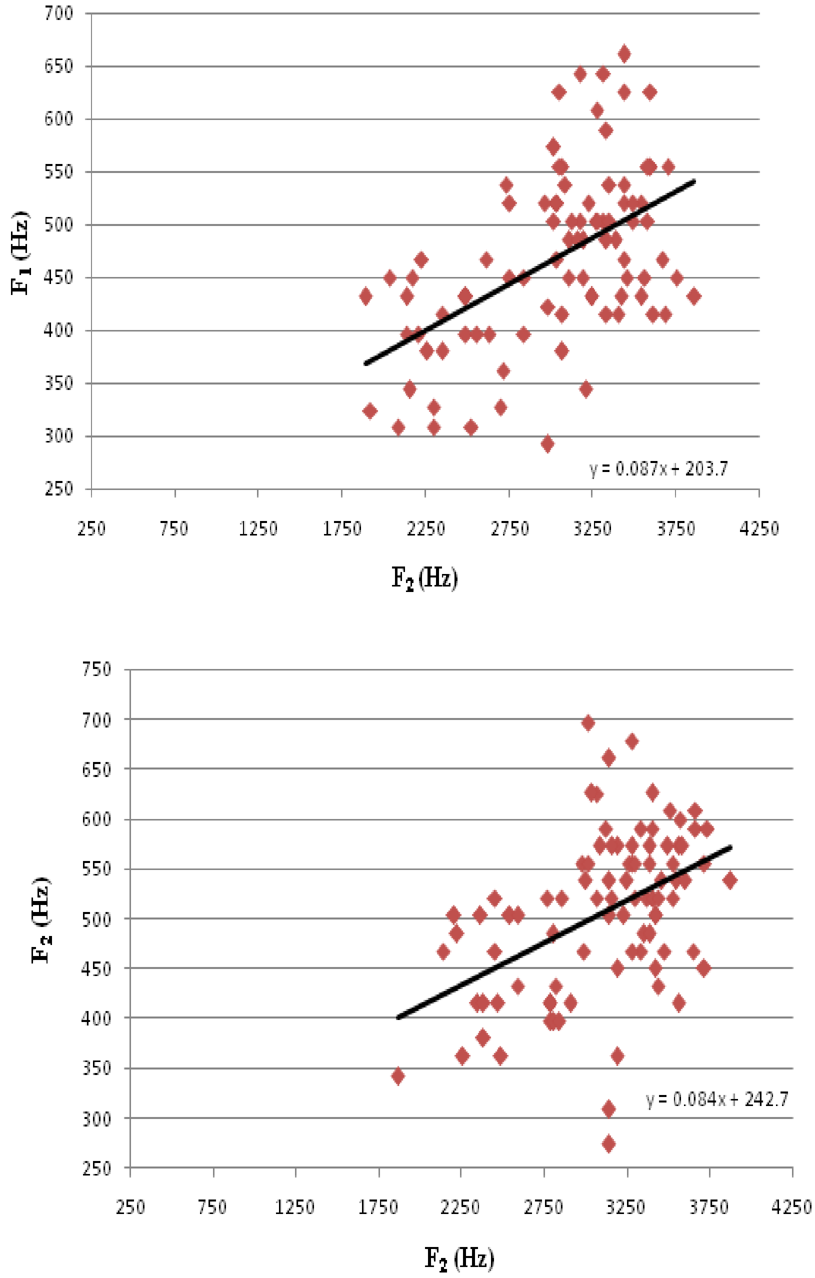


Figure 12: Isovowel line of /i:/ in all word positions.

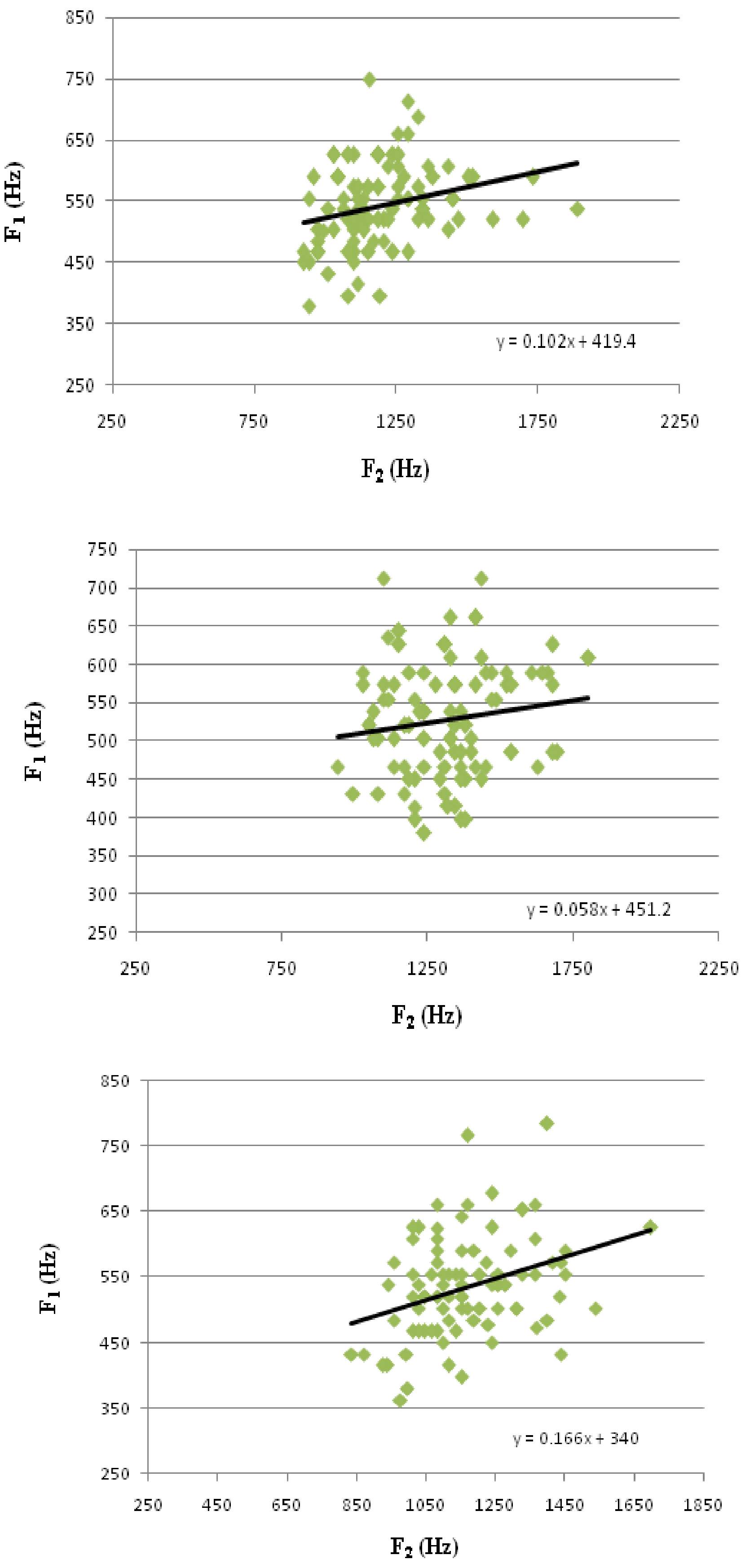


Figure 13: Isovowel line of /u/ in all positions.

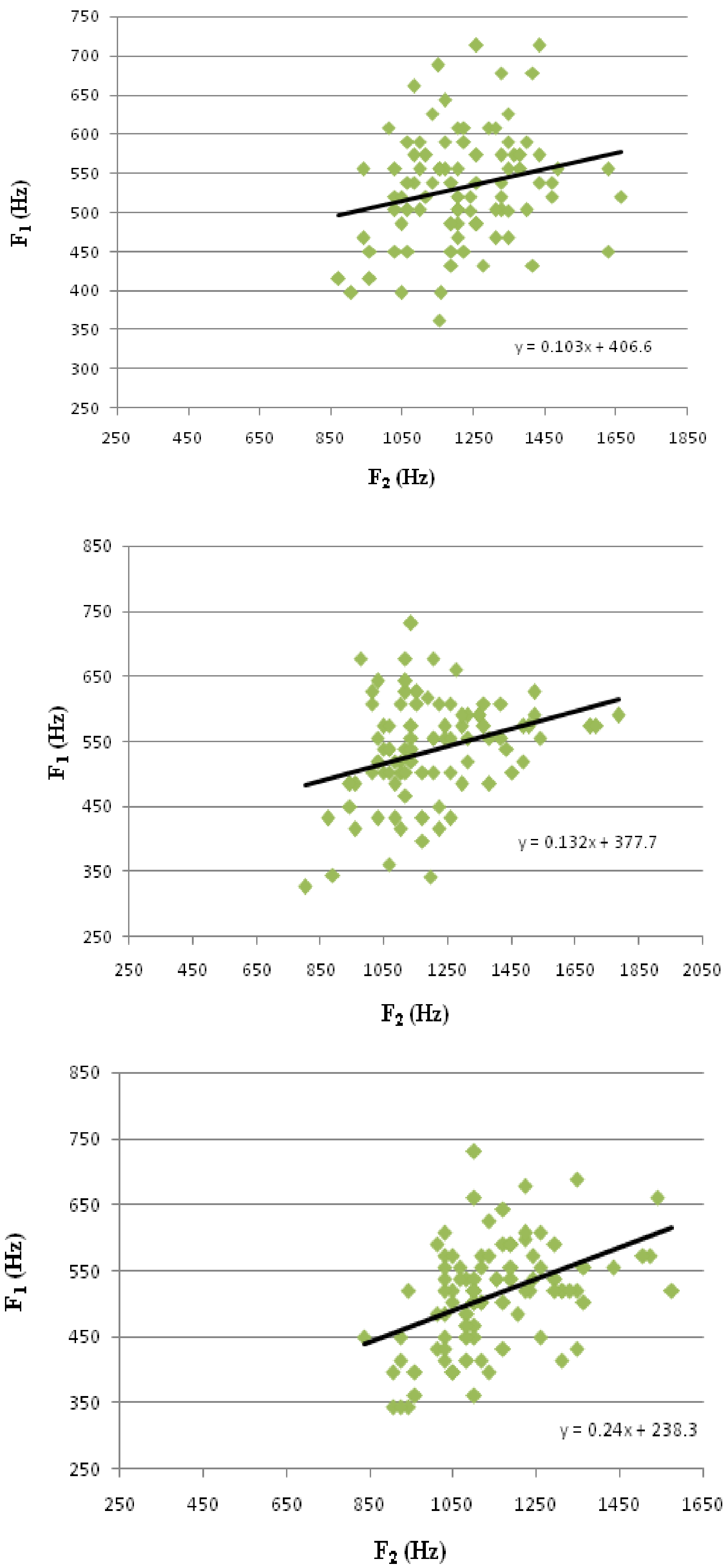


Figure 14: Isovowel line of /u:/ in all positions.

Figures 15 and 16 show isovowel lines of vowel /e/ (initial, medial and final) and /e:/(initial and medial) in all positions.

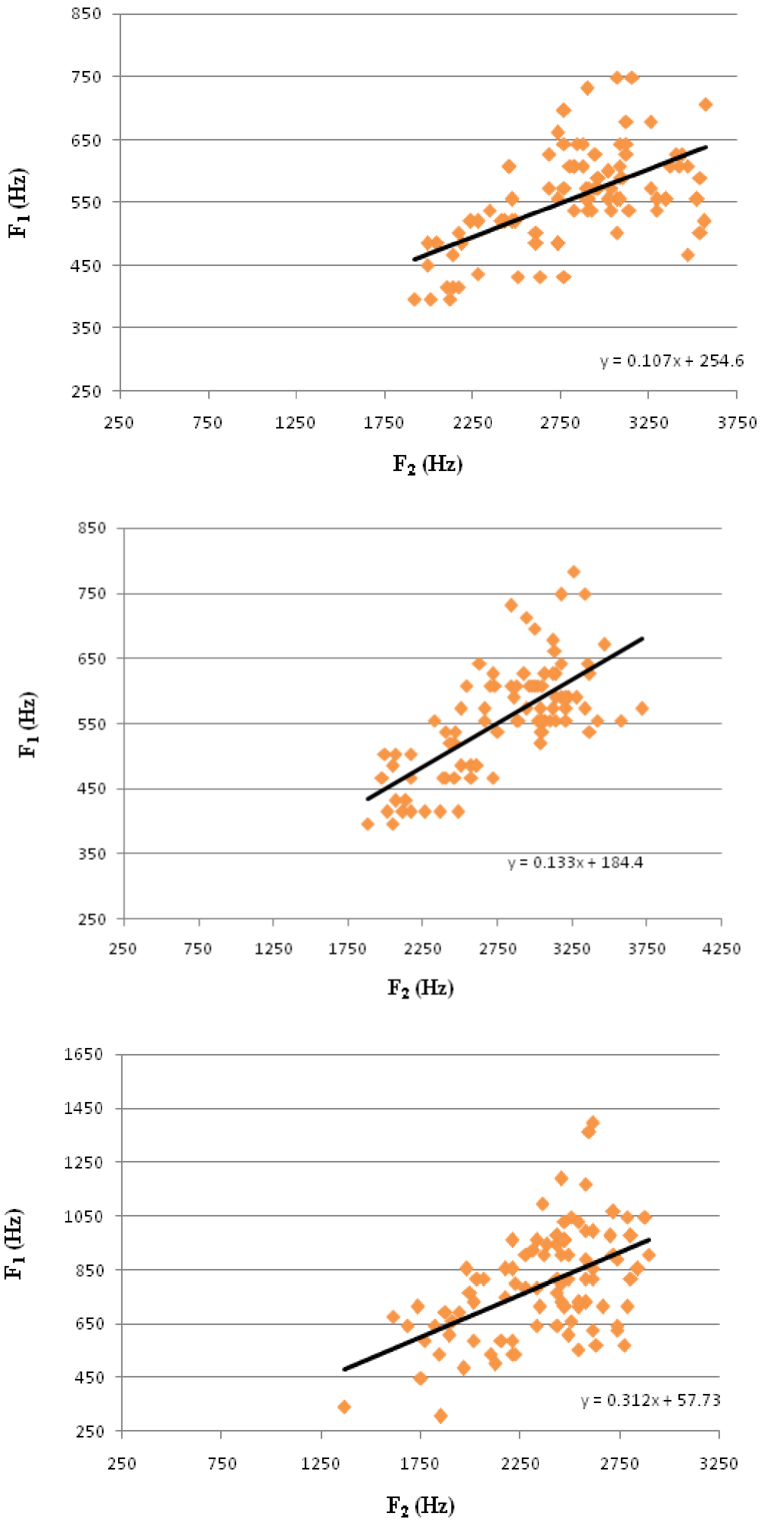
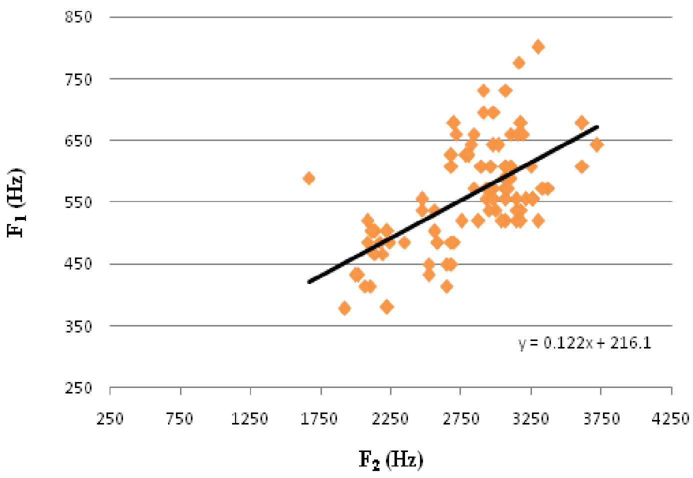


Figure 15: Isovowel line of vowel /e/ in all positions.



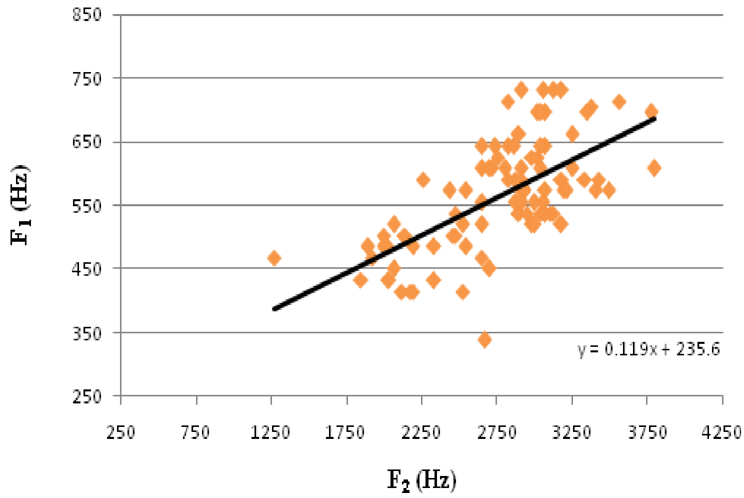
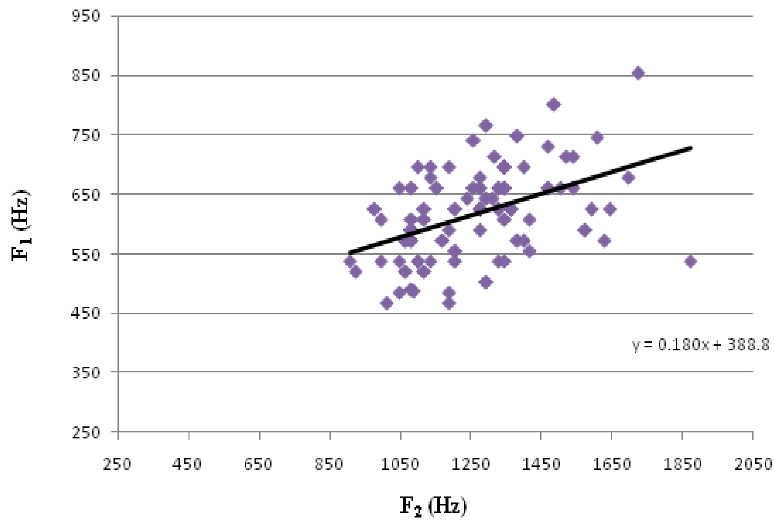


Figure 16: Isovowel lines of vowel /e:/.

Figures 17 and 18 show isovowel lines of vowel /o/ and /o:/ in all positions (initial and medial word positions).



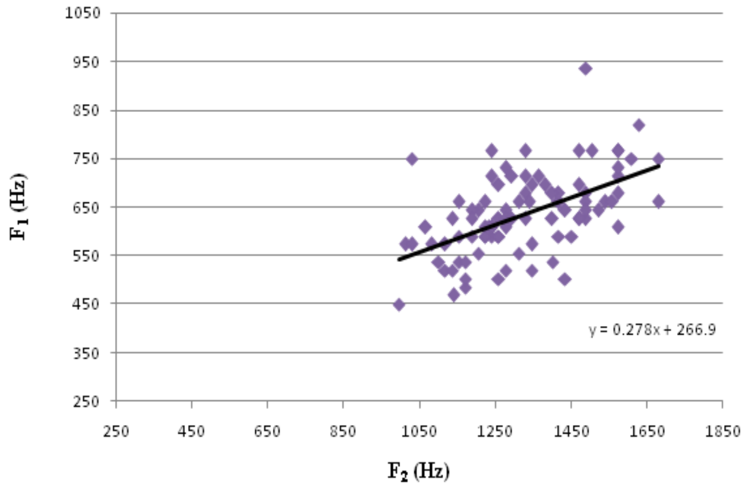
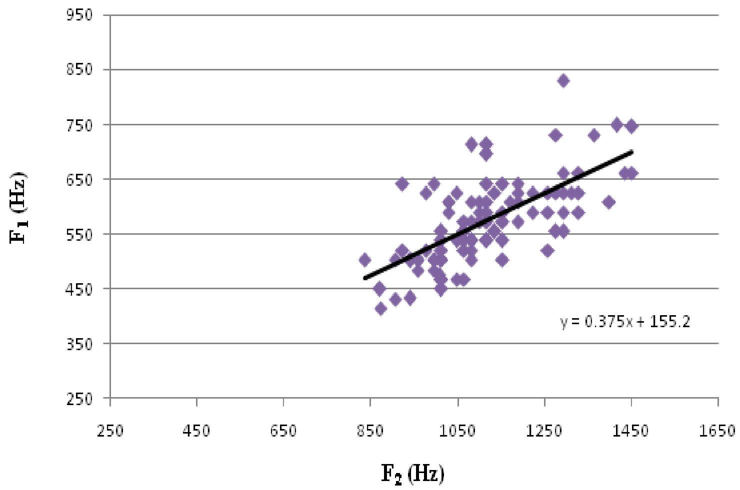


Figure 17: Isovowel line of vowel /o/.



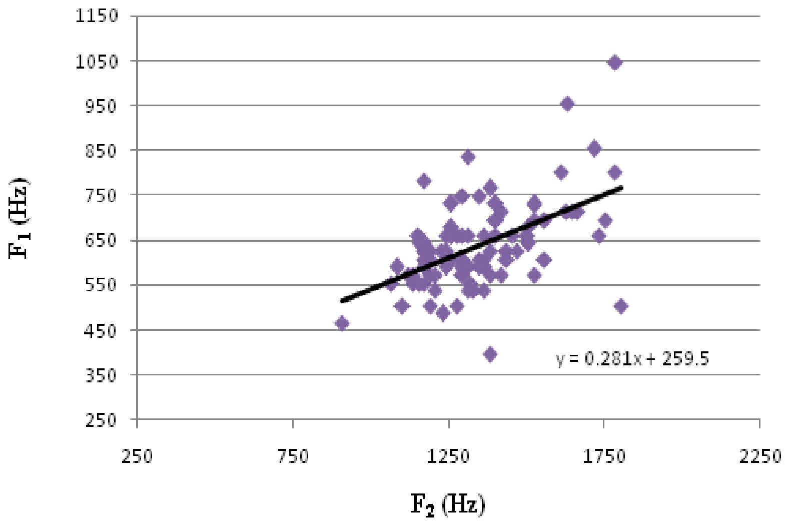


Figure 18: Isovowel line of vowel /o:/.

To summarize, results indicated higher F_2 on vowel /i/, in all the age groups, and in females.

(2) Effect of age, gender, position, length and vowel on Frequencies of first two formants

Effect of age, gender, position, length and vowel on F_1: Mixed ANOVA was done to study the main effects and interactions of within subject (age, gender) and between subject variables (length-long and short, vowel, position-initial and medial). Vowels in word-final position were analyzed separately as all the vowels were not present in that position. Results of mixed ANOVA for F_1 revealed a significant main effect of age [$F(2,84)=51.220$, $p< 0.05$], gender [$F(1,84)=4.638$, $p< 0.05$], position [$F(1,84)=15.528$, $p<0.05$], length [$F(1,84)=4.904$, $p< 0.05$], and vowel [$F(4,336)=590.296$, $p<0.05$]. Among the interactions, vowel*gender [$F(4,336)=16.618$, $p<0.05$], vowel*age [$F(8,336)=3.968$, $p<0.05$], length*vowel [$F(4,336)=15.095$, $p<0.05$], length*position [$F(1,84)=89.367$, $p<0.05$], vowel*position [$F(4,336)=92.168$, $p<0.05$] vowel*position*age [$F(8,336)=2.003$, $p<0.05$], length*vowel*position*age [$F(8,336)=2.962$, $p<0.05$], vowel*position*gender*age [$F(8,336)=2.570$, $p<0.05$], and length*vowel*position [$F(4,336)=25.826$, $p<0.05$] were significant. Post Hoc Bonferroni test results showed significant difference (0.01 level) between F_1 of all the vowels. Further, results of Duncan Post Hoc test showed significant differences between age groups on F_1 of vowels. F_1 of vowel /a/ was significantly higher than that of other vowels. Females had significantly higher F_1 compared to males. F_1 of vowels in the age group of 4-5 years was significantly higher than that in other age groups.

3-way repeated measures ANOVA and paired t-test were done to study the effect of position on F_1 of vowels across age and gender. Repeated measures ANOVA was done when the vowel occurred in all three positions, and t-test was done when the vowel occurred only in word-initial and medial positions.

Short vowels

4-5 years Males: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{F(2,28)=63.765, p<0.01}], and vowel /e/ [{F(2,28)=51.330, p<0.01}],. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position.

4-5 years Females: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{F92,28)=36.870, p<0.01}], and vowel /e/ [{F(2,28)=11.693, p<0.01}]. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position.

7-8 years Males: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{F(2,28)=20.857, p<0.01}], and vowel /e/ [{F(2,28)=20.891, p<0.01}]. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position. Results of t- test [t(14) = -2.285, p<0.05] showed significantly higher F_1 for vowel /o/ in word-medial position compared to that in word-initial position.

7-8 years Females: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{$F(2,28)=33.381$, $p<0.01$}]and vowel /e/ [{$F(2,28)=37.081$, $p<0.01$}]. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position. Results of Post Hoc test showed significant difference between word-medial and word-final position of F_1 of vowel /i/ in females in the age 7-8 years. F_1 of vowel /i/ in females was significantly higher in word-medial position compared to that word-final position.

18-20 years Males: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{$F(2,28)=19.819$, $p<0.01$}], and vowel /e/ [$F(2,28)=65.928$, $p<0.01$}]. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position. Results of t-test showed that F_1 of vowel /u/ was significantly higher in word-medial position compared to that in word- final position.

18-20 years Females: Results of repeated measures ANOVA showed main effect of position on F_1 of vowel /a/ [{$F(2,28)=54.202$, $p<0.01$}], and vowel /e/ [{$F(2,28)=39.897$, $p<0.01$}]. Results of post-hoc test showed that F_1 of vowels /a/ and /e/ was significantly higher in word-medial and word-initial position, respectively compared to that in word-final position. Results of post-hoc test also revealed that F_1 of vowel /u/ was significantly higher in word-final position compared to that in word-initial position.

Long vowels

4-5 years Males: Results of t-test [{t(14)=-2.829, p<0.05}] showed significantly higher F_1 of vowel /o:/ in word-medial position compared to that in word-final position.

4-5 years Females: Results of t-test [{t(14)=-2.933, p<0.05}] showed significant difference between positions for vowel /i:/. F_1 of vowel /i:/ was significantly higher in word-initial position compared to that in word-medial position.

7-8 years Males: Results of t-test [{t(14)=-2.386, p<0.05}] showed significant difference between positions for vowel /i:/. F_1 of vowel /i:/ was significantly higher in word-medial position compared to that in word-initial position. Results of t-test [{t(14)=-3.889, p<0.05}] showed significantly higher F_1 of vowel /o:/ in word-medial position compared to that in word-final position.

7-8 years Females: Results of t-test [{t(14)=-2.267, p<0.05}] showed significant difference between positions for vowel /i:/. F_1 of vowel /i:/ was significantly higher in word-medial position compared to that in word-initial position.

18-20 years Males: Results of t-test [{t(14)=-5.446, p<0.01}] showed significant difference between positions for vowel /i:/. F_1 of vowel /i:/ was significantly higher in word-medial position compared to that in word-initial position. Results of Repeated measures ANOVA [F(2,28)=7.224, p<0.05] showed significant main effect of position for F_1 of vowel /u:/. F_1 of vowel /u:/ was significantly higher in word-medial compared to that in word-final position. Results of t-test [{t(14)=-

8.630, $p<0.05$}] showed significantly higher F_1 of vowel /o:/ in word-medial position compared to that in word-final position.

18-20 years Females: Results of t-test [{$t(14)=-2.267$, $p<0.05$}] showed significant difference between positions for vowel /i:/. F_1 of vowel /i:/ was significantly higher in word-medial position compared to that in word-initial position. Further, the results of Repeated measures ANOVA [$F(2,28)=7.224$, $p<0.05$] showed significant main effect of position for F_1 of vowel /i:/.

To summarize, results indicated that F_1 of vowels were higher in word-medical position most of the times.

Effect of age, gender, position, length and vowel on F_2: Results of mixed ANOVA for F_2 revealed a significant main effect of vowel [$F(1,84)=42.482$, $p<0.05$], length [$F(4,336)=3806.95$, $p<0.05$] and position [$F(1,84)=53.840$, $p<0.05$]. Among the interactions, vowel * gender [$F(4,336)=32.065$, $p<0.05$], vowel * age [$F(8,336)=66.930$, $p<0.05$], vowel * gender * age [$F(8,336)=4.650$, $p<0.05$], position * age [$F(2,84)=4.616$, $p<0.05$], length * vowel [$F(4,336)=45.663$, $p<0.05$], vowel * position [$F(4,336)=24.681$, vowel * position * gender [$F(4,336)=2.860$, vowel * position * age [$F(8,336)=3.129$, $p<0.05$], length * vowel * position [$F(4,336)=23.262$, $p<0.05$], length * vowel * position * age [$F(8,336)=3.237$, $p<0.05$] were significant. Results of Post Hoc Bonferroni test showed significant difference (0.01 level of significance) between F_2 of all the vowels except /u/ and /o/. Further results of Duncan's Post Hoc test showed significant difference across age groups. F_2 of vowel /i/ was significantly higher than that of other vowels. Females had significantly higher F_2 compared to males. F_2 of vowels in the age group of 4-5 years was significantly higher than that in other age groups.

3-way repeated measures ANOVA and paired t-test were done to study the effect of position on F_1 of vowels across age and gender. Repeated measures ANOVA was done when the vowel occurred in all three positions, and t-test was done when the vowel occurred only in word-initial and medial positions.

Short vowels

4-5 years Males: Results of repeated measures ANOVA [{$F(2,28)=17.984$, $p<0.01$}] showed main effect of position on F_2 of vowel /a/, and vowel /e/ [[{$F(2,28)=47.461$, $p<0.01$}]. Results of post-hoc test showed that F_2 of vowel /a/, and /e/ was significantly higher in word-medial position compared to that in word-final position.

4-5 years Females: Results of repeated measures ANOVA [{$F(2,28)=17.459$, $p<0.01$}] showed main effect of position on F_2 of vowel /a/, and vowel /e/ [{$F(2,28)=47.457$, $p<0.01$}]. Results of post-hoc test showed that F_2 of vowel /a/ was significantly higher in word-medial position compared to that in word-final position; F_2 of vowel /e/ was significantly higher in word-initial position compared to that in word-final position.

7-8 years Males: Results of repeated measures ANOVA [{$F(2,28)=4.082$, $p<0.05$}] showed main effect of position on F_2 of vowel /a, and vowel /e/ [{$F(2,28)=47.073$, $p<0.01$}]. Results of post-hoc test showed that F_2 of vowels /a/ and /e/ was significantly higher in word-medial position compared to that in word-final position.

7-8 years Females: Results of repeated measures ANOVA [{$F(2,28)=14.583$}]

showed main effect of position on F_2 of vowel /a/, vowel /i [F(4,28)=4.946, p<0.05], and vowel /e/. Results of post-hoc test showed that F_2 of vowels /a/, and /i/ was significantly higher in word-medial position compared to that in word-final position; F_2 of vowel /e/ was significantly higher in word-initial position compared to that in word-final position.

18-20 years Males: Results of repeated measures ANOVA [{F(2,28)=38.619, p<0.01}] showed main effect of position on F_2 of vowel /a/, vowel /u/ [{F(2,28)=27.197, p<0.01}], and vowel /e/ [{F(2,28)=36.578, p<0.01}]. Results of post-hoc test showed that F_2 of vowels /a/, /u/, and /e/ was significantly higher in word-medial position compared to that in word-final position. Results of t-test [t(14)=-4.153), p<0.05] showed significantly higher F2 of vowel /o/ in word-medial position compared to that in word-initial position.

18-20 years Females: Results of repeated measures ANOVA [{F(2,28)=58.001}] showed main effect of position on F_2 of vowel /a/, vowel /u/ [F(2,28)=17.297, p<0.01}] and /e/ [{F(2,28)=60.798, p<0.01}]. Results of post-hoc test showed that F_2 of vowels /a/, and /u/ was significantly higher in word-medial position compared to that in word-final position; F_2 of vowel /e/ was significantly higher in word-initial position compared to that in word-final position.

Long vowels

4-5 years Males: Results of t-test [{t(14)=-4.404, p<0.05}] showed significantly higher F_2 for vowel /o:/ in word-medial position compared to that in word-initial position.

4-5 years Females: Results of 3-way repeated measures ANOVA [[{F(2,28)=4.471, p<0.05}] revealed main effect of position on F_2 of vowel /u:/. F_2 of vowel /u:/ was significantly higher in word-initial position compared to word-final position. Results of t-test [{t(14)=-3.086, p<0.05}] showed significantly higher F_2 for vowel /o:/ in word-medial position compared to that in word-initial position.

7-8 years Males: Results of t-test [{t(14)=-5.477, p<0.01}] showed significantly higher F_2 for vowel /o:/ in word-medial position compared to that in word-initial position.

7-8 years Females: Results of t-test [{t(14)=-3.086, p<0.05}] showed significantly higher F_2 for vowel /o:/ in word-medial position compared to that in word-initial position.

18-20 years Males: Results of t-test [{t(14)=-4.676, p<0.01}] showed significantly higher F_2 for vowel /a:/, vowel /i:/ [{t(14)=-4.676, p<0.05}], and vowel /o:/ [{t(14)=-8.486, p<0.01}] in word-medial position compared to that in word-initial position; F_2 of vowel /e:/ [t(14)=3.810, p<0.05] was significantly higher in word-initial position compared to word-medial position. . Results of repeated measures ANOVA [{F(2,28)=4.529, p<0.05}] revealed main effect of position on F_2 of vowel /u:/. F_2 of vowel /u:/ was significantly higher in word-initial position compared to word-final position.

18-20 years Females: Results of t-test [{t(14)=-5.542, p<0.01}] showed significantly higher F_2 for vowel /a:/, vowel /i:/ [{t(14)=-6.805, p<0.01}], and vowel /o:/ [{t(14)=-7.297, p<0.01}] in word-medial position compared to that in word-initial position.

To summarize, results indicated that F_2 of vowels were higher in word-medical position most of the times.

Effect of vowel length on F_1 of vowels

4- 5 years Males : Results of Paired t test showed significantly higher F_1 in short vowel /i:/ compared to long vowel /i:/ in word-initial position [t(14)=2.891, p<0.05] and vice versa for vowel /a/ [t(14)=-2.785, p<0.05] in word-medial position.

4-5 years Females: Results of Paired t test showed significantly higher F_1 for long vowel/a:/ compared to short vowel /a/ [t(1)=-3.066, p<0.05] in word-medial position and for vowel /e/ [t(14)=-2.733, p<0.05] in word-initial position.

7-8 years Males: Results of Paired t test showed significantly higher F_1 for long vowel /i:/compared to short vowel /i/ [t(14)=-2.981, p<0.05] in the word-medial position and significantly lower F_1 for short vowel /e/ compared to long vowel /e:/ [t(14)=-2.540, p<0.05] in word-medial position.

7-8 years Females: Results showed significantly higher F_1 for long vowel /a:/ compared to short vowel vowel /a/ [t(14)=-2.981, p<0.05] in the word-medial position.

18-20 years Males: Results showed significantly higher F_1 for short vowel /a/ [t(14)=-3.126, p<0.05] in word-initial and word-medial positions [t(14)=-5.631, p<0.01], short vowel /i/ [t(14)=4.158, p<0.05] compared to long vowel vowels in word-initial position; short vowel /u/ [t(14)=2.934, p<0.05] in word-initial and word-final [t(14)=3.216, p<0.05 positions and higher F_1 in long vowel /u:/ [t(14)=-2.301, p<0.05] in word-medial position.

18-20 years Females: Results showed significantly higher F_1 for long vowel /a:/ [t(14)=-7.070, p<0.01] compared to short vowel vowel /a/in the word-medial position, significantly higher F_1 for short vowel /i/ [t(14)=2.628, p<0.05] compared to long vowel /i:/ in word-initial position, /u/ [t(14)=3.665, p<0.05] in word-initial [t(14)=2.484, p>0.05] and /o/[t(14)=5.444, p<0.01] in word-final position.

To summarize, vowel length did not have any pre-determined effect on F_1 of vowels.

Effect of vowel length on F_2 of vowels

4- 5 years Males : Results of Paired t test showed significantly higher significantly higher F_2 for short vowel /a/ [t(14)=3.374, p<0.05] in word-initial and word- medial position [t(14)=5.478, p<0.01], vowel /u/ [t(14)=2.434, p<0.05] and vowel /e/[t(14)=2.359, p<0.05] in word-medial position, vowe /o/ [t(14)=4.271, p<0.05] in word-initial position. Results also showed significantly higher F_2 for long vowel /i:/ [t(14)=-3.015, p<0.05] in word-medial position.

4-5 years Females: Results revealed significantly higher F_2 for short vowel /a/ [t(3.010, p<0.05] in word-initial and word-final positions [t(14)=5.608, p<0.01]; vowel /o/ [t(14)=2.507, p<0.05] in word-initial position, and significantly higher F_2 for long vowel /i:/ [t(14)=-3.473, p<0.05] in word-medial position.

7-8 years Males: Significantly higher F_2 for short vowel /a /[t(14)=2.580, p<0.05] in word-initial and word-medial positions [(14)=4.581, p<0.01]; vowel

/o/ [(t)=3.318, $p<0.05$] in word- initial position, and significantly higher F_2 for long vowel /i:/ [t(14)=-3.093, $p<0.05$] in word-medial position was observed.

7-8 years Females: Results showed significantly higher F_2 for short vowel /a/ [t(14)=2.614, $p<0.05$[in word-initial and word-medial position[t(14)=4.392, $p<0.05$] ; vowel /o/ [t(14)=2.542, $p<0.05$] in word-initial position, and significantly higher F_2 for long vowel /i:/ [t(14)=-3.093, $p<0.05$] in word- medial position.

18-20 years Males: Results showed significantly higher F_2 for short vowel /a/ [t(14)=3.877, $p<0.05$] in word-initial and word-medial position [t(14)=4.155, $p<0.05$], vowel /u/ [t(14)=5.715, $p<0.01$] in word- medial position, and vowel /o/ [t(14)=3.022, $p<0.05$] in word-initial position. Significantly higher F_2 for long vowel /i:/ [t(14)=-5.335, $p<0.01$] in word-medial position was also observed.

18-20 years Females: Results showed significantly higher F_2 for short vowel /a/ [t(14)=5.976, $p<0.01$] in word-initial and word-medial position [t(14)=8.017, $p<0.01$], vowel /u/[t(14)=3.263, $p<0.05$] in word-medial position, and vowel /o/ [t(14)=3.263, $p<0.05$] in word-initial position. Significantly higher F_2 for long vowel /u:/ [t(14)=-6.468, $p<0.01$] in word-initial position was also noticed.

To summarize, vowel length did not have any pre-determined effect on F_2 of vowels.

CHAPTER V

DISCUSSION

The results indicated several points of interest. First of all, ***vowel /a/ has the highest F_1 and vowel /i/ has the highest F_2 across all age groups and gender.*** The results are in consonance with those of Peterson and Barney (1952), Eguchi and Hirish (1969), Hillenbrand, Getty, Clark, and Wheeler (1995), Kushalraj (1983), Sreedevi (2000), Riyamol (2007), Lee and Iverson (2008), and Krishna (2009). Formant frequencies of vowels are dependent on tongue height or tongue advancement. As the height of the tongue increases, the frequency of the first formant (F_1) decreases and the second formant frequency (F_2) is directly related to the tongue advancement/position (Fant, 1960). A consistent lowering of F2 is observed as the front cavity is enlarged. This is due to the retraction of tongue. A general rising of F1 is observed as the size of the pharyngeal cavity is decreased. Thus, one would expect a high first formant frequency if the tongue is positioned low at the back of the oral tract. The oral cavity would be roughly divided into two cavities during the production of vowels: the front and the back. Though erroneously, to a large extent, F_1 depends on the volume of the back cavity and F_2 largely depends on the front cavity volume (Fant, 1960). Thus, one would expect a high first formant frequency if the tongue is positioned low at the back of the oral tract. During the production of vowel /a/, the tongue height is lowest as compared to other vowels which increase the F_1. Vowel /i/ is a front vowel, thus having the maximum tongue advancement which increases the F_2. This explains the highest F_1 of vowel /a/ and highest F_2 of vowel /i/.

Second, ***females had higher formant frequencies as compared to males.*** Similar findings were reported by a number of authors including Peterson & Barney, 1952; Eguchi and Hirish, 1969Tiku, 1994 in Kashmiri, Busby & Plant, 1995; Ampathu, 1998 in Malayalam, Sreedevi, 2000 in Kannada, Man, 2007, Riyamol, 2007 in Malayalam, Lee and Iverson, 2008, and Krishna, 2009 in Telugu. Earlier studies have suggested that there are clear differences in morphology of male and female vocal tract, including changes in overall length of vocal tract and the relative proportions of the oral and pharyngeal cavity. These gender differences were not apparent in children, but emerged at puberty, implying that they were part of the vocal remodelling process that appears during puberty in males (Fitch and Giedd, 1999). By 4 years of age, there is a appearance of variation in formant frequencies between genders, which becomes more evident by 8 years and distinct by 16 years of age (Vorperian & Kent, 2007). The higher formant frequencies can be attributed to the length of the vocal tract. Females have shorter vocal tract length as compared to males. Thus, high formant frequencies can be expected in oral tracts that are smaller in size (Fant, 1960).

Third, ***formant frequencies decrease with increase in age.*** The results are in consonance with other studies done in different languages across the world (Peterson & Barney, 1952-American English; Busby & Plant, 1995-Australian English; Eguchi and Hirish, 1969-English; Lee & Iverson, 2008-Korean; Chen et.al., 2013-Madarin) and in Indian languages (Ampathu 1998; Sreedevi, 2000; Krishna, 2009). Ampathu (1988), reported that the formant frequencies decreased with the increase in age from 7-8 to 20-25 years. Kent (1976) reported that the formant frequency values of children are higher than that of adult males and females. As a result of the overall development, substantial modifications appear in the speech production system. The most apparent difference between the vocal tract of a child and an adult is the length and the ratio of the horizontal oral cavity length versus the vertical pharynx length changes from 2:1 in infancy to approximately 1:1 in adulthood (Goldstein, 1980).

Structural changes, and refinement in motor control, produce varied acoustic patterns. The formant frequencies in children differ by virtue of sexual dissimilarity in jaw opening, pharynx size, and larynx position (Bennett, 1981). Between the age of 3 to 5 years, the structural development of speech articulators occurs most rapidly and then, the development of larynx is slow until puberty (Eguchi & Hirish, 1969). Formants (F1-F3) are highly sensitive to variation, with respect to age and gender; slow decrease in formant frequencies; decrease in F1-F2 area; reduction in variability of formant frequency (Vorperian & Kent, 2007).

Fourth, ***in general, the scaling between formant frequencies of 18-20 years: 7-8 years: 4-5 years varied between 1: 1.2: 1.3.*** Table 26 shows the mean of scaled values of both formant frequencies and figure 19 shows the scaling.

Age in yrs		18-20	7-8	4-5
F1 Short vowel	Male	1	1.23	1.4
	Female	1	1.15	1.22
F1 Long vowel	Male	1	1.84	1.97
	Female	1	1.76	1.82
F2 Short vowel	Male	1	1.26	1.32
	Female	1	1.18	1.19
F2 Long vowel	Male	1	1.34	1.38
	Female	1	1.27	1.24

Table 26: Mean of scaled values of both formant frequencies.

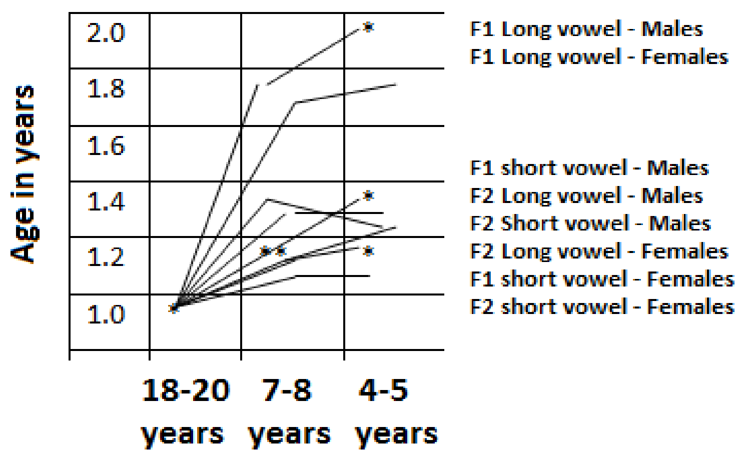


Figure 19: Scaling of formant frequencies in 3 age groups.

Fant (1975) has established links between the female/child vocal tract relationship when compared to the male/female and male/child relationships. This may imply a more uniform scaling between child and female vocal tract dimensions. However there are various factors which could influence the data used within the respective analyses. Vowel quality, and thus formant height may be influenced by dialect and articulatory behavior.

The pharynx has mainly skeletal muscular walls approximately 13 cm in length in an adult male lies parallel to the cervical region of the spinal column and runs from the base of the skull to 6^{th} cervical vertebra. It has three regions – nasopharynx, oropharynx, and laryngopharynx. The pharynx is funnel shaped. The oral cavity – oral cavity proper and the vestibule region – runs parallel to the anterior hard palate and soft palate and junctures with the oropharynx. Oral cavity varies in its epithelial composition, in some places the epithelium being strengthened by keratin (Martland, Whitefield, Beet & Baghal-Ravary, a175.pdf).

"Earlier research has shown that certain vocal tract dimensions are similar when height, weight and age are controlled, but the participants should also be considered in terms of their gender related development patterns. the rates of growth are noticeably different for males and females. This may lead to difficulties when using such data to create synthetic voices, since the averaged formant frequencies may be raised or lowered in favour of the dominant gender over a specific age range. This is further complicated by the differing growth rates within each gender, which can be estimated by considering a subjects height for a given age" (Martland, Whitefield, Beet & Baghal-Ravary, a175.pdf). The differences in formant frequency obtained between age groups in the present study can be attributed to the language and the dimensions of the paryngeal and the oral cavity in these age groups. It can be observed that greater changes were observed in males compared to females.

Fifth, ***there were small differences between short and long vowel pairs in F_1 and F_2 values.*** Stevens and House (1963) investigated the formant of American English Vowels in the context of 14 consonants. Results revealed that, the first formant shifts are quite small. For front vowels, there is a downward shift in F2 due to the consonantal environments and the shift is noticed to a larger extent for lax (short vowels) compared to tense vowels. The consonantal environment surrounding the vowels also brought about considerable differences in the vowel formant frequencies between speakers. The authors found that different consonantal contexts affected the formant frequencies of vowels and that they varied significantly from one to another. Yet another observation was that, the consonantal context causes orderly shifts in the formant frequencies based on the place of articulation, manner of articulation, and voicing characteristics of the consonant. In Indian context, the differences in formant frequencies of short and long vowels were reported by Tiku (1994) in Kashmiri, Jensen and Menon (1972) in Malayalam, and Krishna (2009) in Telugu.

Sixth, ***formant frequencies varied depending on the position of vowels in the word.*** Most often, formant frequencies were higher in word-medial position than any other position. This can be attributed to the coarticulation of neighbouring consonants. Coarticulation refers to the influence of a preceding or following speech sound on a speech sound which sometimes may become more like the influencing speech sound. There are two types of coarticulation: anticipatory coarticulation, when a feature or characteristic of a speech sound is anticipated (assumed) during the production of a preceding speech sound; and carryover or perseverative coarticulation, when the effects of a sound are seen during the production of sound(s) that follow. The term coarticulation may also refer to the transition from one articulatory gesture to another (Terry, 1997).

Finally, ***vowel /u/ and /u:/ had higher F_2 compared to the results of earlier studies in other langauges.*** However, the F_2 was almost similar to those reported by Sreedevi (2000) in Mysore Kannada. The results of the present study may be owing to the less lip rounding in Tulu.

The results of the present study have formed the database of formant frequencies of vowels Tulu. The results obtained in the present study can be used indirectly to imply tongue positions of vowels used in Tulu and can form a basis for estimating formant frequencies in various age groups. The variations in formant frequencies can be attributed to a specific language or dialect and should not be mistaken as a characteristic specific to disordered speech. The data also is helpful in speaker identification (SPID). Finally the results of this study have the potential to provide the grounds for the next phase of research to directly compare across the dialects of Tulu to determine the presence or absence of differences.

The sample size considered for the study was small - fifteen males and fifteen females in each age group – and three age groups and hence the results obtained from the study cannot be generalized to the entire population. However, the data obtained in the present study provides the foundation for the characteristics of vowels in Tulu from which further research can be conducted. Future studies can on the larger sample size and various other age groups of Tulu speakers is warranted.

CHAPTER VI

SUMMARY AND CONCLUSION

Speech is a unique form of communication in which the speech waves in the form of acoustic energy transmits the information. The interaction of one or more source with the vocal tract filter system results in speech waveforms (Fant, 1960). Speech sounds are most commonly divided into vowels and consonants. A vowel sound is usually formed as sound energy from the vibrating vocal folds escapes through a relatively open vocal tract of a particular shape. . Each vowel has a specific, characteristic vocal tract shape which is determined by the position of-the tongue, jaw, and lips. Vowels can be distinguished from consonants based on the patterns of acoustic energy. Vowels demonstrate at least two formant areas, as they are highly resonant. Thus, vowels are more intense compared to consonants (Ladefoged & Johnson, 2010; Buaman-Waengler, 2012).

Acoustically, vowels can be classified based on the formant pattern, shape of the vocal tract, spectrum, and duration. The peaks of the sound spectrum are called as formants. The frequencies of such peaks are termed formant frequencies. Formant frequencies of vowels are dependent on tongue height or tongue advancement. As the height of the tongue increases, the frequency of the first formant (F_1) decreases, and the second formant frequency (F_2) is directly related to the tongue advancement/position (Fant, 1960). The oral cavity would be roughly divided into two cavities during the production of vowels - front cavity and back cavity. Though erroneously, to a large extent, F_1 depends on the volume of the back cavity and F_2 largely depends on the front cavity volume (Fant, 1960).

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).

Tulu language is considered as one of the five Dravidian languages; other four being Telugu, Tamil, Kannada and Malayalam. It is spoken in Udupi district and Dakshina Kannada district of Karnataka state and also spoken in the northern part of Kerala state. In India, 1.72 million people speak it as their native language, which is increased by 10 percent over the 1991 census (census 2001). There is no literature which explains about the changes in formant frequencies across gender and age in Tulu language. Hence the present study aimed at analyzing the frequencies of first two formants of 10 vowels in Tulu and measured the main effect of age and gender. The objectives of the study were to (a) investigate the frequencies of first two formants of Tulu vowels, (b) determine the effect of age (4-5years, 7-8years, 18-20 years) on frequencies of first two formants of Tulu vowels, (c) determine the effect of gender (males and females) on frequencies of first two formants of Tulu vowels, and (d) determine the effect of position and length on the frequencies of the first two formants of Tulu vowels.

Participants included normal Tulu speaking 15 males and 15 females each in the age range of 4-5years, 7-8years and 18-20years. A list of 25 picturable words consisting ten vowels in different word positions was used as stimuli. Participants were instructed to name the pictures presented visually on a laptop screen thrice. The participant was prompted if he/she was not able to name the picture, presented in random order at a gap of 3-5 seconds. The speech sample was audio recorded using a digital voice recorder.

The speech samples were played to two Speech-Language Pathologists (native speaker of Tulu) to judge the correctness of production of vowel. For acoustic analysis, PRAAT (Boersma & Weinik, 2011) software was used. The speech Sample was depicted as spectrogram (wide band bar type) and frequencies of the first two formants of the vowels were extracted by placing the cursor in the steady state of the formant of the vowel. A commercially available SPSS was used for statistical analysis. Mean and standard deviation of formant frequencies in three age groups were calculated. Mixed ANOVA, 3-way repeated measures ANOVA and T-test were done to determine the main effects and interaction between the within subject and between subject variables on the formant frequencies.

The results of this study indicated highest F_1 in vowel /a/ in all the age groups and genders. Highest F_2 was observed in vowel /i/ in all the age groups and genders. Females had higher formant frequencies as compared to males and formant frequencies decreased with increase in age. Small differences between short and long vowel pairs in F_1 and F_2 values was noticed Formant frequencies varied depending on the position of vowels in the word. Most often F_1 and F_2 were higher in word medial position compared to word initial and word final position. Vowel /u/ and /u:/ had higher F_2 compared to the results of earlier studies in other languages.

The age, gender, length and position related data of the Tulu vowels inferred in this study would serve as a good reference in the evaluation of Tulu speaking communication impaired and also aid the professionals working with the disordered population to design appropriate treatment strategies.

The study was limited to three age groups and 30 participants in each age group. Future studies in dialectical variations in formant frequencies of Tulu vowels in different age groups and variations in formant frequencies in clinical populations are warranted.

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