ACOUSTIC CHARACTERISTICS OF VOWELS IN KANNADA

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A Thesis Submitted for the
Degree of Doctor of Philosophy (Speech and Hearing)
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August, 2000

DEDICATED TO

MY HUSBAND AND DAUGHTER

CERTIFICATE

This is to certify that the thesis entitled "Acoustic Characteristics of vowels in Kannada" submitted by Ms. N. Sreedevi for the degree of Doctor of Philosophy (Speech and Hearing) is the result of work done by her at the Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore, under my guidance.

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DECLARATION

*I declare that this thesis entitled "**Acoustic Characteristics of** vowels **in Kannada**" which is submitted herewith for the award of the degree of Doctor of Philosophy (Speech and Hearing) of University of Mysore, Mysore is the result of the work carried out by me at Department of Speech Sciences, All India Institute of Speech and Hearing, Mysore, under the guidance of Dr. N. P. Nataraja, Ph.D., Professor of Speech Pathology, Department of Speech Pathology and Audiology, Applied Sciences University, Amman, Jordan.*

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INTRODUCTION

CHAPTER 1

INTRODUCTION

"Speech is a form of communication in which the transmission of information takes place by means of speech waves which are in the form of acoustic energy. The speech waveforms are the result of interaction of one or more source with the vocal tract filter system" (Fant, 1960).

Picket (1980) stated that the study of acoustic characteristics of speech sounds will give information about the articulatory nature of the sound and also how these sounds are perceived. Acoustic analysis of speech sounds provides information about the source characteristics like fundamental frequency, intensity, filter characteristics like formant frequencies, formant band widths, and the temporal characteristics like vowel duration, consonant duration apart from the spectral characteristics. The speech sounds are mainly classified into vowels and consonants. In speech, vowels are acoustically dominant because of their higher energy levels and longer duration than the consonants. Vowels are the result of interaction of minimally obstructed vocal-tract and vocal fold vibration. Different vowels are produced by the modulation of laryngeal acoustic energy by various configurations of the vocal tract.

Vowels are the simplest sounds to analyze and describe acoustically. Vowels are associated with a steady state articulatory configuration and a steady state acoustic pattern. A vowel can be indefinitely prolonged as an articulatory or acoustic phenomenon. Vowels are characterised by formants. Males, females and children have marked differences in their formant frequency values even though they are heard to be phonetically equivalent. A close acoustic analysis of vowels reveals that they differed not only in the formant frequencies but in several other aspects as well. Lehiste & Peterson (1961) found that vowels differ from one another in the following ways: 1) Vowels have inherent differences in duration. Long and tense vowels have longer durations than short and lax vowels. Vowels produced with an open jaw position are longer than vowels produced with a relatively close jaw positions. 2) When vowels are produced with other sounds , they differ in their formant frequencies. For eg. Tense vowels tend to have proportionately short transition and long steady states and lax vowels have long transitions and short steady states.

In recent years a number of acoustic and physiological studies have been conducted concerning the development of speech motor control in young children. Reasons for investigating this phenomenon range from attempting to gain a better understanding of normal children's progress toward adult like speech production abilities and for establishing a more adequate basis for evaluating speech motor disorders in both children and adults (Kent & Forner, 1980; Robb, Saxman and Grant, 1989; Sharkey & Folkins,1985; Smith,1978; Smith & Mc Lean - Muse, 1986,1987). Regardless of the specific purposes that have prompted these studies, two measures that have frequently been discussed when comparing speech motor skills among different age groups or between normal and disordered speakers are : a) the duration of various units of speech and b) the variability of inter and intra subject duration measures. One reason for considering these parameters is that at least for children and disordered adult speakers they are thought to be global indicators of neuro motoric integrity for speech production. Such studies of the speech of both normal and disordered children and adults have commonly observed the tendencies toward decreasing duration decreasing inter and intra subject variability for normal as compared to disordered speakers.

Acoustic analysis are appropriate to test certain hypothesis about developmental changes in anatomy, motor control and phonological functions. Acoustic analysis of speech of children is safe and convenient compared to EMG, X ray etc. Acoustic analysis of infant cries have been directed towards the identification and diagnosis of developmental disorders upon the assumption that many of these disorders are signaled by deviations in an infant speech production. Bosma, Truby & Lind (1965) proposed that an infant's neurological maturity might be evaluated from factors such as stability of laryngeal co-ordinations and the mobility of vocal tract components during crying. Abnormally high FO has been considered to be indicative of asphyxia. Brain damage and hyperbilurumia and low FO may signal Down's syndrome.

Ladefoged (1975) states that even though the vowels of different languages are perceived as same, there are subtle differences between them. These differences can be studied by the acoustic analysis of the speech sounds. Hence, the study of the acoustic characteristics of vowel sounds of a language becomes important.

In English and other Western languages, many have studied the acoustic characteristics of the vowels of their respective languages. There are very few studies regarding the acoustic characteristics of the vowel system of Indian languages. In Kannada, there are only three studies which have made an attempt to measure the formant frequencies of vowels. Rajapurohit (1982) studied the formant frequencies of Kannada vowels based on the utterances of one male subject only. Similarly Savithri (1989) had analyzed the short vowels of Kannada language for the first three formants from the utterances of three male subjects. This study provided information regarding the formant frequencies for the short vowels of Kannada language Rajapurohit (1982) reported vowel duration of Kannada vowels after analyzing 405 word utterances of one subject. Savithri (1986) made a study of durations of vowels in Kannada using the utterances of ten subjects. She studied the influence of voicing, manner and point of articulation of the following consonants on vowel duration. . Venkatesh (1995) made an attempt to study the intrinsic duration , fundamental frequency and intensity, formant frequencies and bandwidth of the vowels of Kannada language in the context of a single consonant *f\d* in adult males and females. In English and other Westen languages many have stueid the acoustic characteristics of the vowels of their respective languages. But there are very few developmental studies particularly regarding the acoustic characteristics of Indian languages and more specifically in Kannada. Hence, the present study was planned to study the following temporal and spectral parameters of all the 10 vowels in Kannada in the context of 12 consonants in children, adolescents and adults :

1. Temporal parameters .

a. Duration of the vowel (VD)

b. Duration of the word having the test vowel (WD)

2. Spectral parameters

a. Formant frequency 1 (Fl)
b. Formant frequency 2 (F2)
c. Formant frequency 3 (F3)
d. Fundamental frequency at the mid point of the vowel (IFO)
e. Intensity at the mid point of the vowel (I0)

AIMS OF THE STUDY

(a) To study and compare the developmental changes in the spectral and temporal parameters of vowels in three age groups (7-8 yrs, 14-15 yrs and 25 - 30 yrs).

(b) To study the temporal and spectral parameters in males and females of the three groups

(c) To study the effect of the consonant environment on the temporal and spectral characteristics of the ten vowels in Kannada

The objectives of the present study was to de/termine some of the temporal and spectral characteritics of vowels of Kannada language (Mysore dialect). Thirty normal subjects (10 subjects each in three age groups) having Mysore dialect of Kannada as their mother tongue were chosen for the study. The sentences which had a meaningful disyllabic test word ($C_1V_1C_2V_2$) with a carrier phrase were used for the study. These words had one of the 12 consonants as C_1 and one of the ten Kannada vowels as V_1. Each subject uttered a list of 73 sentences belonging to one of the three randomized lists, which the words, with the target vowel, along with the carrier phrase. These utterances were recorded in a sound treated room . The sentences were digitized . directly using a 12 bit ADC at 16,000 sampling rate and stored on the secondary memory of a computer (Pentium - 100MHz). Only the words which were judged as 'correctly uttered ' by three judges were considered for further analysis.

Hypotheses **proposed** in **the study**

1. There is no significant difference across different age group in terms of temporal parameters in Kannada language.

2. There is no significant difference across different age group in terms of spectral parameters in Kannada language.

.3. There is no significant difference across males and females in terms of temporal parameters in each age group.

4. There is no significant difference across males and females in terms of spectral parameters in each age group.

Implications of **the study**

1. This study provides the acoustic and temporal description of all the Kannada vowels in three diferent age groups, i.e, children, adolescents and adults. Hence a developmental trend of these measures considered are obtained.

2. This information can be used in evaluating the speech deviations of patients with various speech disorders.

3. The data obtained is useful in synthesizing Kannada speech sounds and recognition of the same.

4. The study also provides information on the effect of various consonantal contexts on the vowels.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

It is believed that speech evolved as a result of the many disadvantages of hand signals or gestures. Sir Richard Paget (1930) sums up this speculation quite neatly. " What drove man to the invention of speech , was, as I imagine , not as much the need of expressing^ his thoughts (for that might have been done quite satisfactorily by bodily gesture) as the difficulty of 'talking with his hands full'. It was the continual use of man's hands for craft man ship, the chase, and the beginnings of art and agriculture, that drove him to find other methods of expressing his ideas, namely, by a specialized pantomime of the tongue and lips".

The final frame of reference for considering the nature of language and speech development in man is from studies of the brain and the vocal tract. There is some evidence that the temporo-parietal association cortex, critical to language, has increased in size as hominids evolved to the homogenus. Also the earliest homo skull fragments reflect a large Broca's area, important to the motor control of speech, than that in primates outside the homogenus. Geschwind (1967) of the Harvard Medical School in Boston has demonstrated that the primary receptive areas in the brains of man and apes are similar; the difference between them lies in the development in man's brain of primary association areas, especially the temporo parietal area which conveniently lies in the midst of the auditory, visual, and motor-sensory area. The development of this association area presumably accounts for the naming behavior in man.

The vocal tract has also changed during hominid evolution. The larynx has evolved from an organ adapted especially for respiration to one which, after other adaptations to such changes as erect posture, was finally uniquely adapted for sound production in human speech. The supralaryngeal area has also evolved because. of several factors: the improvement of vision over olfaction as a means of gaining information about other animals and the need to produce a wide variety of distinctive sounds. The final adaptation of the vocal tract for speech is unique in the homogenus (Borden& Harris (1980).

Negus (1949) a British physiologist was the first to systematically study the evolution of the larynx and the vocal tract. He illustrated how the simple sphincter of the lung fish, which was maximally efficient for respiration (it simply worked as valve to open or close the access to the lungs), gradually changed during evolution to the complex arrangement of muscles which are found in the human larynx, differentiated to control the opening, closing, tension and shape of the vocal folds. Thus creating differences in voice quality and fundamental frequency. The tract above the larynx which in earlier species of mammals efficiently separated the digestive tract from .the respiratory tract, was first adopted in man to his upright position. Vision replaced the sense of olfaction (smell) as the primary sense, freeing the epiglottis to lower and separate from the soft palate. In sheep dogs, for example, olfaction is primary, and the epiglottis is high, making contact with the soft palate to produce a discrete respiratory channel from the nose to the lungs. Dogs can smell danger while eating, for the oral cavity is separate, and the food goes down a channel at each side of the larynx to the esophagus leading to the stomach. Thus, there is no confusion of the two channels and no danger of food entering the lungs. This separation of the respiratory and digestive tracts is also present for human babies when they are nursing. The tongue and larynx of the baby elevate, the tongue to press against the nipple and the larynx to connect with the nasal passage so the baby can continue to breathe while feeding. This arrangement is quickly lost as the baby develops, however, and young children and adults have larynges and tongues which have descended in the throat, producing a pronounced L-shaped vocal tract. This arrangement is maximally efficient for producing the large variety of distinctive sounds used in human speech, but is less efficient for respiration and digestion since they share a common pathway, the pharynx (Borden & Harris, 1980).

Lieberman, (1975) a linguist with special training in the acoustics of speech, estimated the possible vocal tract areas which each specimen might assume and fed this information to a computer programmed to computer the formant frequencies (or resonance) of all possible speech sounds. The possible resonance were compared to those known to be produced by humans to evaluate how closely each type of vocal tract might approach the sounds of speech as we know them today. The computer simulations for neonate humans and modern chimps resulted in resonance patterns which corresponded well with the actual sounds made by such vocal tracts, although the computer indicated that the chimp might be holding back. He may be able to produce a larger variety of sounds than he actually does, Greater apes and human babies produced more neutral vocal sounds such as /e/ or /a /, usually quite nasal, and are incapable of the vocal tract adjustments necessary for the more extreme vocal sounds /i/ /a/ or /u/. The simulations of vocal tract resonance which may have been possible for the 'classic' Neanderthal man and other hominids were determined in the same way. The epiglottis is close to the soft palate in the baby. The long pharynx in the adult human, which along with the oral cavity, produces the two chamber resonator distinctive in human adults. Along with the various anatomical changes in the speech system there are several acoustical changes also taking place in the speech of the children.

Speech is the key to human existence. It bridges thle differences and helps to give meaning and purpose to life. Travis (1971) defines communication as the process by which the individual interacts with his or her environment and with himself or herself. In the process of communication the individual relates and exchanges experiences, ideas, knowledge and feelings with others using symbols and transmits those symbols either through auditory or visual modes. For communication, human beings use several symbolic systems, eg., Speech, sign language, writing, singing, morse code......etc. Speech is one of the most commonly used and efficient modes of communication.

Skinner & Shelton (1978) define speech as a process of encoding the linguistic message by producing coded vocal patterns which become meaningful to the listener with the background of the same language. It is well known that no one definition can encompass all aspects of "speech" completely. According to Fant (1960) "speech is a form of communication in which the transmission of information takes place by means of speech waves which are in the form of acoustic energy. The speech is the result of the interaction of source and filter" i.e.,

$$P = S*T$$

where P = Speech, S = Source, mainly glottal pulses
T = Transfer function of the vocal tract

Thus the speech is a coded complex acoustic signal which is produced by the action of vocal tract and has an encoded linguistic message.

To understand the nature and function of speech, it is necessary to know the mechanism involved in the production of speech. Speech production is a process where the concepts, ideas and feelings are converted into linguistic code; linguistic code into neural code; neural code into muscular (articulatory) movement and finally muscular movement leads to acoustic signal (Ainsworth, 1975). Hence, speech is just a particular type of acoustic signal and its production can be explained in terms of source signal and resonance of the vocal tract. It can be analyzed into its component frequencies and intensities by conventional methods.

The vocal tract, the apparatus used for speech production, is evolved primarily as a part of the respiratory and digestive systems. Human beings have learnt to use these systems to produce speech. Vocal apparatus consists of the lungs, trachea, larynx, pharyngeal, oral and nasal cavities. In the process of breathing, air is drawn into the lungs by expanding the rib cage and lowering the diaphragm. This reduces the pressure in the lungs and air flows in, usually via. Nostrils, nasal tract, larynx and trachea. The air is normally expelled by the same route. By contracting the rib cage and relaxing the diaphragm. This increases the air pressure in the lungs and the air flows out.

While speaking, the lungs are filled with air and the pressure inside the lungs is increased by the contraction of rib cage and diaphragm. This increase in pressure forces the air from the lungs to the environment. At the superior end of the trachea, there is a structure known as larynx. The larynx is a valvular system consisting of three valves. The lower most valve is formed by vocal folds and is made up of ligaments and muscles. The orifice between the vocal folds, the glottis, is opened, by the pressure of expiratory air.

Once the vocal folds are opened the pressure below the vocal folds reduces due to the escape of air. As the air flows through the glottis, the subglottal pressure is reduced. The air flow from subglottal cavity to supraglottal cavity through a narrow opening, leads to a negative pressure at the glottis, and draws the vocal folds together which can be explained using the Bernouli principle. The elasticity of the vocal folds also helps in drawing the vocal folds to the midline. As the vocal folds close, the pressure again builds up, forcing the folds apart and the cycle is repeated, thus the vocal folds are set into vibration. This process produces a weak quasi-triangular acoustic signal and is known as phonation. The quasi-triangular air pulses so produced excite the resonance cavities in the oral and nasal tracts. The sound will radiate from lips or from the nostrils depending upon the closing and opening of the velopharyngeal port respectively. The rate at which the vocal folds vibrate depends upon its tension, mass, length and the sub glottal air pressure. The sounds generated by the vibration of vocal folds are known as voiced sounds. The voiceless sounds, are produced by a turbulent flow of air caused by a constriction at some point in the vocal tract. This constriction may be formed by the lips, the tongue or the velum. Another source of excitation can be created by closing the vocal tract completely or partially at some point, allowing the pressure to build up, and then suddenly releasing it or creating the friction of air. This form of excitation is employed in the production of plosive or fricative consonants. The modulated or unmodulated airflow through the glottis is further modified by the vocal tract to form speech sounds, which are mainly divided into vowels and consonants.

The vowels are produced by voiced excitation of the vocal tract. For the production of a vowel the vocal tract normally maintains a relatively stable shape and offers minimal obstruction to the air flow. This facilitates the laminar flow of glottal pulses through the vocal tract. During the production of vowels in Kannada (an Indian language), the velum is normally elevated to prevent the excitation of the nasal tract. In some languages such as French, the vowel nasalization is phonemic in nature.

The vocal tract may be considered to be a tube of about 17cm long, closed at the source end (the glottis) and open at the radiatory and (the lips). The cross sectional area of the vocal tract is small compared to its length, so acoustic waves propagate longitudinally in the tract. These waves may be described by the sound pressure (p), and the volume velocity (u), as functions of distance along the tract from the glottis.

In the production of vowel sounds, the action of the glottis forms the basic source of sound and this sound is then propagated through pharynx and oral tract to out side. Here, the vocal tract acts as a filter that emphasizes some of the components of the source sound, namely those at and near the resonant frequencies of the tract. Therefore, it was possible to state that the formation of vowels as the result of filtering action of the pharyngeo-oral tract on the sound source produced by the glottis. This theory led to the first production of "model vowel" based on vocal tract shape. The source-filter theory explains generation of vowel spectra, in detail, as combination of: (a) the spectrum of the glottal sound source (b) the filtering of this spectrum and (c) it's transmission through the vocal tract.

Tosi (1979) defines vowel "as a continuant sound (it can be produced in isolation without changing the position of articulators), voiced (using the glottis as the primary source of sound), with no friction (noise) of air against the vocal tract". In other words, vowel "is a speech sound resulting from the unrestricted passage of the laryngeally modulated air stream, radiated through the mouth or nasal cavity without audible friction or stoppage". (Nicolosi, Harryman & Kreshech, 1978). Vowels are described in terms of:

(a) the relative position of the constriction of tongue in the oral cavity (front, central and back)
(b) the relative height of the tongue in the oral cavity (high, mid and low) :
(c) the relative shape of the lips (spread, rounded and unrounded)
(d) the position of the soft palate (nasal and oral)
(e) the phonemic length of the vowel (short and long)
(f) the tenseness of the articulators (lax and tense)

Consonants are defined as the speech sounds produced with or without vocal fold vibration, by certain successive contractions of the articulatory muscles which modify, interrupt, or obstruct the expired air stream so that its pressure is raised and facilitates the production of burst or frication etc., (Nicolosi, Harryman & Kreshech, 1978). Consonants are described based on:

(a) the manner of articulation (stop, fricative, affricate, glide, trill.... etc.)
(b) the place of articulation (bilabial, dental, alveolar, retroflex, velar... etc.)
(c) role of vocal folds (voiced and voiceless)
(d) the position of the soft palate (nasal and oral)

The vowels serves the following purposes:

1) Vowels are the segmental sounds of speech. They carry information as the vowels are longer in duration and higher in energy, they carry the speech for a longer distance, i.e., in speech transmission the vowels act like carriers.
2) Even though the consonants carry more information, due to their non linearity, shorter duration and low energy they diminish very fast. Hence it is difficult for the listener to perceive them. Vowels like string binds the consonants together and helps even in the perception of consonants and thus speech.

3) As the vowels are voiced and of longer duration, the speech prosody (intonation, stress and rhythm) is determined by the vowels.

Vowel System of Kannada Language

Kannada is the official and local language of Karnataka State in India and spoken by nearly 36.5 million people (1991 Census, Government of India). This is one among the four important Dravidian languages, which is spoken predominantly in South India. Kannada language has the high level, recorded literary history for past eleven centuries. Even though dialectical and style variation can be observed for each distinct, this language has five district dialects namely Mysore, Mangalore, Dharwad, Gulbarga and Shimoga dialects (Upadhyaya, 1976). The Mysore dialect of Kannada is considered as the standard dialect and predominantly used in literary works viz., books, newspapers, radio, television and cinemas. Hence, the vowels of Mysore Kannada dialect were selected for the present study.

Nayak (1967) states that / ae,), ^ / vowels are present in the colloquial Kannada as allophonic variations of /e:, o, and a/ vowels. Nayak (1967), Upadyaya (1972), Schiffman (1979), Andronov (1982), Rajpurohit (1982) and Venkatesh (1995) have listed and described the vowels of Kannada language. The detailed description of the vowels present in the Mysore dialect of Kannada are given below.

/a/ short low central vowel
/a:/ long low central vowel
/ i / short high front unrounded vowel
/ I:/ long high front unrounded vowel
/ u / short high back rounded vowel
/u:/ long high back rounded vowel
/e / short mid-front unrounded vowel

/e:/ long mid-front unrounded vowel
/o/ short mid-back rounded vowel
/o:/ long mid-back rounded vowel

To understand the speech sounds of a language it is necessary to learn about the articulatory and acoustic nature of the speech sounds. Earlier, phoneticians have described the articulatory nature of speech sounds thoroughly. However, the speech sounds are perceived by the human being as an acoustic event. These acoustic events are the consequence of articulatory movements. Hence the study of acoustic characteristics of speech sounds will give information about articulatory nature of the sound and also how these sounds are perceived (Picket, 1980). As anatomical canges accompany acoustical changes also with increase in age, these changes are reviewed in the following section.

Development of speech in terms of anatomical changes:

Marked anatomical differences for the organs of speech production have been documented between children and adults. Significant differences between the infant and adult vocal tracts have been observed. There are well defined anatomical differences between the vocal mechanism of adult males and females, as well as acoustic and perceptual differences between their vocal productions (Negus, 1949; Hollien & Shipp 1972; Fant, 1973; Singh and Murray, 1978).

According to Kent and Murray (1982) the infant's vocal tract is not simply a miniature or smaller version of the adult's (Fig 1). The differences between the two include: (1) a much shorter vocal tract; (2) a relatively shorter pharyngeal cavity; (3) a tongue mass placed relatively farther forward in the oral cavity; (4) a gradual, rather than a right-angle, bend in the oropharyngeal channel; (5) a high larynx; and (6) a close approximation of the velopharynx and epiglottis). The differences in anatomical structure affect the nature of vocal productions. For example, the close relationship of laryngeal and velopharyngeal cavities lead to nasal breathing and early nasal vocalizations by the infant. It is only after the velum and epiglottis grow farther apart, when the infant is about four to six months old, that non nasal vocal sounds first appear in significant quantities.

Kent (1981) and Laitman and Crelin (1976) are of the opinion that there are some major differences in the phonatory and resonatory anatomy between adults and infants

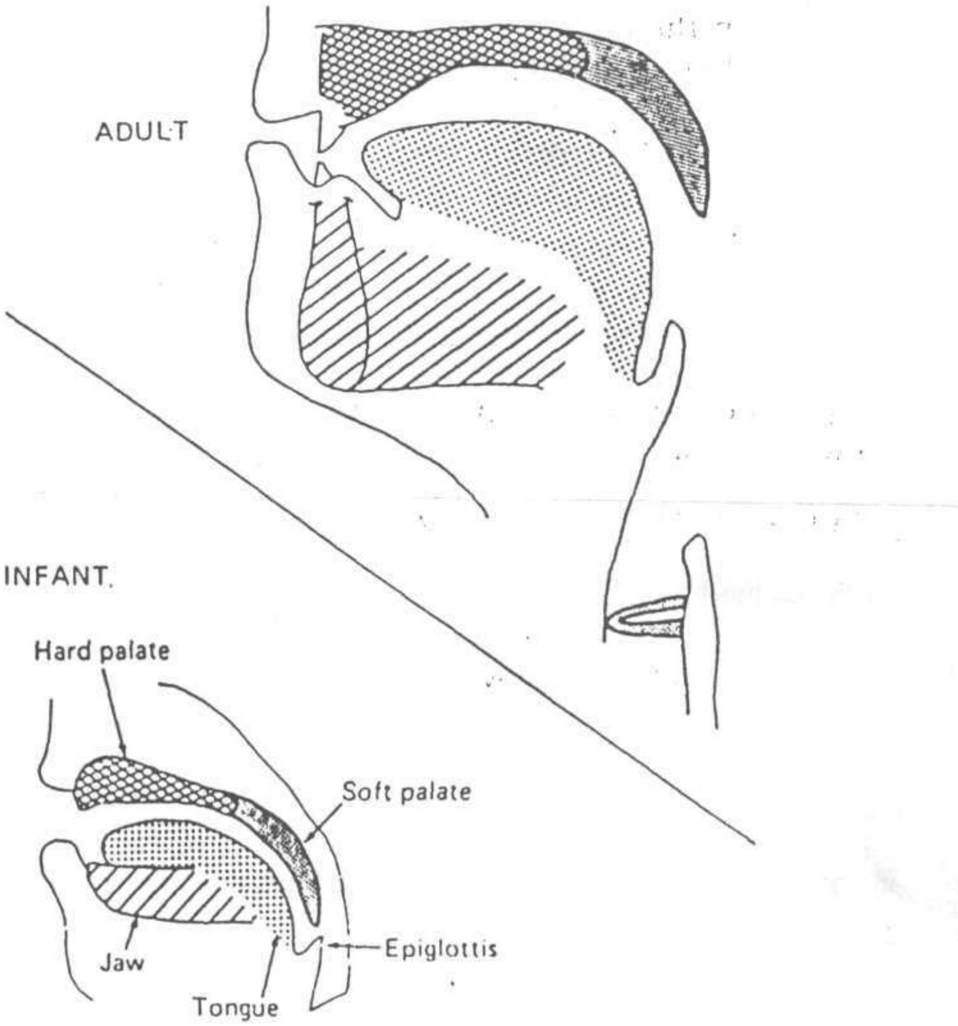


FIGURE 2-1. **Vocal tracts of adult and infant.** From R.D. Kent and A.D. Murray, "Acoustic Features of Infant Vocalic Utterances at 3, 6, and 9 Months." j *ASA,* 72 (1982): 353-365.

and one major characteristic of the adult vocal tract is that it forms a right -angle configuration at the cranio vertibral junction . That is, the oral cavity lies along a horizontal axis aligned with the spinal cord. This makes the adult vocal tract a cavity that is sharply bent around the oropharynx, giving it the right angled configuration. This configuration is absent in any other species as well as in the human infant. In the infants under six months of age, there is only a gradual bending of the oropharyngeal cavity. This infant configuration is due largely to the fact that the epiglottis is positioned very high in the oropharyngeal tract such that it is in contact with the velum, similar to the other species. In contrast, the epiglottis is positioned much lower in the vocal tract in the human adult. Additionally, in the infant, the larynx is also positioned quite high, somewhere around the second cervical vertebra (C2) position. In the adult, the larynx is positioned much lower, i.e., close to C5. This lowered position of the epiglottis and the larynx provides for a much larger oropharyngeal and pharyngeal cavity in the adult. By adulthood, the epiglottis and the velum are well separated and not in contact with each other. This decent of the larynx takes place sometime between four to six months of age and produces the sharp bending of the vocal tract in the adult (Kent, 1981; Laitman and Crelin, 1976; Sasaki et al.,1977).

"The significance of this configurational difference between the adult and infant vocal tract is well accounted. For non- speech purposes, one major consequence is that this allows for the simultaneous feeding and respiration in the infant. Infants can continue to breathe while feeding because the velum and the epiglottis are juxtaposed. The larynx needs to be closed off by the epiglottis only during the brilf moments of a swallow. A second major difference is that the infants have no control over their soft palate. Therefore, they are obligatory nasal breathers. That is, they can only breathe through the nose. However, this lack of control of the velum has a major consequence from the standpoint of speech production and language development. It impacts on the type of speech sounds that can be produced in such a vocal tract" (Gopal,1992).

It is opined that the infant is unable to produce most consonant sounds because the production of stops, fricatives and affricates require sufficient amount of air pressure in the oral cavity. In the human adult, this is made possible by sealing off the nasal passage at will by elevating the soft palate and narrowing the constriction through which the air flows in the oral cavity. In the infant, this failure to seal the nasal cavity results in the loss of air pressure; therefore, the production of most consonants is compromised. This is one major reason why infants do not produce consonant sounds before the ages of four to six months. Second, the distinction between nasal and non-nasal sounds is lost. Generation of nasal Vs non-nasal sounds requires the ability to control the soft palate at will. Absence of this control renders most vocalic sounds, even vowels, as having a strong nasal component (Kent and Murray, 1982).

Even though the vocal tract of a child is smaller in size than that of an adult, one cannot easily assume that the formants have higher frequencies in proportion to the vocal **tract with** age as a whole, because different parts of the vocal tract change at different rates. Negus (1949) pointed out that the larynx develops most rapidly between three and five years and more gradual until puberty is reached. Negus (1949) reported that the length of the vocal cord was 3 mm at birth, 5.5 mm at 1 year, 7.5 mm at 5 years 8mm at age 6.5 years, 9.5 mm at 15 years, 12.5 to 17 mm in adult females and 17 to 23 mm in adult males. Vocal cords generally lengthen rapidly up to six years and gradually after that. Kaplan (1960) reported that laryngeal growth primarily occurs during the first three years and during puberty. Naider (1965) reported that rapid development of larynx began at 13 years (in boys) and completed at approximately 15 years. Until puberty, the larynx is of equal size in males and females although both begin to enlarge at puberty, the male larynx out distances the female, especially in the growth of its antero posterior dimensions. Aronson (1990) made the following observations regarding the developmental changes in vocal system:

1. By adulthood, the membranous portions of the male vocal folds range from 11.5 to 16mm in length, a 4-8 mm increase from puberty. However, the female membranous vocal folds increase in length to only 8 to 11.5., a 1 to 3.5 mm increase.
2. The dimensions of the infra glottal sagital and transverse planes grow in the male to 25mm and 24mm., respectively, and in the female, to 18mm and 17mm respectively.
3. The angle of the male thyroid lamina decreases until it become 90 degrees, while in the female larynx, the angle remains approximately 120 degrees.
4. The laryngeal mucosa loses transparency and becomes stronger; the epiglottis flattens, increases in size, and elevates; and the tonsils and adenoids partially atrophy

5. The larynx descends in the neck. The neck itself elongates. Because of the greater enlargement of the thorax in the male, there is a more prominent increase in vital capacity.

Crelin (1973) stated that sex related changes in the larynx begin to appear as early as the third or fourth year. These, structural modifications may be greater in the preadolescent males than the preadolescent females and may result in the age related fundamental frequency lowering.

According to Kahane (1978) the anterior posterior dimension of the male cartilage is approximately 20% larger than that of the females. The membranous vocal fold lengths differ by 60%. According to Hirano (1983) membranous length of vocal fold grows at a rate of 0.4 mm for females and 0.7 mm/year for males, up to the age of 20 approximately. It has been generally thought that much of the growth in vocal fold length takes place around puberty, particularly in males. Evidence for this would be the sudden drop in F0 and the noticeable protrusion of the Adam's apple at puberty. Kahane (1978) has reported a 62% increase from age 10 to age 16 for five males and 34% increase from the age of 12 to age 16 for five females. Over the same years, the linear growth of larynx in Hirano's data is about 48% for males and about 27% for females. When the larynx is fully developed the female vocal folds will have a membranous length of about 10mm and the male about 16mm. An important aspect of vocal development is the changing morphology of vocal fold tissues. For voice classification increases in vocal fold length are a key consideration. Also important are the development of the vocal ligament and the thyroarytenoid muscle. The growth rate is 0.4 mm per year for females and 0.7 mm per year for males. This leads to a maximum adult length of around 16 mm for males and 10 mm for females. At infancy the membranous length is approximately 2 mm.

Hirano, Kurita and Nakashima (1981) have reported that "the major deviations from the model occur at ages 3 to 10 years. Length appears to increase in a rather constant manner. There may be compensating dimensional changes in the vocal fold tissue layers, or there may be changes in tissue elasticity. It is reported, for example, that development of the vocal ligament and the thyroarytenoid muscle begins at the age 3 to 4 years. This could stiffen the tissue, on the average, counteracting the drop in F0 due to increasing length. It is also possible, though less likely, that children maintain a hyper tense musculature in the larynx while producing fundamental frequencies in speech during those years. Children are able to produce sounds as loud as adults with much smaller vocal folds and lungs as higher frequency guarantees a high intensity, all else being equal. Vocal intensity increases about 8 to 9 dB per octave increase in F0. At 300 Hz their speaking F0 is about an octave higher than a male-female adult average of 150 Hz. Children's vocalizations are not simply scaled-down versions of adult vocalizations". According to Stathopoulous and Sapienza (1991), children aged four to eight years produce time-varying air flows similar to those of adults when asked to phonate at soft, comfortable, or loud levels of intensity. With membranous vocal fold lengths less than half of the adult value, this is possible only if either the lung pressure or the amplitude of vibration are significantly greater in children. They measured the lung pressure and indeed found a 50 to 60 percent greater value for children than for adults. In addition, lung volume excursion relative to vital capacity was also greater in children. Basically, then children attempted to match the vocal loudness of adults by working harder. They compromise the length of their vocal utterances to achieve this equality in loudness. It is well known that children take more frequent breaths during speech.

The most obvious vocal change in adolescence occurs during puberty, especially in males. The male hormone, testosterone, is responsible for the disproportionate growth of the larynx, along with other sexual characteristics. This disproportionate growth is primarily in the membranous vocal fold length, resulting in a protruding Adam's apple. Apart from an increase in vocal fold length , there is also an increase in the bulk of the thyroarytenoid muscle in the male pubertal larynx. The vocal fold thickens and the overall mass of the vocal fold increases. The enlarged thyroiarytenoid muscle produces a register change and changes in vocal quality. As the bottom of the vocal fold bulges out, the glottij becomes more rectangular than wedge-shaped (convergent). During vibration, then, glottal closure can be obtained over a greater portion of the vocal fold, and thereby over a greater portion of the cycle. Most of the entire body of the vocal fold is set into vibration, with greater overall amplitude. The result is a voice with rich timbre, which is called chest or modal voice.

Titze (1989) has made a comparison between male and female larynges on the basis of overall size, vocal fold membrane length, elastic properties of tissue and pre phonatory glottal shape. Two scale factors have been proposed that were useful for explaining differences in fundamental frequency, sound power, mean airflow and glottal efficiency. FO was scaled primarily according to the membranous length of vocal folds (scale factor of 1.6) where as mean airflow, sound power, glottal efficiency and amplitude of vibration included another scale factor (1.2) that was related to overall larynx size.

Oiler (1980) divided the early stages of speech developments in to phonation stage (Birth to 1 month), cooing stage (2 to 3 months) and expansion stage (4 to 6 months). Vowel production dominates infant vocalization throughout the first year. Vowels have been less extensively investigated, primarily because they are particularly difficult to transcribe reliably and, thus difficult to characterize. For example, Lieberman (1980) reported inter-transcriber reliability of 73 percent for the vowels produced by children aged about 3 to 14 months. Lieberman (1980) used spectrographic analysis as a supplement to phonetic transcription and reported little change in the average formant frequency values over the period investigated. However, the various vowels transcribed for four month olds showed considerable acoustic overlap in formant frequencies. A month later, spectrographic analysis yielded identification of a rudimentary vowel triangle. The gradual differentiation in the acoustic vowel space could be seen to continue until the age of three years. The vowels most often perceived over the entire period were lax.

Irwin (1943) has reported that it was apparent from data found in the literature that infants during the second quarter of the first year of life produce most of the vowel elements and about half of the consonants. When these results were compared with those for the first month, during which about half of the vowel elements and very few consonants were present, it became evident that a great expansion in the mastery of sounds had occurred during the fist six months.

Irwin (1948) has studied the complete course of development of each vowel sound by two month intervals from birth to two and a half years. The analysis was in terms of the percentage of the total occurrence at each of fifteen age levels considered. The analysis showed that while-most of the vowel sounds were used by young infants, only three of them, /E/, /I/and / ^/ were consistently cued by infants at the first age level (1-2 months). The new born infants vowel sound repertoire was decidedly unlike that of the adult. There was in infant vocalization, a preponderance of front and middle vowel utterances during the first year of life which there after gradually diminished, while back vowels increased until two and a half years, the percentage of distribution approximated that of the adult with out however being identical with it.

Peterson & Barney (1952) from their study of English vowels, found that children used fundamental frequencies between 250 and 275 Hz. Lieberman (1975) has stated that children's fundamental frequency ranged up to 500 hz. Age was not specified in both sources. Fairbanks, Willey and Lassman (1949) reported that average fundamental frequency in reading was 294 Hz for 7 year old boys, 297 Hz for 8 year old girls. Fairbanks (1942) has given the monthly average F0 of the cries of the infants over a 9 month period; average F0 was 373 Hz at 1 month, 415 Hz at 2 months, 485 Hz at 3 months and 585 Hz for 4 through 9 months. Sheperd & Lane (1968) recorded all vocalizations of two infants from birth through five months and reported that average F0 was 419 Hz at birth, 398 Hz at 21 days 416 Hz at 45 days and 438 Hz for the duration of the study. Keating & Buhr (1978) showed that some children often use both higher and lower fundamental frequencies than have previously been mentioned. Their data consisted of tape recordings of 6 children age ranging from 33 weeks for the youngest child to 169 weeks for the oldest child. Even though this data reflected FO values of non-cry utterances, there was considerable variations in the use of high FO among the children in the study. This finding indicates that the range of FO that could be considered normal is higher than previously reported, and the occurrence of high FO in itself may not be an indication of a pathological condition. Keating & Buhr (1978) have concluded stating that very low and very high fundamental frequencies are common of all stages of language acquisition.

There are some Indian studies also on FO of new born infants. Indira Nandyal (1982) recorded and analyzed the cry samples of 13 normal full term infants. She reported it to be varying between 398 Hz to 1470 Hz. Venugopal (1995) studied the acoustic parameters in infant cry at various developmental stages i.e., from 1st day to 3 months using Multi-dimensional voice program. The results showed that there was no consistent change in FO during this period and the FO varied from 341 Hz to 615 Hz. Visalakshi (1998) studied the FO of normal full term infants, using spectrography, age ranging from 16 hours to 11/2 months and the mean FO ranged from 318 Hz to 630 Hz. Sangeetha (2000) studied cries of 23 new born infants using multi-dimensional analysis of voice and reported the F0 to be varying from 372 Hz to 462 Hz in them.

In a study by Buhr (1980) recordings of vocal production of an infant (age 16 - 64 weeks) were subjected to perceptual and acoustic analysis. Sounds resembling the vowel sounds of English were identified and formant frequency measurements were made from spectrograms. Significant longitudinal trends for individual vowel sounds were not apparent during this period, although formant relationships for some vowels after 38 weeks were consistent with the notion of restructuring of the infant's vocal tract. Analysis of F1/F2 plots over time revealed the emergence of a well developed vowel triangle. The results of this study suggested that early infancy may be characterized by a gradual development of neuromuscular ability in the tongue, coupled with an expansion of the size and a change of shape of the oral cavity and changes in jaw movement in the production of utterances. The frontal portion (acute axis) of the vowel triangle seems to precede the back portion (grave axis) in developing a conclusion which can be anatomically based: The musculature of the lips, jaw and frontal portion of the tongue seem to develop at a faster rate than the neck, a process which may take several years. There seems to be differential development of the vowel triangle because the incidence of frontal vowels was much higher than that of back vowels. Also the analysis of the formant data indicated that only minor changes in formant relationships had occurred between 16 and 64 weeks.

Kent and Murray (1982) investigated the acoustic features of vocalic utterances at 3, 6, and 9 months (seven infants at each age). The range of Fl and F2 frequencies increased somewhat across each age interval, but the majority of the vowels used by the 9-month-old infants showed roughly the same formant pattern as did the vowels of the younger subjects. Given the anatomical differences between adults and infants, it is not surprising that the range of possible infant vowel productions should be more restricted than those of adults. In a study of 10-month-old infants vowel productions drawn from four linguistic communities-Arabic, Chinese, English, and French- de Boysson-Bardies, Halle, Sagart and Durand (1989) found that the categories of front-low and mid-central vowels accounted for the vast majority of vowels from all four groups. Acoustic analysis revealed characteristic patterns of vowel production for each group within those limits, however, with more high-front vowels for English, for example, and more low-back vowels for Chinese. The investigators interpreted these differences in vowel production to show that infants begin to position their lips and tongue in a manner specific to the language of their environment even before they produce word-forms modeled on adult speech.

It is commonly asserted in the literature that prior to adolescence there are no significant differences in the vocal mechanisms or vocal productions of boys and girls (Murphy, 1964; Luchsinger & Arnold, 1965; Kaplan 1971). Despite these assertions, there was some anatomical and perceptual evidence which supported the existence of sex related vocal differences, prior to puberty. Crelin (1973), suggested that sexual differences in laryngeal growth appeared by the third year. Perceptual differences between the voices of male and females children had also been demonstrated. Several studies have shown that listeners could judge the sex of child speakers with some degree of accuracy from beep voice samples (Weinberg & Bennet 1971; Bennet and Weinberg, 1979).

A close look at the existing child physiological literature indicates that there is controversy over whether the developing child is simply a miniature adult structure (Bonhuys, 1977; Gollin 1981) or whether system growth is achieved in a non linear manner from childhood through adolescence (Polgar & Weng 1979). Non linearities in growth may reflect differences between children and adults that underlie a speech system that is not only smaller but functionally different. There is acoustic literature supporting the concept that the child's speech mechanism functions similar to the adults, but their durations are lower and more variable (Kent & Forner 1980; Ohde, 1985; Smith 1978). Acoustic data implicating structural differences contrary to the miniature adult model have been available for quite some time. Children's formant frquencies are higher than adult values, but not apparently in a simple linear manner. Fl, F2 & F3 increments from children to adults are not predictable based on increases in vocal tract length alone.

Physiological and anatomical data on the laryngeal and respiratory systems also support the nonlinear/functionally different view of children's speech. Polgar & Weng (1979) in a review article on respiratory physiology of children, provide evidence that children's airways were different from adults in ways other than size. For example the static recoil of the lungs did not change in a linear manner through out childhood. Anatomical data on the vocal folds also strongly supported the notion of a non isotopic relationship between the adult and child speech mechanism. Hirano, Kurita and Nakashima (1983) note not only the most obvious differences between children and adults , that was that the vocal folds were longer and more massive in adults, but also that the inner structure of the vocal folds was different. It was not until girls and boys reach adolescence that structure and size of the vocal folds are adult like. Hence one cannot expect the laryngeal and respiratory systems in children learning speech to function in the same manner as the adult systems.

Adolescence is the period of change associated with the shift from childhood to adult status. It involves growth spurts and marked physiological/psychological changes and the appearance of both primary and secondary sexual characteristics. Data reported on physical changes suggested that adolescent growth spurts, while variable, could start for boys as early as 12 years of age and last for several years (Marshall & Tanner, 1986).

It has long been established that major changes in vocal output were closely related to adolescence. It has also been suggested that down ward shifts in speaking fundamental frequency level (SFF) mark this process (Aronson 1990; Boone and Mc Farlane, 1988; Luchsinger & Arnold 1965). Curry (1940) provided an early test of this idea. He compared the data obtained from 6 year olds and 18 year olds with 14 year old boys who presumably represented an adolescent population. His data for 14 year olds (mdn=242Hz) suggested that as a group his subjects probably had not started the voice change process.

Perello (1956) argued that age of onset for adolescent voice change (AVC) might he affected by climate. Subsequent studies did not provide much specificity about AVC, a situation which may be due to variation among the research protocols, population size and measurement procedures employed by these investigators. About all that could be established was that, SFF tends to be variable for boys between 13 & 16 years and that it dropped consistently for well over 220Hz for preadolescent boys (Bennett, 1983; Comut, Riow-Bournet and Louis) 1971; Eguchi & Hirsh 1969; Fairbanks et al; 1949; Hasek, Singh and Murray, 1980) to 115-130Hz for adult males. (Fitch , Holbrook and Tallahasser, 1970; Hollien & Jackson 1973; Hollien & Shipp 1972; Kuenzel 1989). The lack of specificity among the data appears due to the (Sectional) research designs employed by the researchers who studied AVC.

Many of the characteristics and processes associated with adolescence have been reasonably well understood; others have not. Still unanswered are questions about adolescent voice changes. Hollien, Green & Massey (1994) carried out a study in order to obtain data which would complement available information on the subject and provide additional specificity about voice changes and pubescence at least for boys. A longitudinal study was conducted in which 48 males were tracked over a 5-year period. Voice measurements were made including speaking fundamental frequency (SFF) and phonational frequency range (PFR). Subjects were drawn for the age group of 10.5 to 11.5 year old boys. Out of 65 boys selected 48 subjects completed the five year study. Results showed that vocal shifts were found to be most highly correlated with the adolescent process. While stable adolescent voice change (AVC) was observed to commence sometime during the 6 years period of 10-16 years, it was initiated in a majority of boys between the ages of 12.5 and 14.5 year (Mean 13.4 year). It was also found that both the onset and duration of voice change extended over a longer period of time than had been previously thought. Based on the results it was concluded that AVC was a robust predictor of pubescence; hence AVC behavioral vector was useful in defining adolescence.

There are several studies which have probed the developmental changes in spectral parameters of speech. A high FO in the voices of children contributes to a large error in the estimation of formant frequencies. The widely spaced harmonics associated with a high FO give a poor resolution of the resonance characteristics. The investigator might mistakenly judge a strong harmonic to be a formant. Most of the literature on the new born infant cry indicated that FO fell in the range of 400-600 Hz. Fairbanks (1942) reported a range of 153-888 Hz for an infant in the first month of life and a range of 63-263 lHz for the first nine months of life.

Studies have been conducted to investigate average fundamental frequency in children of various ages prior to adolescence. No major differences have been found between male and female voices from birth until puberty according to the measures of average pitch and pitch range. Pitch distinction between male and female begins during puberty and continues through out adolescence. These voice changes, the result of growth of the phonatory, resonatory, and respiratory anatomy, roughly parallel the appearance and development of the secondary sex characteristics. The pitch and quality changes that occur at puberty are much more apparent in males than in females because of the greater magnitude of the pitch drop. The voice at puberty begins with a husky quality and an unsteady pitch, oscillating perhaps one to two tones. Although the pitch fluctuates from day to day, the general trend is downward. With time, the high tones become less steady, the low tones more stable. A study of pitch change by Mc Glone and Hollien (1963) found that female voice dropped 2.4 semitones between age 7 or 8 to 11 to 15. In a study of 15-, 16- and 17 year old females Michel et al. (1 966) found average fO of 207.5, 207.3, and 207.8 Hz respectively, their similarities indicated that by 15 years mutational change of voice was essentially completed in females. Comparison of the pitch in the male at puberty and at the termination of adolescence indicated that the male voice droped approximately by one octave. Curry (1940) found the median FO in 10- and 14-year old boys to be 269.7 Hz and 241.5 Hz respectively, whereas in 18-year old the frequency had dropped to 137.1 Hz.

Michel, Hollien & Moore (1965) have reported that females attain adult speaking fundamental frequencies (SFF) by 15 years of age. Kushal Raj (1983) has reported that SFF decreases with age, males showing a sudden decrease around 11 years of age. And no significant difference found between males and females until 11 years. Rashmi (1985) has reported marked lowering of SFF in males at 14 years and in females from 8 years onwards. In general females show little change in F0 and SFF as a function of age. Figure 2 shows the fundamental frequency obtained by several Indian investigators. Eguchi & Hirsh (1969) have reported that F0 starting about 300Hz at three years decreases slightly with age. However the largest decrease of F0 seems to occur between 3 and 6 years. 13 year old boys had an average F0 of 221 Hz still an octave higher than that of adult males (124 Hz) whereas girls of the 13 years had an average F0 of 239 Hz not very different from that of adult females (221 Hz). SD between subjects was not

FUNDAMENTAL FREQUENCY ACROSS DIFFERENT AGES

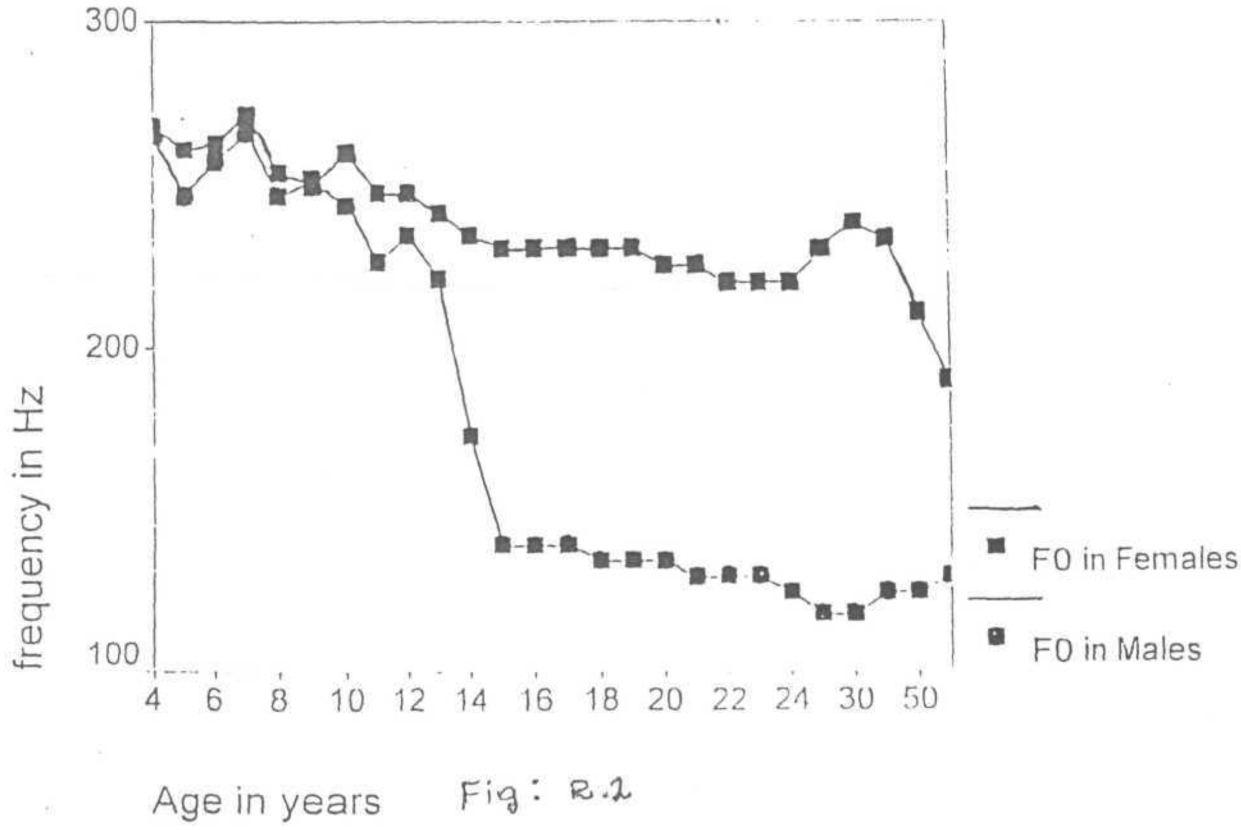


Fig: 2.2

dependent on age. It ranged from 20 to 45 Hz. Intra subject variability for three year old children was about 40 Hz. There was a gradual decrease with age reaching a minimum value (12 Hz) at 10 or 12 years and there was no further reduction.

Scale factors calculated from the data of Eguchi and Hirsh (1969) indicated that children often had average Fl values approaching those of adult female subjects. In the light this unusual result, the formant frequency values reported by Eguchi and Hirsh (1969) had to be treated cautiously considering the data for F2, which was more systematic than those for Fl, during the developmental period of three to thirteen years. Second formant scale factor changed at the annual rate of 3.4% for an adult male referent and by about 2% for an adult female referent.

Kent (1976) has reported that F0 values were distinguished by sex only after the age of 11 years although smaller sex differences might occur before that age. The F0 dropped slightly during the first three weeks or so, but then increased until about the fourth month of life, after which it stabilized for a period of approximately five months. Beginning with the first year F0 fell sharply until about three years and then it made a more gradual decline, reaching puberty at 11 or twelve years of age. A sex difference was apparent by the age of 13 years which marked the beginning of a substantial drop for male voices - adolescent voice change. Females exhibit a decrement some what in excess of an octave whereas for males it was more than two octaves.

Studies on Indian population have indicated that in males the lowering of FO was gradual till the age of 15 years (Samual,1973), 13 years (Usha, 1978) and 14 years (Rashmi,1985). Rashmi (1985) reported that a significant difference was observed for FO between 13 to 14 years and 14 to 15 years for vowel /a/.

Attempts have been made to note the development of the vocal tract and formant scale factors. Formant frequencies of vowels in children are higher than for adult females and higher yet than the values for adult males. This is because of the difference in length of the vocal tract. (Potter and Peterson, 1948). Fant (1960) argues that there are differences other than the size between the vocal tract anatomies. A linear change in the formant structure has been reported in the literature (Peterson and Barney, 1952). Fant (1960) determined that scale factors for Fl and F2 were low for rounded back vowels. And the scale factor for Fl was high for very open front or back vowels. He also pointed out that these differences were consistent with differences in vocal tract anatomy between males and females. Euguchi & Hirsh (1969), compared the children's formant frequencies with that of adult males and females. The developmental trend appeared more strongly when children Vs adult male comparison was made. Children aged 6 years had average Fl values equal to those for the woman subjects. At about age 11 or 12 years the variability in children's data was same as the variability of the adult data. The higher the FO the greater was the variability error in estimating the formant frequencies from the spectrograms. They viewed their data on Fl and F2 as evidence that the young children were more inaccurate in articulatory positioning than the older subjects. The variability decreased until about the age 11.

Potter and Stein Berg (1950) reported that repeated stutterances by a number of talkers showed a standard deviation of 20-40 Hz for the firstformant and 40-70 Hz for the second formant. Peterson and Barney (1952) reported a standard deviation of a 15.3 Hz for first formant of the vowel /i/. They attributed this to intra subject variability.

Eguchi & Hirsh (1969) have provided Fl and F2 values for various vowel types in 84 subjects between the ages of 3 and 13 years and adults. They noted a systematic lowering in average Fl and F2 as a function of increasing age, which was attributed to a generalized lengthening of the vocal tract. The study also focused on measures of variability associated with talker repetitions, age and different vowels. They found that typical standard deviation with any set of five trials was about 10 Hz. Formant frequency of 13 year old girls were close to those of adult female while 13 year old boy had higher formant frequencies than adult males, The variability of formant frequencies was higher for mid vowels than for high front and high back vowels, but for all vowels the variability decrease with age. For second formant also the dependence on age was the same. Variability of/a/ was the highest of vowels and lowest for /i/*l* and /u/..

Study by Eguchi and Hirsh (1969) can be summarized as follows:

A) Clear decrease on first and second formants between 3 and 5 years

B) Reduction of the second formant was greater than first formant

C) The first formant of /a/ was independent of age

D) Between subjects standard deviation of formants were unrelated to age and sex

E) The acoustical results were in accordance with the rapid anatomical development of the vocal tract between the ages 3 and 5 years.

F) Development of front cavity had a greater influence on formant than back cavity

G) Variability of formant for given vowels between Subjects was independent age and sex.

The lack of fundamental frequency data for infants and toddlers in the above study may be related to the difficulty in accurately estimating fundamental frequencies during this age. This has been well documented problem and related to an interaction between the child's high fundamental frequency (FO) and the overlaid harmonic structures. The problems that resulted have been essentially one of increased sampling error. The widely spaced harmonics associate with a high FO give a poor resolution of the resonance characteristics. The investigator is liable to mistakenly judge a strong harmonic to be the peak, or center frequency of a formant. Fortunately with in the past 10 years there have been methodological improvements for estimating formant frequencies. These approaches include use of ultra wide band sound spectrography, power spectrum analysis, and linear predictive coding analysis. Each procedure or a combination of procedures has been shown to successfully estimate formant frequencies in the presence of a high FO. Clearly, attention to FO is. necessary while performing formant frequency analysis of young children's voices.

Under normal speaking and listening conditions, listeners have little difficulty differentiating the voices of adult men and women on the basis of voice alone, suggesting that the acoustic parameters which underlie sex identity in the adult voices are perceptually prominent. Indeed both phonatory and vocal tract resonance characteristics appear to provide highly relevant information about the sex of an adult speaker (Schwartz, 1968, Schwartz & Rine 1968, Ingemann 1968, Coleman 1971, 1973, Lass, Waters and Tyson, 1976). Weinberg & Bennett (1971) have reported listeners are generally able to identify the sex of 5 & 6 years old children through recordings of their speech. Differences in average fundamental frequency characteristics among the children did not account for the recognition performance of listeners. The extensive overlap in the distribution of mean voice fundamental frequencies for these two perceptually discrete groups makes it apparent that average fundamental frequency characteristics did not account for listeners recognition performance.

It is known that listeners can acoustically differentiate the recorded voices of men and women and that these perceptions are related to acoustic variables reflecting sexual differences in overall head and neck size (Schwartz, 1968, Coleman 1971; Lass et. al 1976). Since preadolescent boys and girls do not evidence the sexual pronounced sexual differences in size seen among adults, it has been assumed that listeners would be unable to discern the sex of a child on the basis of speech recordings. However, several investigators have now shown that sexual characteristics are perceptually prominent in the voices of many children prior to the onset by puberty (Marshall, 1972; Sachs, Lieberman and Erickson, 1973; Bennet & Weinberg 1979a, 1979b).

Bennet & Weinberg (1979b) under took a study to enlarge the understanding of acoustic properties which influence the perception of maleness and femaleness in the voices of 73 pre-pubertal children. Perceptual judgements of sex identity were obtained in response to tape recordings of whispered and normally phonated vowels, normally spoken sentences and sentences spoken in a monotonous fashion. The results of this work suggest that cues stemming from differences in vocal tract dimensions and /or articulatory behavior provided the first degree cues about the sex identity in these pre adolescent children. Although laryngeal source cues could have provided relevant information about the sex of a few children, this variable was felt to play a relatively minor role in the sex recognition process. It was also found that removing certain supra segmental cues in the monotone condition simply did not disturb the perception of most children's sex identity because other cues provided the most relevant information. Intonation patterns were therefore viewed to play a supportive role, serving to further delineate sex characteristics.

Bennet (1980), found that many of the six and seven year old speakers showed sex differences in formant frequencies that were significantly related to listener's judgement for vowel identity. She studied 42 normal monolingual children (males and females) between 7.2 and 8.9 years of age. Results showed that the standard deviation for formant frequency varied between 13 and 22 in males and between 14 and 18 for females. A clear sex dimorphism in vocal tract resonance existed among the 7 & 8 year old studied. In the F1-F2 plot there were areas where values of two sexes overlapped and instances where some children's formant frequencies fell in regions typical of the opposite sex, the majority of male and females clustered in separate regions with each of the vowel areas. For formant 1 the overlap was least pronounced for the vowel /ae/, followed by / E / and /A/ and most pronounced for /i/ and /I/. For F2 values, there was substantial sex separation across all the five vowels considered. Consistent differences were seen for F3 and F4 also between males and females. It was likely that both the oral and pharyngeal cavities contribute to the overall sex differences for adults where as for children it may only be the pharynx. Bennett (1980) reported that mean formants of all five vowels were consistently lower in male children in the 7 & 8 year old group. It was also observed that the extent of the sex differences varied as a function of the formant and the vowel. The range of mean differences extended from 12 Hz for Fl of /i/ to 582Hz for F4 of/ae/. When Fl & F2 were plotted, while there were areas where values for these two sexes overlapped and instances where some children's formant frequencies fell in regions typical of the opposite sex, the majority of males and females clustered in separate regions within each of the vowel areas. With respect to Fl frequencies, the extent of overlap between the two sexes was least pronounced for the vowel /ae/, followed by // and *IN* and most pronounced for /i/ & /l/. With respect to F2 values, there was substantial sex separation across all five vowels. The purpose of this investigation was to measure the vowel formant frequency characteristics of a large group of preadolescent boys and girls, and describe relations between formant frequencies and body size. Bennett (1980) concluded that at the age of 7-8 years, the sex dimorphism in vowel formant frequencies was well defined in a large majority of children. Averaged across all measured formants of all five vowels, the overall sex distinction was about 10%. The range of differences extended from about 3% for Fl of /i/ to about 16% for Fl of /ae/. These findings were interpreted to suggest that overall differences in children's formant frequencies occurred chiefly as a result of sex differences in pharynx size, but that sex specific articulatory behaviors could have further enhanced the sex distinction. In particular, males might have used smaller jaw openings, more lip rounding and lower larynx positions than females. Gross indices of body size were always significantly related to these children's formant frequencies suggesting that the larger overall body size of male children also result in a larger vocal tract.

Hasek, Singh & Murry (1980) investigated the acoustic attributes of voices of preadolescent children as a function of age and sex. Voice samples of sustained vowel /a/ were obtained from 180children (15 male and 15 females at ages five, six, seven, eight, nine and ten years). Fundamental frequency measurements were obtained to determine sex related differences and age related trends. Acoustic analysis revealed that a male/female difference in fundamental frequency occurred by age seven and fundamental frequency decreased significantly in male children only.

A major problem in the spectrographic analysis of children's speech is the poor resolution of formants, which is the result of the widely spaced harmonics of the high fundamental frequency. An attempt has been made by Huggins (1980) to overcome this problem by exciting a child's vocal tract with an artificial larynx, using a fundamental frequency appropriate to a man. This method has promise for tracking formants in children's speech.

Benette (1980) has shown that the formant frequency values for preadolescent girls were about 10% higher than those for boys at the same age, although the differences varied across vowels and formants. The values of Fl, F2 & F3 and F4 were measured for five vowels, / i, I, E, ae, /\/ produced by 42 children 7 to 8 years old. The range of differences extended for about 3% to 16% for Fl . Measures of body size were always significantly related to these children's formant frequencies. Other previous studies examining F0 values of preadolescent children have indicated that values decreased with increase in age, but there have not been any consistent differences related to gender (Kent, 1976). Bennett (1983) recorded a general decrease in F0 values with increase in age for data collected over a three year period from a group of the same preadolescent boys and girls. There were no differences that were related to gender. The 15 boys and 10 girls were 8 to 11 years of age over a period of three years. However, Hasek, Singh & Murry (1980)) reported lower F0 values for boys of 7-10 years of age than for girls at the same ages. Values for boys decreased with increase in age, but this was not in the case of girls. For younger children, 5 to 6 years old, there did not appear to be any differences in F0 values between the two genders. The average time from the onset to completion of adolescent voice change is three to six months, one year at most. In females, the voice change was completed by the age of 15 years, and in males by the age of 14 or 15 years. Although the onset of voice change occurred earlier in females, males and females complete the change at approximately the same age. It is difficult to draw conclusions emerging from sex related differences and age related trends due to differences in procedures and lack of comparison for the entire preadolescent age range. However, the available data does not suggest significant differences in FO prior to the age of ten years (Cornut, Rion-Bourret; & Louis, 1971; & Kent 1976).

Bennet's (1980) study was designed to sustain frequency patterns of substantial samples of male and female children aged 5 to 10 and to investigate both sex related differences and age related trends of fundamental frequency. Voice samples of the sustained vowel /a/ were obtained from 180 children, 15 male and 15 females at ages 5, 6, 7, 8, 9 and 10 years. Measurement of F0 was obtained to determine sex related differences and age related trends. Results indicated that the average F0 of female children aged 5 to 10 was significantly different from the average F0 of male children of the same age. The difference between mean F0 for male and female children was significant at ages 7,8, 9 and 10 years and the study suggested that the decline in F0 for the group as a whole was due primarily to the changes in male voices. No significant difference in F0 between age of 5 and 10 years was found for female children, but the effect of age on F0 was significant for males. Study suggested that a significant difference between the average F0 of preadolescent male and female children begin to Emerge by the age of 7 or 8 years. This suggested that the decrease in F0 between childhood and adulthood occurred primarily after the age often years for females. Similar results, were reported by Vuoreakoski, Lendo, Tjerulund, Vuoreakoski and Perheentupa (1978), who found a decrease in F0 for males between the ages of eight and ten, but no corresponding change for females during the same period.

Rashmi (1985) studied children from four to 15 years and reported that there is lowering of fundamental frequency with advancing age up to 14 years. She also studied vowel duration in these children and has reported that both males and females show a consistent decrease in the vowel duration as a function of age.

Sorenson (1989) investigated the fundamental frequency characteristics of 30 children between the ages of 6 and 10 years in a variety of speech tasks (sustained vowel production, spontaneous speech and reading). The results indicated that average fundamental frequencies across tasks for the boys was approximately 262 Hz and for girls approximately 281 Hz. Statistical analysis indicated that there were no significant difference in the fundamental frequency of boys and girls in this age range. High vowels had higher fundamental frequency values than their spontaneous speech or reading for both groups of speakers. The results of this research were in agreement with previous research that indicated no significant differences in the F0 of males and females of six to ten years.

Over the years much effort has been made in determining the F0 characteristics of preadolescent children. The result of these research studies with few exceptions, indicate that prior to puberty there was no significant difference in the FO characteristics of male and female children in the age range of 6-10 years (Fairbanks, Herbert & Hammed 1949; Fairbanks, Wiley & Lass man, 1949; Murphy 1964; Luchsinger & Arnold 1965; Eughci & Hirsh 1969; Kaplan 1971). Kent (1976) indicated that the average FO of males and females in this age range was between 200 Hz & 325 Hz. The overall average F0 of the male and female subjects in Sorenson's (1989) investigation fell with in that range. Hasek, Singh and Murry (1980) found a systematic lowering of fundamental frequency in a similar age.

Robb, Saxman and Grant (1989) studied the vocal fundamental Frequency (FO) for a group of seven young children. The children were followed longitudinally for a 12month period, spanning pre word, single word and multiword vocalizations. The FO characteristics were analyzed with reference to chronological age, vocalization length and lexicon size. Measures of average FO and FO variability changed little during the 12 month period for each child. A rising falling intonation contour was the most prevalent FO contour among the children. In general the influence of vocalization length and language acquisition on measures of FO was negligible. It was suggested that uniformity in vocal FO was present in early vocalization across pre word and meaningful speech periods.

Children were also studied for the intrinsic pitch phenomenon (IP). They had higher associated vowel FO values for /i/ & /u/ than for /ae/ & /a/ (Peterson & Bamey 1952). In 8 and 9 years old children, the IP phenomenon was found to distinguish high from low vowels (Ohde, 1985). The FO tends to be higher in vowels with high tongue positions like /i/ and /u/ than for the tongue position of vowels like /ae/. Their data for children demonstrated that an IP phenomenon associated with the vowel height feature is was similar to that of adults.

Lieberman (1980) recorded utterances of five children whose ages ranged from 16 weeks to 5 years. The formant frequency data obtained showed that the most obvious acoustic distinction between the formant frequencies of the vowels of these young children and the vowels of older children and adults is the higher values of the formant frequencies. The younger and smaller the child, the higher are the formant frequencies for specific vowels. F3 was about. 6.5 kHz for *lil* at ages 50-60 weeks, 5.5 kHz from 81-96 weeks and 4.5 kHz from 125-161 weeks. As the children grow, their formant frequencies fall. There is no evidence that children attempt to mimic the absolute formant frequencies of the adult speech that they hear. This was so ever for vowels, where, in theory, the child could shift the formant frequencies toward the lower frequencies of adult speech. Computer modeling studies by Stevens and House (1955) demonstrated that a child could, by means of compensatory maneuvers, (eg lip rounding) and produce an /I/ vowel that had lower formant frequencies than we would expect if we considered the length of the child's supra-laryngeal vocal tract.

The most widely cited publications for formant frequency development covering the infancy period are Buhr (1980) and Kent & Murray (1982). Buhr (1980) reported formantl (Fl) formant 2 (F2) and formant 3 (F3) values for one infant who was recorded biweekly between the ages of 4 & 16 months. Kent & Murray examined 21 infants at the age of 3, 6 and 9 months. A consistent finding across these studies was a developmental increase in the range (dispersion) of Fl & F2 values, while average Fl & F2 remained unchanged. The increase in range of fundamental frequency values was thought to reflect anatomical enlargement of the infant's developing vocal tract. A larger vocal tract allowed for greater variability of tongue movement, which was shown acoustically as an increase in the range of Fl & F2 values for vowel like productions.

Busyby & Plant (1995), in their study, the fundamental frequency (FO) and the first three formant frequency (Fl, F2 & F3) values of vowels produced by 40 pre adolescents were measured. There were five boys and five girls in each of four age groups 5, 7, 9 & 11 years old. The eleven non diphthong vowels of Australian English which can be produced in a stressed syllable were used. The FO values decreased with increases in age, but there was no clear difference between boys and girls. In general, the Fl & F2 & F3 values decreased with increase in age and the values for girls were higher than those for boys. The purpose of this study was to determine whether there were any systematic differences related to age and gender in the formant frequency values of vowels produced by preadolescent boys and girls. Most of the previous studies have examined the effects of variation in age or gender separately, or data have been combined across different age and gender groups. Differences in formant frequency values related to both of these two variables have not yet been fully reported. It has been previously shown that, in general, the formant frequency values of vowels produced by children decrease with increase in age. There has also been some data indicating that the formant frequency values for girls were higher than those for boys at the same age.

Robb, Chan & Gilbert (1997) in their study collected non-cry vocalizations from 20 normal children ranging from four to 25 months. A total of 1,743 vowel like sounds were used in the acoustic analysis. The snecific acoustic, features measured, included the fundamental frequency and the formant frequencies Fl & F2. Statistical analysis showed little change in formant frequency as a function of age. But as chronological age increased, formant bandwidths decreased. In this study, the only identifiable change in either Fl or F2 was an increase in Fl at 18 months. It is unclear as to the why this increase has occurred. One possibility was that the cross sectional sampling paradigm yielded data for 18 month olds which were not representative of the age period. Alternatively, the high Fl at 18 months might have reflected a transitional point in vocal development resulting from other changes in anatomical or linguistic maturation. Hence it was likely that Fl & F2 did not significantly lower during the infant and toddler periods. Any developmental changes, which might have occurred in vocal tract anatomy during this period, might involve a more complex reconfiguration than a simple lengthening process. Two possibilities were offered for the lack of age related lowering in Fl and F2 across the first two years of life. First, it was important to consider the role of nasalization in young children's vocalizations. Based on perceptual phonetic analyses, the younger infants produced vocalizations, which are primarily nasal consonants. Due to the coupling of the nasal cavities to the oral and pharyngeal cavities, nasalized vowels showed an additional low frequency energy peaks which was introduced into the sound spectrum below the natural Fl. The additional low frequency peak might have been judged to be Fl, thereby obscuring any age-related decreases in Fl & F2, which might have occurred. A second possibility for the lack of lowering in Fl and F2 was to acknowledge that vocal tract growth occurring in a disproportionate manner. As the infant reached toddler hood there was a decrease in nasal cavity influence and increase in vocal tract length which contributed to the acoustic effect of relatively stable Fl and F2 values during the 4-25 month age period. Systematic reduction in Bl and B2 could be attributed to the gradual reduction in nasalization. Also it represented the child's development of velopharyngeal competence.

There are several studies on developmental aspects of temporal features in speech. Di Simoni (1974b) made osctllographic measurements of vowel and consonant durations in CVC and VCV utterances of children aged 3, 6, and 9 years and found that the variability of the duration decreased with age. In addition the durational data revealed that influences of context and utterance length on segment duration began to appear between 3 and 6 years of age. He interpreted his data as evidence of a developmental pattern in which the control of duration changes rapidly in the period between three and six years which parallels the result of Eguchi and Hirsh (1969). That is the durational differences already begin to appear by three years of age although the differences do not reach statistical significance until the age of age six. Also the vowel duration in the voiced consonant environments were found to increase with age where as in the voiceless consonant environment vowel duration relatively remained constant for all ages tested.

A general conclusion that might be drawn from acoustic studies of speech development was that beginning by at least three years of age, the variability of speech motor control progressively diminished until the age of 8-12 years when adult like stability was achieved. In case of formant frequencies, intra subject variability decreased as the age increased from three years to 11 years. Similarly the inter subject variability for FO progressively decreased with age until a minimum was reached at about 10-12 years. The declining variability appears to reflect an increasing precision of motor control over a five to eight year interval. The studies of Tingley & Allen (1975) and Eguchi & Hirsh (1969) indicated that an adult like precision of motor control was acquired only by about 11 years of age, that was the maturation of the motor skills in speech was not complete until the child enters puberty.

Di Simoni (1974a) studied the effect of vowel environment on the duration of consonants in the speech of three, six and nine year old children. The nonsense syllables chosen were /isi/, /isa/, /asa/ and /asi/. Though the differences in duration of /s/ in *lil* and /a/ environments were not significant, it was noted that the duration of /s/ was greater in a final /i/ environment than it was in a final /a/. Vowels in voiceless consonant environment were shortened in duration compared to voiced consonant environment (Peterson & Lehiste, 1960 & House and Fairbanks, 1953). They also reported that vowels in sibilant consonant environments were typically longer in duration than those in plosive consonant environments. Di Simoni (1974b) also studied the influence of consonant environment on duration of vowels in the speech of three, six and 9-year-old children. The consonant chosen were */p/, /b/, /s/,* & /z/ and vowels were /i/ and /a/. Results indicated that mean duration of vowels in the voiceless consonants environments remained relatively constant for all ages tested while the duration of vowels in voiced consonant environment were found to increase . with age. Vowel.duration values compared for both voiced and voiceless consonant environment conditions were found significantly different in six years and nine years old subjects but not in three-year-old subjects. This indicated that the observed durational vowel effects due to consonant environment developed over a long period of time. Durational differences had already began to emerge by age three but do not reach statistical significance until six years. The most rapid changes occurred between three to six year old period.

Rashmi (1985) report that both males and females show a decrease in the vowel duration with increase in age. In males, the decrease is statistically significant up to the age of 11 years and in females up to nine years. The standard deviations also decreased with age showing that the variability in the duration decreases as a function of age.

There are several studies comparing the acoustic parameters of children with adults. First, children's speech generally is slower than adult speech. For example, Mc Neill (1974) reported speaking rates of slightly over three words per second for adults, about 2.5 words per second for 4 to 5-year-olds, and 1.6 words per second for children of above two. Not surprisingly, then, the durations of individual segments are longer in children's speech (Naeser, 1970; Smith, 1978; Kent and Forner, 1980). Smith (1978) reported that the durations of nonsense utterances were 15 percent longer for four year-olds than for adults and 31 percent longer for 2-year-olds than for adults. Similarly, when Kent and Forner (1980) measured durations of phrases and short sentences, they found them to be 8 % longer for 12-year-olds than for adults, 16 % longer for six year olds than for adults.

Second, children's speech differed from adult speech in its variability. When children make the same utterance several times, the duration of individual segments vary more than for adults (and Hirsh, 1969; Tingley and Allen, 1975; Kent and Forner, 1980). This difference in reliability of production may be an index of the child's linguistic and neuromotor immaturity. In general, a young child's speech patterns were less well controlled than an adult's, and there was evidence that the control continues to improve until the child reaches puberty (Kent, 1976).

A third difference between the speech of children and adults was in patterns of coarticulation. Data on this difference are not abundant, but Thompson and Hixon (1979) reported that with increasing age, a greater proportion of their subjects showed nasal air flow beginning at the midpoint of the first vowel in /ini/. They interpreted this to mean that anticipatory coarticulation occurred earlier for progressively older subjects. In other words, more mature speakers showed increased anticipation in producing a phonetic sequence.

This issue of longer duration in children was of interest for two reasons: First reduction of segment duration with age may be a consequence of neuromuscular maturation. Therefore, durational measurements might be one way of characterizing child's developmental changes in attaining adult like speech motor control. A second reason was that developmental patterns in the control of duration are a necessary substrate for research on the acquisition of phonological process (Kent, 1980, Smith, 1978). Collins, Rosenbek and Wertz (1983) pointed that most normal speakers of

English reduce the duration of the vowel as the words increased in length. A comparison of vowel duration in males and females showed that females showed a longer vowel duration at all the age levels.

In recent years, a number of acoustic studies have observed that children's speech segments, syllable, words etc. tend to decrease in durations and also become less variable from younger to older groups of subjects (Chermak & Schneiderman 1986; Kent & Forner 1980; Smith 1978, 1992, 1994; Smith et al 1983;Tingley and Allen, 1975). Although both duration and variability had commonly been observed to continue decreasing until as late as 10-12 years of age before reaching adult like levels (Kent & Forner, 1980; Smith et al 1983), the basis for such changes was not especially clear. They were typically assumed to be due to neuromuscular maturation; to greater experience with the process of speech production or to a combination of both maturation and experience. While both maturation and experience are likely to be involved in the duration and variability changes that occur during children's speech production development, additional research is needed to help clarify the particular effects of these factors.

Acoustic and physiological studies have determined that the process of speech production development typically extends well beyond the time when children could produce various individual sounds of their native language correctly often until approximately 10-12 years of age (Tingley & Allen (1975); Kent 1976, Kent & Forner (1980); Smith, Sugarman & Lang (1983), Chermak & Schneiderman (1986). One common observation from such studies was that young children frequently manifested both longer durations and greater variability (i.e. a larger range of duration across repeated production) than older children and adults while producing the same target stimuli. The longer speech segment durations and greater variability in children might be due to vary basic physiologic properties like brain maturation and neuronal transmission, as well as higher level motor programming and other linguistic and non linguistic factors (Tingley & Allen, 1975; Sharkey & Folkins, 1985; Schwartz, 1988; Smith 1992). It has been proposed by Kent & Forner (1980) that duration may be the primary factor of importance in considering children's speech motor control development and that variability is essentially a consequence of duration rather than being a meaningful measure of speech production in and of itself. From this perspective, variability tends to be viewed as an epiphenomenon and as a result, merely a secondary measure that is not particularly unique in the development of children's speech production abilities.

In contrast, it has also been hypothesized that variability is relatively independent of duration and that both of these parameters are important measures of children's speech production with each providing significant information about speech motor control development (Smith 1992). In support of this neuromotor maturation hypothesis for explaining the occurrence of greater variability in children, it has been observed for instance that when children talk faster than normal or when adults talk slower than normal resulting in comparable duration, children's temporal variability was still commonly greater than adults variability (Smith et al 1983). In addition, Smith (1992) found that speech segment durations and their associated variability were not as strongly related as indicated by various other investigators (Kent & Forner, 1980; Chermak & Schneiderman 1986; Crystal & House 1988). Thus, from this perspective, variability is considered to be a significant indicator of general neuromotoric integrity for speech production in its own right, rather than simply an artifact of durations. Therefore, the conclusions associated with these contrasting hypothesis remain somewhat unclear.

Smith (1994) to assess two competing hypotheses pertaining to children's speech production development, relationships between segmental durations and their associated variability were studied in three groups of children and a group of adults who produced a variety of stimuli under normal, fast rate and bite block conditions. Because it was found that there was very less significant correlation between duration and variability, it was concluded that these two parameters did not manifest merely a mathematical relationship, as has sometimes been suggested. Findings based on the rate change data, as well as comparisons of duration and standard deviation for intrinsically short VS long segments, also indicated that duration and variability are not very closely correlated. The fact that duration was found to approach adult like levels at a younger age than variability provided additional support for the conclusion that duration and variability were relatively independent measures that could both be used for gaining a better understanding of children's speech production development.

In Smith's (1994) study, the subjects produced eight CVC words embedded in a carrier phrase. Subjects included five year olds, eight year olds, eleven year olds and five adults. Although virtually all of the experimental and intrinsic duration data considered indicated that duration and variability were not closely correlated, this did not necessarily mean that it was not reasonable to continue to view both measures as possible reflections of neuromotor maturation for speech production. ' The fact that they did not show a very strong relationship allowed for the possibility that they might each provide somewhat different interpretation about a child's development. It was evident that variability seemed to reach adult-like levels later in the process of development than did duration. For all three groups of children duration was approximately 26% greater than the adults average value, where as variability was about 64% greater than the adults average value. It was observed that of a variety of phonetic units measured in this study, the shortest ones were generally not the least variable, nor were the longest units typically the most variable ones. Taken together, this assortment of findings from a number of different perspectives substantially weakened claims that a strong mathematical link existed between duration, and variability. The fact that duration and variability were basically independent of one another thus seemed to lend support to the neuromotor maturation hypothesis. That was in addition to duration, variability was a unique and important measure of children's speech production development. Hence, it was quite clear on the basis of a variety of converging findings that temporal variability was not a function of duration (as proposed by the so -called 'mathematical' hypothesis), rather there was a substantial amount of independence between these two parameters. Thus the neuromotor maturation hypothesis appeared to be a more appropriate account of children's speech production development. That was because duration and variability were basically independent of one another, they both appeared to be useful measures of children's progress toward adult - like speech production capabilities, with duration typically reaching adult levels earlier than variability.

A number of cross sectional acoustic studies have found that young children's speech segments tend to be longer and more variable than those of older children and adults. However, very little longitudinal information of this nature is available that considers changes across time for individual children. Smith, Kenny & Hussain (1996) conducted a longitudinal analysis of several temporal characteristics of the speech of 12 children of various ages who were each seen twice approximately one and a half years apart. For the group, durations decreased on average from the initial to the follow up recordings by approximately 10% and temporal variability decreased by about 40%. For the individual children however, it was found that some of them showed few, if any changes in some of the temporal measurements made at two different times, whereas others showed substantial differences. Younger children also did not necessarily show longer durations or greater variability than older children nor did younger children always showed greater changes across time than older children. Thus, although cross sectional studies indicated that there was a general tendency when comparing groups for increased age to be associated with shorter durations and reduced variability, individual children might not evidence such patterns or changes across time.

Katz, Beach, Jenouri and Vema (1996) examined the way children and adults produce acoustic correlates for phrase boundaries during speech. Adults and children ages (five and seven) were asked to describe groupings of colored blocks, first in a relatively spontaneous manner and next under more structured conditions. Acoustic analysis indicated that adults reliably control both duration and fundamental frequency (FO) to signal phrase boundaries, where as children of both age groups demonstrate little evidence of either type of information being used. This is interpreted as that children as old as age seven do not produce prosodic cues for standing ambiguity in their every day speech.

Schwartz, Petinou, Goffman, Lazowski and Carter Sciello (1996) examined the acoustic characteristics of stress in young children's productions of minimal pairs of novel words (eg: Sofi vs So'fi). Fourteen two year olds participated as 'subjects. Their productions were analyzed in terms of vowel duration , peak amplitude and peak fundamental frequency. The analysis revealed that children produced stressed and unstressed syllables distinctively along each of the dimensions examined. When compared to the adult, the children's stressed and unstressed syllables were less distinct than to adults along each of the acoustic correlates. Further more, the acoustic features of both stressed and unstressed syllables appear to be subject to developmental change.

To summarize the review on developmental changes, it can be said that speech is a neuromuscular activity and it's acquisition is a complex process, one that involves learning a language (its syntax, semantics, and phonology) - a speech code that relates meaning to sound, and a motor skill by which the speech organs are controlled to produce rapid and overlapping movements. Developing speech differs from adult speech in various ways and the acoustic characteristics of speech vary with age as the anatomical changes take place. Young children differ from adults not only in their obvious misarticulations, but also in their slower speaking rates, greater variability (error) in production, and reduced anticipation in articulatory sequencing. Thus the developmental changes in anatomy contributes significantly to the type of speech sounds possible in the human infant.

Articulatory changes:

Many aspects of children's skilled motor performance are known to improve with age and experience. In general, it has been observed primarily from acoustic based studies that children often do not show completely adult like speech timing characteristics until as late as 10-12 years of age.-For eg. temporal variability decreased as children grew older (Tingley & Allen, 1975: Kent, 1976: Smith et. al.,1983) and children's speech segments were frequently longer in duration than those of adults (Smith, 1978: Kent & Forner,1980). Ostey and Felthans (1984) found that stressed vowels showed greater displacements and greater peak velocities than unstressed vowels and that the range of three to 11 year old children's tongue dorsum displacements was approximately two thirds of that shown by adults.

Watkin & Fromm (1984) observed that upper lip displacement was more than twice as great in the production of four and seven year old versus 10 year old children and that the variability of articulator displacements decreased significantly with increasing age. Sharkey & Folkins (1985) determined that the durations of lip and jaw opening movements and open postures and the timing between the onset of lower lip and jaw opening all decreased in variability with increasing age in four to 10 year old children.

As young children's speech segment durations are often longer than those of adults, Smith and Gartenberg (1984) hypothesized that at least two factors could be responsible for the temporal differences which have been observed in acoustic measurements of children's and adult speech. It was possible that physical characteristics of children's less mature speech mechanisms might limit the rate at which they perform articuiatory movements, due to factors such as development of the nervous system (Crelin, 1973) and growth of the orofacial region (Subtelney, 1957). It was also hypothesized that in addition to such physical factors, children's longer segment durations could be a result of not yet having learned to anticipate and plan sequences of speech gestures in the same manner that adults do (Thompson & Hixon, 1979: Kent & Forner, 1980). Thus children's organizational skills might also restrict them from producing articuiatory gestures as rapidly as adults do, which could result in longer segment durations. Smith and Gartenberg, 1984 suggested that the longer acoustic durations in children's versus adult's speech seemed to involve both physical level and organizational level factors.

' Smith and Mc Lean Muse (1986) further investigated the issue concerning possible relationships between articuiatory and acoustic duration factors. Ten children in three age groups (4-5, 7-8 & 10-11 year olds and 10 adults served as subjects. As has been noted in a number of acoustic and physical studies of children's speech (eg. Smith, 1978; Kent & Forner, 1980; Smith et al., 1983; Sharkey & Folkins, 1985), measures of children's speech were more variable than those of adults. There has been some question as to whether this greater variability in children's speech was a result of their less mature nervous systems or whether it is simply a statistical consequence of their longer segment duration. The data of Smith and Mc Lean Muse (1986) seemed to at least primarily support the idea that children's greater variability is more than just a statistical artifact. In conclusion, their data support the idea that the development of speech skills occurred over a substantial period of time. Despite the fact that the children in all three age groups produced the stimuli in a manner that would be considered perceptually 'correct' a number of differences were observed between articulatory characteristics of their speech and those of the adults. Even as late as 10 - 11 years of age, differences in the nature of children's articulatory pattern continued to be present in their speech. According to them, the exact reasons for these differences is not entirely clear and further research should help classify the effects of possible neuromuscular , anatomical and perhaps somewhat 'higher level' factors upon children's speech production.

Stevens & House (1963) have shown that the acoustic properties of phonologically equivalent vowels greatly because of co-articulation with adjacent phonemes. In continuous speech, target states were seldom reached (Lindblom, 1963; Stevens & House 1963). This target undershoots or vowel reduction problem could be compensated for if listeners make use of the direction and rate of change of formant to identify vowels.

Sharkey and Folkins (1985) examined the opening gestures associated with lower lip and jaw movements for *Pol* and *Iml* produced by 4 -, 7 - and 10 year olds and a group of adults. In general, they found significant differences in kinesmatic variability between all the groups of children versus adults, but very few differences between the older and younger children. They indicated that, one reason they might not have found many differences among the three groups of children could have been because /b/ and /m/ were sounds which were mastered very early and therefore even young children thus had substantial experience producing such sounds. The purpose of this study was to examine displacement variability of lower lip and jaw movements to determine whether sounds that are generally learned earlier and should therefore have been practiced more (eg. Stops and nasals) would be less variable than sounds that tend to develop later. (eg. Fricatives). Another issue of interest in this study was whether certain articulators might be more variable in the production of sounds than others. Such a claim has been made by Nittrouer (1993), who indicated on the basis of acoustic data that children appear to acquire adult like jaw movements sooner than they do tongue movements. Sharkey & Folkins (1985) also noted some possible differences in performance for lower lip as compared to jaw movement characteristics, with lower lip not achieving adult like levels of variability quite as early as jaw. It is assumed that the reason for this could be that jaw movements do not need to be as precise in achieving various articulatory configurations as the lower lip does, particularly in the case of fricative productions.

The kinesmatic investigation found that speech production variability tends to decrease with increase in age. Study also showed no significant differences among the consonants examined that would provide support for the prediction that later developing sounds (Fricatives) have more variability. It was also observed that there were differences that between lower lip and jaw. In addition to differences in magnitude, it was observed that lower lip tended to show a reasonably linear pattern of decreasing variability across the three groups of children to the adults. Any development that occurred for jaw variability basically appeared to be completed between five and eight years of age, where as development of lower lip displacement variability had not been entirely completed by even 11 years of age. Thus it was possible that the more intricate movements of the lips and tongue may not achieve adult like stability as early in the process of articulatory development as jaw movements do.

Smith and Mc Lean Muse (1987) investigated the kinesmatic characteristics of the speech of children and adults under 3 speaking conditions a) in a normal manner b) at a faster than normal rate; and c) while holding a bite block between their molars to restrict mandibular movement. Data was collected for children (3 age groups, 4-5, 7-8 and 10-11 years old) & adults (6 in each age group).

For the normal condition, it was found that net peak velocity was quite comparable among the 3 groups of children and the adults. Net peak velocity increased significantly for all four groups of subjects when they spoke at a fast rate, but it did not increase significantly in the bite block conditions. Results showed that when adult speakers increase their rate of speech, they typically decrease articulatory displacement and or increase articulatory velocity. But in all the three groups of children, a fast speaking rate was associated with both an increase in peak velocity and an increase in displacement. However displacement values were more adult like for the older vs the younger children in the fast speaking rate condition, perhaps indicating that the older children were beginning to develops some what more efficient production abilities.

In conclusion, in this and other studies (Smith and Gartenberg, 1984; Smith & Mc Lean-Muse, 1986), a number of similarities have been observed between the performances of normally articulating children and adults in Kinesmatic measures of speech production. Also, various differences were also observed. In many ways, it was these differences that were of most interest, since they suggest that even when children produce consonants which are perceptually 'correct', articulatory characteristics of their speech and that of adults may not be comparable. In addition such differences indicate what articulatory change must occur for young children to perform in adult like fashion. They also suggested that normal articulatory development continues in some reports until at least 10-11 years of age, and probably longer.

Johnson, Ladefoged and Lindman (1993) reported that most studies of speech production find some differences between speakers. They conducted a x-ray micro beam study of such individual differences in the production of American English vowels. The results showed within speakers consistency and between speaker variability in the production of the vowels of American English. The individual differences found was considered due to individual characteristics in vocal tract anatomy.

First the different articulatory patterns that were observed might have occurred because of between speaker differences in pallet placement. A second possible source of the different articulatory patterns is speaking rate. The third possible explanation of the individual differences reported here is that the speakers may not have been speaking the same dialect. They conclude saying that the speakers of the same language and dialect may use different articulatory plans.

Smith & Kenney (1994) conducted an experiment to determine whether adults and children could voluntarily minimize the amount of variability in their speech when specifically asked to try to do so. At the outset it was hypothesized that they could be able to reduce variability, much as they are able to decrease segmental duration in their speech when they are asked to. The results showed that there was no clear general tendency for decreases to occur in variability when subjects focussed on being as consistent as possible in repeating the tokens. It thus appears that subjects may function at relatively optimal levels when participating in repetition tasks whether or not they are explicitly instructed to do so.

To conclude, it can be stated that children's organizational skills might be restricting them from producing articulatory gestures as rapidly as adults do which could result in longer segment durations. Several studies on this issue suggested that the longer acoustic durations in children's speech seemed to involve both physical level and organizational level factors (Smith and Gartenberg, 1984).

Vowel duration:

Among segmental durations "vowel duration" is an important parameter which provides information on the prosodic as well as linguistic aspect of speech. Vowel duration can be used to signal the stressed syllable (Fry, 1955); mark the word boundaries (Lehiste, 1959); identify the syntactic units (Gaitenberg, 1965) and to distinguish between similar phonetic segments (Denes, 1955 and Lisker & Abramson, 1964). Duration data is of immense use in applied research, viz; automatic generation of speech for a reading machine for the blind and the automatic recognition of speech from the acoustic waveform. Thus it is essential to study vowel duration to understand the speech production, perception and the language structure.

The term intrinsic duration of vowel refers to the duration of a segment (vowel) as determined by it's phonetic quality (Lehiste, 1970). Gopal (1987) defined the vowel duration as the duration from the onset of vowel to the offset of the vowel. The onset and the offset of a vowel were determined by the presence and absence of clearly visible first two formants on the spectrogram, respectively.

Many have investigated the duration of these vowels and quantified the relationship between different subclasses of vowels in many languages. It was found that there was an invariant relationship between tense and lax vowels across several contexts that influence the vowel duration, while others did not find such a relationship. In English-Heffner (1937); House & Fairbanks (1953); Peterson & Lehiste (1960); House (1961); and Umeda (1975); in German - Maack (1949); in Danish - Fischer Jorgensen (1955); Nooteboom (1972); in Swedish - Elert (1964); in

Thai - Abramson (1962); in Spanish - Navarro Tomas (1916) and in French - O'Shaughnessy (1981) have studied the vowel duration. There are only few studies in Indian languages. The studies carried out in Indian languages are: in Telugu by Majumder, Datta & Ganguli (1978) and Nagamm Reddy (1988); in Tamil by Balasubramanian (1981); in Malayalam by Velayudhan (1975) and Sasidharan (1995); in Hindi by Aggarwal (1988); and in Kannada by Rajapurohit (1982); Savithri (1986, 1989) and Venkatesh (1995). These studies had varied purposes; i.e., to know: (1) the durational organization of speech segments (2) physiologic vs linguistic nature(3) factors that influence the duration and (4) to incorporate the durational rules of vowels in speech synthesis to improve its quality.

The duration of speech sounds may be affected by several phonation conditioning factors. To a certain extent, the duration of a segment may be determined by the nature of the segment itself, that is, by its print and manner of articulation. The term Intrinsic duration may be used to refer to the duration of a segment as determined by its phonetic quality (Lehiste, 1970).

A great number of investigations have been devoted to problems of intrinsic duration. As for as the vowels are concerned, their duration appeared to be correlated with tongue height. Other factors being equal, a high vowel has been found to be shorter than a low vowel. The languages in which this has been found to be include English (Heffner, 1937; House and Fairbanks 1953; Peterson & Lehiste, 1960; House, 1961), German (Maack 1949), Danish (Fischer - Jorgensen 1955), Swedish (Elert, 1964); Thai (Abramson 1962), Lappish (Aima 1918) & Spanish (Navarro Tomas 1916). Lehiste (1970) stated that it was quite probable that the differences in vowel length according to degree of opening are physiologically conditioned and thus a constitute phonetic universal. The greater length of low vowels is due to the greater extent of the articulatory movements involved in their productions). Since acoustic phonetic techniques reached a relatively high level in English speaking countries earlier than elsewhere, English has been most extensively studied, and there has been a slight tendency to assume that what holds for English is true in general. It so happens that in English, the voicing of a post vocalic consonants strongly affects the duration of a preceding vowel (House & Fairbanks, 1953; Zimmerman & Sapan 1958; Peterson & Lehiste, 1960; House, 1961; Delattre 1962).

Effect of rate of speech and utterance length on vowel duration has also been studied. Previous investigators have shown that vowel duration decreased as the number of syllables in a word increased, when carrier phrases constituted the material. Umeda (1972) found that, in connected text factors other than the number of syllables in the word have stronger influence in vowel duration. It turned out that differences were very small if present at all, in vowel duration in connected text material. This investigation was conducted to find whether the differences resulted from speaker's idiosyncrasies or from different speech modes - carrier phrase reading and connected speech. Two subjects read lists of mono-syllabic and polysyllabic words in carrier phrases. Measurements were taken on the duration of one vowel /ae/, in stressed syllables in words of varying length. Results from the carrier sentence material confirmed previous findings of the decreased duration, at least up to three syllables. One subject while showing the characteristic shortening in vowel duration in the carrier phrase mode, exhibited almost no differences in duration of the vowel in connected text. Apparently the dependence of vowel duration on number of syllables was one of the dominating factors in the carrier phrase mode, but was a negligible factor in connected speech.

Lindblom (1968) has shown that in the utterance of adult speakers, both consonant duration and vowel duration decreased as the overall length of an utterance is increased. Others also have reported this effect. Di Simoni (1974c) studied the presence or absence of that effect in child speakers with the hope of observing any developmental effects which might be present. 30 subjects took part in this study were 3-, 6- and 9 year old children who were randomly selected. It was observed that average durations of segments decreased with age, as did the variation in subject productions. The presence of the effect of decreased duration of phonemes due to increased length of utterance was seen only in 6 and 9 year old groups. Moreover the differences became more striking with age. This experiment shows aspects of the chronologic sequence of development of durational control systems in children and suggested the possibility of a hierarchy of co - articulatory functions.

/Harris & Umeda (1974) from their study showed that the two speakers had the typical duration pattern of carrier sentences in the carrier phrase readings. Apparently the difference between the vowel duration of carrier sentences and that of connected text reading was not because of the individual speaker, but because of different speaking modes that the speaker was using in two conditions. Harris & Umeda (1974) opine that it was misleading to generalize a temporal rule by studying one particular speech mode. It seems that what mattered was not the length of the sentence, but the nature of the sentence. It was also possible that in carrier phrases, the speaker did not have to convey the content of the message to the listener, and so prosody became more mechanical. In connected text the speakers primary task is to make the listener understand the content of the message. For comprehension, various other factors were more dominant in determining the temporal aspects of speech than number of syllables in a word. In order to convey meaning, the speaker must have made the listener aware of the relative significance of the linguistic units, and syntactic relationships between the units. It seemed therefore that the role of prosody in the two situations, carrier phrases and connected text, was different.

Gopal and Syrdal, (1984) studied the effects of speaking rate on spectral and temporal characteristics of American English vowels. Five women and five men, native American English speakers without strong regional dialects produced the carrier phrase sentence 'I said hvd again' at slow, conversational and fast rates. Twelve vowels, were studied in /hvd/ context. Spectral measurements included fundamental frequency and the first four formants. Temporal measurements made were vowel duration, syllable duration and closure duration. Durations, duration differences and rate related changes were quite systematic within and across vowel types. Results indicated that the duration of long vowels and diphthongs were compressed more than that of short vowels as speaking rate increased. Spectral differences were relatively small across speaking rates.

Crystal & House (1988) measured duration data from connected speech signals for three slow and three fast adult talkers and analyzed. The results supported the general rule stated by Kent & Forner (1980) that slow speakers were more variable in timing control than fast speakers and reinforced their suggestion that the standard deviation of segmental distributions may be a poor index of a talker's neuromuscular speech skills.

De Jong (1991) reported that the effects of voicing manner and number of consonants on the duration of previous vowels in English could be created in three ways: by planned expansion or contraction of the entire vowel by changing the relative timing of consonant and vowel gestures or by modifying the duration of the closing movement for the consonants. An X-ray micro-beam data base of two speakers of American English reciting monosyllabic words which differed in their final consonants was studied to evaluate these three accounts. In this data base, vowel duration differences due to the voicing of the following consonants were amplified by the presence of accent. Also, many of the duration differences associated with the following consonants were localized in the later portion of the opening movement, suggesting that subjects often create vowel duration changes by initiating the consonant closing gesture at an earlier or later time relative to the opening gesture.

Effect of consonant environment on vowel duration has been studied by various researchers. One of the most carefully controlled studies of the influence of the place of articulation on duration was carried through by Fischer-Jorgensen (1964).

She used Danish nonsense syllables containing the vowels i, u, y followed by b, d, g and preceded by /h/ or by the same consonant as that following the vowel. A second list of test words contained all possible consonants followed by -ud> & -id>. The words were spoken by seven different subjects 6 or 12 times each; the test material contained 3,520 vowels, 2, 106 post vocalic consonants, and 1, 386 cases of 'open interval' after initial stops. Fischer-Jorgensen (1964) established the differences in the durations of vowels in all environments, the durations of consonants, the differences between the durational relationships in mono syllabic and disyllabic words and variations between speakers. The results of the study was summarized as follows; The duration of a vowel depended on the extent of the following consonant. The greater the extent of the movement, the longer the vowel. This explained the fact that all vowels were shorter before *Pol* than before /d/ and /g/. Since two different articulators were involved in the sequence, vowel + labial, there was no time delay in moving the articulator (ie., the tongue) from vowel target to consonant target. On the other hand, /u/ was particularly long before /d/. Before /g/, */u/* had an intermediate value; the movement involved was relatively small, but the back of the tongue was not as mobile as the tip of the tongue and the closing process took more time. Fischer - Jorgenson's (1964) findings agreed with observations reported for English by Peterson and Lehiste (1960). In this study short vowels were found to be longest before /t/, shorter before /k/ & shortest before /p/. For the voiced plosives, the order of the duration of short vowels was g>d>b (where the consonant letter means 'vowel before the consonant). The same order as for voiceless plosives was established for short vowels before fricatives and affricates. Vowel length decreased in the order

>s> f and z > v. Only for nasals was the order reversed: m> n> n. For long vowels, the decreasing order before following consonants was t > k > p; d > g> b; > S > f; > z > v; and > n > m.

An increase in vowel duration, when the point of articulation of the post vocalic consonant shifts farther back in the mouth, has also been observed for Spanish. Zimmerman and Sapan (1958) listed average vowel durations before following consonants in Spanish disyllabic paroxytonic words as follows; /p/ - 93ms, /B/-130ms, /t/-104ms, / /-136ms, /k/-108ms, /r/-137ms.

House & Fairbanks (1953) found that English vowels were generally longer before dentals than before labials or velars; However, in 1961, House found that the difference was negligible. Maack (1953) studied the problem in German. He found that front vowels were longer before labials and velars than before dentals; back vowels were longest before labials and shortest before velars. Maack (1953) formulated the rule regarding the influence of post vocalic consonants on the duration of vowels that is very similar to Fischer-Jorgemen's (1964) results. Farther the point of articulation of sonorant from that of the following consonant, the longer the sonorant. Maack (1953) also attempted to establish the influence of preceding consonant on a following vowel. He stated that the sonorant was proportionately longer, the closer its point of articulation was to that of the preceding consonant. This observation did not receive confirmation from other studies.

The influence of preceding consonants on the duration of following vowels did not emerge clearly from Fischer-Jorgersen's (1964) study, partly because it was obscured by the different length of the open interval after the explosion. The influence of the manner of articulation of a consonant upon the duration of a preceding vowel seems to be largely dependent on the language of the speakers showed through. This was the case with nonsense words spoken by the subjects of House and Fairbanks (1953); their results reflected the language specific fact that in English, vowels are shortest before voiceless stops, and their duration increases, in this order, when the post vocalic consonants belong to the classes of voiceless fricatives, nasals, voiced stops, and voiced fricatives. Similar results were obtained with English test words in the study by Peterson and Lehiste (1960). Peterson and Lehiste (1960) established the durational ratio of vowel before voiceless consonant to vowel before voiced consonant as approximately 2:3. The average duration of short vowels was 147 ms before /t/, 206ms before /d/, 216 ms before /n/, 199 ms before /s/, and 262 ms before /z/.

In trying to interpret the observed differences in vowel duration when followed by consonants produced with different manner of articulation, House (1961) proposed that the difference in vowel duration before stops and fricatives may be due to some inherent articulatory influences. He hypothesized that the articulation of stop consonants might represent less muscular adjustment from a physiological rest position of the vocal tract and might consequently require relatively less muscular effort than the production of sounds requiring more deviation from the rest position.

However, House (1961) observed that this kind of argument could not be used to explain the influence of the voicing of a post vocalic consonant on the duration of the vowel. Voiceless consonants in English were typically described as aspirated, this characteristic suggested greater muscular effort during .their production, when compared with voiced consonants. Nevertheless, English vowels preceding voiceless consonants were shorter in duration than those before voiced consonants. House(1961) concluded that the shortening, of vowels before voiceless consonants was due to an articulatory activity arbitrarily imposed by the phonological system of English, and constitutes learned behavior in English rather than phonetic universal.

Sharf s (1962) data suggested that, longer a vowel is preceding voiceless stops, greater was the duration added before voiced stops. His data suggested that the relation between duration before voiceless stops and the durational increment is very nearly linear.

Elert (1964) also found that short vowels followed /t/ were 14 ms shorter than short vowels followed by /s/ in Swedish. However, in Swedish, nasal consonant seemed to have a shortening influence on the preceding vowel. In Spanish, a vowel was shortest before a voiceless plosives. Lehiste & Ivic (1963) also compared the languages Czech and Serbo-croatian and forced that the difference between long and short vowels was greatest for /i/ & /u/ in Czech, whereas in Serbo-Croatian the greatest difference was observed in the mid vowels /e/ & /o/.

Halle and Stevens (1967) have claimed that there are rather drastic adjustments in the positioning of the vocal folds and in the manner in which they vibrate when voicing is maintained during certain consonants. According to their argument, the wide separation of the vocal folds during voiceless consonants can be achieved more rapidly than the more finely adjusted smaller separation for a voiced consonant. This would explain the greater duration of vowels before voiced consonants than before voiceless ones. Halle and Stevens (1967) also reported measurements of vowel duration in symmetrical CVC syllables in English in which the vowels before nasals had the shortest duration. They opine that this may be due to the special adjustment of the vocal folds which is needed to maintain vibrations during voiced plosives. No such adjustment is needed for voiced nasals.The measurements presented by Halle and STEvens are at variance with the durations found during the Peterson and Lehiste study (1960) as wellas those reported by Ellert (1964) for Swedish.

Lisker (1974) stated that studies of vowel duration have yielded two well-known and generally accepted formulations 1) vowel duration varies directly with degree of opening 2) vowel duration depends on the following consonant, most strikingly on its voicing state. The first relation is explained as a mechanical effect of the relatively large mass of the mandible; the second is ascribed either to the alleged fortisness of the voiceless consonants or to a presumed need to defer consonant closure while the larynx is adjusted for consonant voicing. Lehiste (1970), said that greater length of low vowels was due to the greater extent of the articulatory movements involved in their production. In his experiment, Lisker reported that there was a tendency for duration to increase with increasing first formant frequency, ie., *IV* & /u/ are shorter on the average than /a/.

Lisker (1974) provided the four explanations for the relation between vowel duration and the following consonant.

1) Vowels are longer before voiced and shorter before voiceless consonants according to a rule of constant energy expenditure for the syllable, longer vowels and voiceless consonants both being more costly in articulatory energy.
2) Vowels are lengthened before voiced stops to allow time for laryngeal readjustment needed if voicing is to be maintained during oral closure.
3) Vowels are shorter before voiceless consonants because those consonants are fortes and fotisness involves the earlier onset of articulatory closure.
4) Vowels before voiceless consonants are shorter because the string closure gesture is accomplished more rapidly, again because of the fortes nature of those consonants.

According to Allen (1978), the measurement error in locating segment boundaries has usually been ignored or assumed to be constant and small. Since the relative magnitude of the error in locating such a boundary may vary greatly by depending upon its phonetic context and the procedures employed, there by affecting the derived inter segment co-variances profoundly and experiment was designed by Allen 1978, to estimate these errors directly. Several tokens of four sentences containing syllables differing in the quality, length, degree of stress, and consonantal context of their nuclear vowels were recorded and sent to several professional phoneticians with instructions to measure the duration of the indicated vowels. The resulting measurement errors varied systematically in several ways. 1. Long stressed vowels had greater errors than short, unstressed ones. 2) initial voiced stops *Pol* were easiest to segment and approximants /w/ hardest with voiceless stops /k/ and fricatives *HI* intermediate. 3) great differences among phoneticians did not appear to depend in any obvious way upon the instrumentation used. Minimum Standard Deviation for measurements of vowel duration by the most accurate phoneticians ranged from about 2 to 5 ms; 95% confidence intervals for carefully measured vowel duration may therefore be expected to range from about 10-25 ms depending on the consonantal context of the vowel.

Zwirner (1959,1962) calculated ratios of short versus long vowels (V/V) for a number of German dialects and used them to establish isophones of quantity. The ratios ranged from 90.3% in the East to 51% in the West. House (1961) studied the duration of twelve American English vowels occurring in fourteen symmetrical consonantal contexts. The vowels and consonants formed the second syllable of a bisyllabic nonsense word of the form /he CVC/. The vowel duration measured from three speakers showed that some vowels could be classified in contrastive long-short pairs or tense-lax pairs, for eg.,/i/ vs /l:/ */u/* vs /U/; /a/ vs /|/ and / / vs /o/. He found that the long vowels were, on an average, 100 ms longer than the short vowels. His data also showed that the difference between tense and lax vowels varied as a function of voicing and the manner of articulation of following consonants. For instance, the difference between tense and lax vowels amidst voiceless stop consonants was about 30 ms, amidst voiced stop was about 80 ms and amidst voiced fricatives was about 120 ms. Not only did the duration difference vary across consonantal contexts, but so did the ratio of V/V:

The Swedish experiment by Elert (1964) brought into focus the difference between long and short vowels in order to be linguistically significant. Languages in which stressed vowels had two contrastive degree of quality, the v/v: ratio was close to 50%, but might vary a great deal. Data were available for a number of languages. In Danish (Fischer - Jorgensen 1955) the average duration of short vowels was 50.5%, of that of the long vowels, In Finnish it was 44.1%. (Wiik & Lehiste, 1968), in Estoman words, it was 58.1% (Liiv, 1962a), in Thai (Abramson; 1962) the duration of long vowels was more than twice that of short vowels.

Sharf (1964) observed that tense vowels were longer than lax vowels in both normal and whispered speech. In normal speech, the tense vowels were 258 ms. And the lax vowels were 185 ms., a difference of 73 ms., and in whispered speech they were 321 ms and 238 ms. Respectively, a difference of 83 ms. Using Stetson's (1951) theory to explain the durational difference between tense and lax vowels as being physiological, Sharf (1964) argued that ". . . . .it is possible that linguistic structure is precipitating factor in producing differences in vowel duration between tense and lax vowels and that dynamic properties of the speech system have acted as a perseverant factor".

In a series of studies, Nooteboom (1972a, 1972b) investigated various intrasyllabic factors that influenced vowel duration in Danish language, particularly the influence of phonological length and the influence of vowel height. He found that long vowels /o:, e:, o:, a:/ were consistently longer than the short vowels. However, Nooteboom (1972) also reported that the absolute difference in duration as well as the durational ratio between the short and long vowels (V/V:) varied depending on the position in the word and the presence or absence of lexical stress. In trisyllabic nonsense words of the type /pVpVpV/ with stress on second syllable, he found that the absolute difference between the short and long vowels was 15 ms, 40 ms and 50 ms for the three positions respectively. Further more, the ratio of V/V: was 0.85, 0.65 and 0.70 for the three positions respectively. Thus, neither the absolute durational difference nor the V/V: ratio;. remained constant in Danish language.

Stalhammar, Karlsson & Fant (1973) and Fant, Stalhammar & Karlsson (1974) studied the duration of short and long vowels in stressed and unstressed conditions, occurring in isolation, in a /h V d/ context and in connected speech of Swedish language. They found that the durations of long vowels did not change much between isolated condition (350 ms) and monosyllabic context (315 ms), but changed markedly from monosyllabic to connected speech (120 ms). The average V/V: (stressed) ratio was 0.60 in monosyllabic contexts and 0.75 in connected speech.

Games (1974a) has studied vowel quality in Icelandic language and she has also examined the durational relationship between long and short vowels in monosyllabic and disyllabic conditions, with the varied voicing and manners of articulation of the following consonant. She found that the duration of short allophones in both monosyllabic and bisyllabic situations constituted one half of the duration of long allophones, maintaining a ratio of 1:2 regardless of absolute durations, segmental environment and the syllable structure. However, this observation was based on a small number of tokens (i.e., 5) of each vowel and this relationship was an average across all of the long vowels and averaged across different consonants. Gopal (1987) with reference to the study by Games (1974) has commented that the relationship for each long - short vowel pair specifically for each of the consonantal contexts separately, had not been considered. Individual long-short vowel pair specifically for each of the consonantal contexts separately, had not been considered. Individual long - short pair relationships for specific contexts may be quite different from averaged ones. Thus this notion of invariance may well be questioned. More importantly, these findings were based on the data collected from one speaker. Thus its generalization was highly questionable (Gopal, 1987).

Dauer (1980) found that the intrinsic factor of quality affected the durations of Greek vowels, with high vowels being the shortest and nonhigh vowels the longest. She also found that vowel s in stressed syllables were longer and had higher intensity than in unstressed syllables. It has been widely accepted that the tense vowels are relatively longer than lax vowels. Since the approximate configuration for tense vowels is said to require a longer period than that for lax vowels (Mitleb, 1984).

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

Maddieson (1993) also carried out a study on vowel duration in Sukuma language. The results were almost similar to Luganda except for the "the surface durational patterns were different". The compensatorily lengthened vowels fell almost halfway between the duration of the long and short vowels, in fact, the mean for lengthened vowels was slightly closer to the duration of short vowels. The mean duration of the compensatorily lengthened vowel in words was 200 ms. Whereas that in words with short vowel was 129 ms and that in words with long vowel was 280 ms. The long vowels were over twice the length of short vowels in this data, but length and vowels were only about one and half times the length of short ones.

Mc Donough, Ladefoged & George (1993) carried out a study on Navajo vowels and the results revealed that Navajo speakers made very clear distinctions between long and short vowels, at least in citation forms of speech. Short vowels were less than half (114 ms in females and males) the length of long vowels (266 ms in females and 264 in males).

Shalev, Ladefoged, & Bhaskararao, (1993) carried out a study on the phonetic properties of Toda language, which is spoken by about 1,000 people in the Nilgiri Hills in Southern India. They found that the mean duration of shot vowels was 68 ms and that of long vowels, 139 ms. The short-long ratio was therefore 1:2.04, or slightly more than 1:2. Engstrand and Krull (1994) conducted a study on the duration of vowels in Swedish, Finnish and Estonian languages and found short and long vowel contrasts, similar to the earlier studies. The relationship between short and long vowels may be language dependent. In some languages, it may be invariant across contextual influences, whereas in other languages it may vary as a function of various other factors. The findings of Games (1974a) for Icelandic vowels could be considered as a support to an invariant relationship. She found this relationship to be constant across segmental environments and the structure of the syllable.

Fourakis, Botinis and Katsaiti (1999) Studied the duration of Greek vowels at slow and fast tempo and reported that low vowels were the longest and the high vowels the shortest. Study by Motoko Ueyama (1999) in Japaneese showed that duration of vowel /a/ is significantly shorter before smaller phrase boundaries than larger boundaries. It was also seen that, phrase final /a/ tends to be lengthened to a greater degree in the noun ending condition than in the particle ending condition.

FACTORS INFLUENCING DURATION OF VOWELS IN SPEECH PRODUCTION

Duration of different segment vary widely depending upon several factors. Klatt (1976) classified these factors as:

1. Extra linguistic factors
2. Discourse level factors
3. Semantic factors
4. Syntactic factors
5. Phonetic factors and
6. Physiological factors

1. Extra linguistic Factors

Under the extra linguistic factors, Klatt (1976) includes speaker's mood, their physical condition and speaking rate. Further age and sex seems to influence the duration of vowels.

a. Speakers mood and physical conditions affect the durational patterns largely. Williams & Stevens (1972) have shown that actors, attempting to simulate various emotional states, speak differently under different emotional conditions. They speak slowly when angry and slower than normal when expressing fear or sorrow.

b. Researchers have studied the influence of speaking rate on long and short vowel types. Some of them have reported that the two vowel types behaved differently with changes in the rate where as others found no difference between the two.

Change in speaking rate tend to change the durational patterns. For example it has been shown that a good fraction of the extra duration goes into pauses when speakers slow down (Goldman-Eister 1968). Huggins (1964) showed that an increase in speaking rate shortened the vowels and consonants. Increase in speaking rate was also accompanied by phonological and phonetic simplifications.

Peterson & Lehiste (1960) observed that the changes in speaking tempo had little effect on the duration of stressed syllable nuclei. In a sub-experiment they found that nuclei that were inherently longer in duration compressed less than the nuclei that were shorter in duration when the speaking rate increased. "However, the notion that longer duration segments (stressed nuclei) compress less than the shorter duration segments is in direct contradiction to Klatt (1973), who just found the reverse" (Gopal, 1987).

Gay, Ushijima, Hirose and Cooper (1974) stated that the consonantal gestures were strengthened when the speaking rate was increased because of the complex reorganization of the motor commands to the articulators. However, the motor commands for vowels were not enhanced. Gay (1978) investigated the effects of speaking rate on changes in the duration of nine vowels in four native American English speakers. He used utterances of the type /PVP/ in a carrier phrase, "It's a _______again". He found that as the speaking rate increased, durations of all vowels decreased for all speakers. Using percent change in vowel duration from one rate to another, Gay (1978) studied whether there were any systematic differences between long (/I:/, */ae/, lal, lul)* and short (/i/, /^/, /u/) vowels. He found that the percent change was same for both vowel types (approximately 0.20 to 0.25), and concluded that there were no systematic differences in the amount of compression between the long and short vowels across rates. Comparison of vowel duration at slow and fast speaking rates from various studies is depicted in table - 2.1.

Peterson & Lehiste 1960; N = 5 (averaged across voiced and voiceless Context)					
	Slow	Fast	Vowels	Slow	Fast
/i/	207	-	/I/	161	-
/ae/	284	-	*/E/*	204	-
lul	235	-	/U/	163	-
Gay (1978) ;N = 4					
/i/	120	90	*/I/*	105	85 .
/ae/	155	125	*/E/*	130	105
/a/	145	155	*/A/*	115	85
/u/	120	90	*/U/*	110	90
Crystal & House (1982); N = 7					
Long	141	115	Short	79	61
Port (1981); N = 5					
/i/	122	83	*IV*	80	61
Gopal and Syrdal (1984); N = 10					
/i/	230	99	*/I/*	176	78
/ae/	263	120	*/I/*	179	87
/a/	260	119	*/A/*	182	87
/u/	249	108	/U/	178	86

Table -2.1: Shows the comparison of mean vowel durations from different rates for different studies

Gopal & Syrdal (1984) found that the vowel durations of fast and slow speakers changed from 40% to 50%. Gopal (1990) investigated the effects of speaking rate on the durations of four pairs of American English tense and lax vowels in four different consonantal contexts (t, d, s, z) using seven subjects. Results showed that the durational behavior of tense and lax vowels as a function of rate was context dependent. It followed one of the two broad patterns (i) in certain contexts most of the tense-lax vowel pairs maintained a constant absolute durational difference across different rates and (ii) in other contexts the change in the tense vowel durations as a function of rate was significantly different from their lax vowel counter-parts, so that the vowels maintained neither an absolute duration difference nor a consonant proportional relationship. Gopal & Syrdal (1984) stated that this result could support partially additive and incompressibility models. They also stated that none of the models were able to capture the durational behavior of these vowels as a function of rate and this suggested a speech timing system that was more complex than the present models proposed (Gopal, 1990).

c. According to Di Simoni (1974b), the mean duration of vowels in the voiceless consonant environment remains constant, whereas that in the voiced consonant environment increased with the age of the speaker. He also found that the variation (i.e., standard deviations) in vowel duration tended to become smaller as a function of age, indicating less speaker variability. The results of this study indicated that the observed vowel durational variations were due to consonant environment develop over a long period of time. Durational differences already begin to emerge by age three years, although the differences do not reach statistical significance until the age of six years. The developmental period in which the most rapid rates of change occur was identified as three to six years of age. Sweetings (1980) found that the vowel duration increased with the age of the speaker.

d. Zue & Lafferiere (1970) observed that longer vowel durations characterized female speech. This phenomenon was also observed by Savithri (1981, 1986), in Sanskrit and Kannada languages. Mc Donough, Ladefoged & George (1993) carried out a study on the vowels of Navajo language and found that there was no significant difference between males and females with respect to vowel duration. Venkatesh (1995) reports that the duration of long vowels in Kannada were longer in female subjects.

2. Discourse level factors

The duration of the final sentence of a read passage will be longer than the non-final sentence of the passage. (Klatt, 1976). It has been observed by Klatt(1976) that the vowel duration has primary importance only in phrase final environments. The final syllable of the sentence was lengthened when compared to the non-final syllable. It was as if the speakers tend to slow down at the end of the conceptual unit.

3. Semantic Factors

Semantic factors also play a prominent role in altering the duration of the vowels. Emphasis and semantic novelty were listed as semantic factors affecting the duration of speech sounds.

a. **Emphasis:** The first semantic factor to be considered was emphasis of contrastive stress. The acoustic correlate of emphasis is an increase in the duration of the word. Studies have indicated that the vowel duration was more for stressed vowels (Klatt, 1976 and Savithri, 1986).

b. **Semantic novelty:** An unusual word would be longest, the first time it appeared in a connected discourse inferring that semantic novelty had an influence on segmental durations (Klatt, 1976).

4. Syntactic factors

a. Phrase structure lengthening: Gaitenberg (1965) found that the syllable or syllables at the end of a sentence were longer than they would be with in an utterance. Similar results were observed by Klatt (1976).

b. **Prepausal lengthening:** The syllables before the pause are lengthened when compared to syllables in other positions (Klatt, 1976). Martin (1970) showed that the segments tend to be lengthened in spontaneous speech just prior to major grammatical constituent boundaries. Lengthening was observed at the end of noun phrases and conjoined or embedded clauses.

It may be a natural tendency to slow down at the end of all motor sequences or the speaker may learn to lengthen the prepausal syllables to enable the listener decode the message better or it is probably related to the general deceleration of motor activity at the end of speaking acts (Klatt, 1976).

c. **Position of the vowel:** Nooteboom (1972) studied the influence of position of vowel in the word on vowel duration. He reported that the absolute difference in duration, as well as in the duration ratio between the short and long vowels (V/V:) varied depending on its position in the word and the presence or absence of lexical stress. In trisyllabic non-sense words of the type /PVPVPVP/ with stressed on the second syllable, he found that the absolute difference between two vowel types was 15 ms, 40 ms. And 50 ms, for three positions respectively, and the ratio V/V: was 0.85 and 0.7 for the three positions respectively. Thus neither the absolute duration nor the V/V: ratio remained constant in Dutch. The word final syllables are somewhat longer in duration than the non final syllables (Oiler, 1973 and Klatt, 1975).

5. Phonetic factors

a. Inherent phonological duration: Each phonetic segment has its own intrinsic phonological duration. Some vowels are short and some vowels are long and some are overlong (Savithri, 1984). The duration of vowels appears to be related to tongue height. Other factors being equal, a low vowel is longer than a high vowel. Experimental evidence for this emerged from studies in English, German, Danish, Swedish, Thai, Lappish, Spanish (Lehiste, 1970 and Klatt, 1976) and Kannada (Savithri, 1986). According to Klatt (1976) the reason for this might be found in the physical processes. It is a known fact that velar height and the degree of closure of the velopharyngeal port varied systematically with vowel articulation. In general, the velum is characteristically lower and the port is more open for low vowels than for high vowels. This takes more time thus explaining the longer duration for low vowels.

Temporal analysis of vowels in Tamil carried out by Balasurbramanian (1981), revealed that the phonologically long vowels are almost twice as long as the phonologically short ones. Other things being equal, open vowels are longer than close vowels.

O' Shaughnessy (1981) reported a weak tendency for vowel duration to vary inversely with vowel height in French vowels. This study showed that high vowels, on average, were shorter than other vowels, but this relation did not occur when mid (long) vowels were compared to low (long) vowels. O'Shaughnessy (1981) also reported that there were two "strong" pre consonantal effects on vowel duration, i.e. (I) lengthening of vowel before voiced fricative and (ii) shortening before voiceless obstruents. He also reported a weak tendency for vowels to be longer after stops than after other consonants.

Mitleb (1984) studied the vowel durations using spectrograms, in English and Arabic languages and found that the vowel duration of low vowels were more than high vowels in both languages. The fact that low vowels tend to be longer than high vowels was attributed to the degree of jaw lowering needed in the production of low vowels. He opined that the temporal structures were language specific variables.

The reasons for this as hypothesized by Halle & Stevens (1967) was that the vocal folds are widely open for the voiceless consonants, whereas for the production of voiced sounds fine adjustments are required. These fine adjustments consume more time than that of wide separation for the voiceless consonants. Further, the velopharyngeal width will be more for voiced stops when compared to the voiceless stops. This widening of the velopharynx for voiced stops required more time which lengthens the vowels preceding voiced stops. In the production of voiced stops, the larynx is depressed to maintain a pressure difference above and below the glottis. However, when compared to the movement of the other articulators, the movement of larynx is sluggish. Thus the more rapidly reacting articulators are delayed to coordinate with the sluggish larynx (Hudgins & Stetson, 1935). Hence vowels were lengthened preceding voiced consonants.

Balasubramanian (1981) studied the duration of vowels in Tamil in various phonetic environments. Word initial and word medial vowels followed by voiceless and voiced consonants were examined in terms of their duration. The study revealed that in syllables of the structure V and CV, vowels were longer when followed by voiced consonants than when followed by voiceless consonants. In syllables of the structure. VC and CVC, however, vowels were longer when followed by a voiceless consonant group than a voiced one. However, Mitleb (1984) studied the vowels in Arabic language and the results revealed that Arabic vowels did not exhibit a difference in vowel duration as a function of the segmental voicing feature.

6. **Segmental interactions:** In German, it has been observed that the front vowels were longer before labials and velars than before dentals and back vowels were longest before velars (Maack, 1953). House and Fairbanks (1953) found that English vowels were generally longer before labials or velars.

Peterson & Lehiste (1960) carried out a study to determine the duration of syllable nuclei in English The durations of all syllable rules in English were significantly affected by the nature of the consonants that followed the syllable nuclei. The influence of the initial consonants upon the duration of the syllable nuclei appeared to be negligible. They found tendency for vowels preceded by fricatives to have somewhat shorter durations than vowels preceded by other consonants. Kenneth (1976) found that vowel duration in fricative environment was longer than in the plosive environments. Whereas, Whitehead & Jones (1976) found that the duration of vowels were significantly longer when it was followed by a fricative than when it was followed by a plosive.

Another secondary influence of consonantal environment on vocalic duration was a place of articulation effect discussed by Fischer-Jorgensen (1964). His findings were (I) before labials and dentals, the duration of back vowels were more than that of front vowels and (ii) before velars, the duration of back vowels were less than that of front vowels. He also observed that the duration of the vowels after voiced stops were longer than those after voiceless stops. In a study carried out by House & Fairbanks (1967), on the influence of consonant environment upon the secondary acoustical characteristics of vowels, it was found that the variations were systematically related to the attributes of the consonants, the most powerful attribute being the presence or absence of vocal fold vibration, followed by manner of articulation and place of articulation. Chen (1970) reported that the lengthening of the vowel was more when it was followed by a dental sound than when it was followed by labial or velar sounds.

Umeda (1975) carried out an extensive study on the temporal behavior of vowels with respect to consonant position. The investigator found that durations of the vowels were least when followed by voiceless stops, and increased when followed by voiceless fricative, nasal, voiced stop and voiced fricative, respectively. Lehiste (1975), states that "Vowel duration tends to increase as the point of articulation of the post vocalic consonant shifts further back in the mouth".

A study carried out on the temporal analysis of the vowels and consonants in Japanese by Homma (1981) revealed that as the place of articulation of the adjacent stops moved toward the back, both voice onset time and vowel duration became longer in the first syllable. In the second syllable, on the contrary, vowel durations became shorter in this direction. Acoustic measurements conducted by Luce & Luce (1985) revealed that duration of vowels produced before bilabials (mean duration is 155 ms) were longer than those produced before alveolars (mean duration is 147 ms) and velars (mean duration is 146 ms). Savithri (1986) reported that in Kannada language vowels preceding retroflex sounds were longer than vowels preceding velars. Because velars involved least coordination of articulators and that the retroflex involved more precise control of the articulators as the tongue has to curl back and touch the palate. Crystal & House (1988) studied the effects of voicing characteristic and found that the place of articulation of the post vocalic important constraint in English since duration has already been implicated as a factor to differentiate inherently tense (long) from the lax (short) vowels, voiced from voiceless fricative etc.," (Klatt, 1976).

7. **Polysyllabic environment:** Nooteboom (1972 a, 1972 b) reported that under the influence of an increasing number of following syllable, Dutch vowels decreased in their duration and however, the vowels with shortest duration were least

affected. This suggests that there might be differential effects of similar factors on the two vowel types. It could alsq mean that when a certain minimum vowel duration was reached the compression effect disappears. Nootboom (1972) found that the influence of number of syllables on both duration of long and short vowels could be predicted by the formula:

V = D/ (m * a) where
V = Predicted vowel duration
D = Duration of the vowel in monosyllabic conditions.
M = No. of syllables, and
A = a constant less than 1.

Even though the same formula was used for both long and short vowels implying that the effect was similar for the two types, the exponent 'a' could vary for the tense and lax vowels. This study showed that the duration range for the two vowel types differed. In case of tense vowels, the monosyllabic vowel duration was around 170 ms and in trisyllabic context it was 100 ms. In case of lax vowels, the monosyllabic duration was around 90 ms and trisyllabic condition it was around 70 ms. Thus, although lax vowels exhibited a resistance to compression when the number of syllables were increased, the tense vowels may also exhibit incompressibility at similarly short durations.

Temporal.analysis of vowels in Tamil carried out by Balasubramanian (1981) revealed that vowel durations were longer in monosyllable than in words having more than one syllable. He also established the fact that vowels were longer, in syllables with simple structures than in syllables of complicated structures. Bhaskar Rao (1988) carried out a study to determine the extent of compressibility of test vowel when the word was made progressively longer by the addition of inflenctional suffixes to the root word in Malayalam, Kannada (Dravidian family), Sindhi and Marathi (Indo-Aryan family) languages. In Kannada and Malayalam which have phonemic vowel length, the reduction of root word was more than the reduction of test vowel. In Malayalam the test vowel was slightly more reduced than in the case of Kannada. The overall reduction of the root word was being done at the expense of the root word excluding the test vowel. In Sinidhi and Marathi, though both the root word and the test vowel got shortened considerably, the reduction was more in the case of test vowel than in the rest of the root word. The reduction in Sindhi was of a larger magnitude than in Marathi. He concluded that increase in number of syllables, decreased the vowel duration.

Physiological factors: Finally the physiological efforts (to minimize the articulatory efforts) have been used to explain the difference in inherent phonological durations of vowels. For example the longer duration of low vowels had been attributed to the extra effort to open the jaw in the context of a consonant (Lindblom, 1968). Some of the physiological efforts have already been mentioned with relevance to the other factors.

Durational Models

Several models have been proposed to explain the way in which control over duration was achieved. Currently two models are recognized. They are the Comb model and the Chain model.

The "Comb model" (Kozhevnikov & Chistovich, 1965) holds that the units of speech are executed according to some underlying preprogrammed time schedule; i.e., the duration of speech sounds to be uttered are determined before they are produced. For example, if the speech sound /a/ is to **be produced, the** duration for which it is to be produced is determined before its production.

According to the "Chain Model", there is no underlying time program or given speech gesture is executed after the preceding gestures have been completed successfully (Ohala, 1973), i.e., the duration of the speech sound to be produced is not pre-determined. Ohala (1973) suggests the "Chain Model" for long term timing and the "Comb model" for the short-term timing. Kozhevnikov & Chistovich (1965) presented evidence for the "Comb model". They **stated that the** durational structure of a sentence was preplanned and that the open syllable was an important unit in this process. Preplanned sequential commands change the articulatory processes, which results in compensatory effect in speech production. This further gives rise to lengthening of the preceding segment when the following segment was shortened **or** vice versa.

Another model called the "Condenser model" suggests that the duration may be stored in terms of the interval of time in a given condenser with a given charge, which needs to discharge to a certain threshold level. Therefore, each unit which is to be assigned a duration is assigned a charge for a condenser. Thus duration rules would be operations on the charge of condensers" (Carlson & Granstrom, 1975).

Vowel Duration in Indian Languages

Velayudhan (1975) carried out a study in Malayalam, official language of Kerala State, on the South-West coast of India, to study the durational aspects of Malayalam vowels in isolation as well as in a variety of phonetic contexts. The results revealed that the short and long vowels tend to keep their ratio in the range of 1:2. It was also seen that the duration of a preceding vowel whether short or long was found to be shorter when followed by an occlusive rather than by a non-occlusive. The duration of the vowel preceding a voiceless long consonant was reduced considerably (as much as 50 percent) as compared to that of the same vowel preceding a short lenis stops which was often fricativized with mild voicing. The ratio of the short versus long opposition was found to be in the range of 1 :2 (table 2.2a)

Balasubramanian (1981) investigated the duration of vowels in Tamil, using four native speakers and the vowels occurring in various positions. Balasubramanian (1981) concluded that:

(a) the phonemically long vowels (V:) were almost twice as the corresponding short (V) vowels in identical environments.

(b) In genera] when other factors are controlled, open vowels were longer than close vowels.

(c) Vowels in simple syllables were longer than vowels in more complicated, cluster syllable structures. As the number of segments in syllables increased the duration of vowels in that syllable decreased.

(d) Vowels were longest when followed by retroflex consonant and shortest when followed by bilabial consonant in word having identical syllable structures. There was no appreciable difference between the durations of vowels followed by dental, palato-alveolar and velar consonants.

Rajapurohit (1982) studied the vowel duration in Kannada language using a single utterance in a single subject using 405 words. These words were not controlled for word length, post vocalic consonants, post vocalic voicing etc. The vowel duration were measured using oscillograph. Ganesan, Agarwal, Ansari and Pavate (1985) studied the vowels of Hindi language in eleven speakers. Nagamma Reddy (1988) studied the vowel duration in Telugu language taking one subject. She used sound spectrograph and electro - kymograph for the durational measurement. .

Savithri (1986) studied the vowel duration in Kannada language and also aimed at identifying some of the variables influencing the duration of Kannada vowels. She used six subjects and 82 trisylabic meaningful Kannada words for the purpose of durational analysis. She studied the influence of voicing, aspiration, nasality, clustering, place of articulation of post vocalic consonant on only three short vowels of Kannada. They were /a/ /i/ & /u/. Savithri (1989) has studied the duration of vowels in ten Sanskrit speakers (tabled 2.26) She found that the duration of long vowels was approximately twice that of the short vowels, their duration being approximately 180 ms and 80 ms. She found that female subjects had longer vowel durations than male subjects. She reported that the vowels preceding strongly aspirated stops were longer than the slightly aspirated stops and the vowels were longer before voiced stops than the voiceless stops. She also found that the vowels were longer preceding retroflex stops and shorter preceding velar stops. Vowels preceding retroflex /r/ were lengthened when compared to other semivowels.The duration of dipthongs were similar to the duration of long vowels. The obtained vowel duration is given in Table 2.3

Savithri (1989) observed that:

(a) high vowels were shorter in duration than low vowels.

(b) The voicing, aspiration and retroflexion of the post vocalic consonant, lengthened the vowel duration

(c) Nasality of the post vocalic consonant reduced the vowel duration.

(d) The vowel duration of the test vowel in simple syllable structure was longer than the vowel in a clustered syllable. She also observed that the vowel produced by female speakers had longer duration than the male speakers.

Venkatesh (1995) studied the effect of the consonant /k/ on vowel duration of all the ten vowels in Kannada language. The results may be summarized as:

a) in Kannada, each vowel had it's own intrinsic duration.
b) The vowel duration varied with the height of the tongue. The high vowels had shortest duration and low vowels had longest duration.
c) Openness and closeness of vowels also affected the duration of the vowel.
d) Rounded vowels had shorter vowel duration when compared to the unrounded vowels.
e) The duration of the long vowels were approximately twice the duration of short vowels.
f) These short and long vowels had different relationship with their respective word duration and syllable duration

g) The duration of short vowels were same in males and females, whereas the duration of the long vowels were different in males and females, with females showing longer duration for long vowels.

Ganguli, Datta and Mukherjee (1998) studied the durational pattern of vowels and syllables in Standard colloquial Bengali (SCB) text reading. Their results indicated that there was marked difference in vowel duration and syllable duration between the controlled speech and the spontaneous speech. The duration of the former case is about only 60% of those of the later. The vowel duration seemed to decrease systematically from mono to trisyllabic words by about 20% in each step. Thereafter there was not much of a change. The results indicated that average segmental dutations, syllabic as well as vowel duration, was compressible with length of the word.

The obtained vowel durations of the above studies are given in Tables 2.2a & 2.2b

Sasidharan (1995) in his study on Malayalam vowels report that the ratio of duration of the short and long vowels was found to be 1 : 1.89 and in the initial and medial position of the word were 1 : 1.85 and 1 : 1.93 respectively.

Peterson & Lehiste, 1960 English	Fant, Henningson & Stalhammar 1969 Swedish	Velayudhan 1975 Malayalam	Majumder, Datta & Ganguli (1978) Telugu	Balasubramaniyan (1981) Tamil	Rajapurohit (1982) Kannada	Ganesan, Agarwal, Ansari &Pavate (1985) Hindi	Savithri 1986 Kannada
V VD	V VD	V VD	V VD	V VD	V VD.	V VD	V VD
i 180		i 135	i 70	i 75	i 60.77	i 151.8	i 80.5
I: 240	I: 410	I: 300		I: 148	I: 136.41	I: 286.2	
e 260		e 150	e 110		e 83.16	e 263.5	
E: 200	E: 400	E: 270	E: 205	E: 152	E 151.16	E: 268.2	
a 260		a 145	105	a 84	a 71.84	a 156.5	a 81.5
A:	A: 410	A: 320	A: 230	A: 160	A 157.8	A: 248.6	
0		0 145	0 120	0 82	0 84	3 251.1	
0:	0: 410	0: 265	0: 200	0: 151	0 146.22	0: 276.1	
u 200		u 100	U 100	u 77	u 58.05	u 159.2	u 80.0
U: 260	U: 390	U: 205	U: 200	U: 151	U 168	U: 255.7	
ai 350	U: 410						
200	Y: 125			80			
ae 330	Ae 410						
230	0: 410			78	64.08		
310							
ou 220				154			
Au 300				86			
Ei 270				154			
I 370							
R 240							

Table 2.2a: Comparison of the duration of vowels across different languages

Nagamma Reddy 1988 Telugu		Savithri 1989 Sanskrit		Venkatesh 1995 Kannada		Ganguli et al. 1998 Bengali	
V	VD	V	VD	V	VD	V	VD
i	60	i	88	i	80	u	60
I:	110	i:	190	I:	166	0	70.5
e	65			e	96		76.7
E:	110	a:	196	e:	176	A	85.8
a	50	a	81	a	89	oe	95.0
A:	130	a:	178	A:	178	e	67.8
o	55			0	92	i	67.2
0:	110	o:	197	0:	168		
u	45	u	87	u	77		
U:	110	u:	180	U:	160		
		ai	198				
		r	121				
		au	197				

Table: 2.2b: Comparison of the duration of vowels across different languages

Savithri (1989) further investigated the vowel duration in Kannada using ten subjects, in 100 words. She used B & K High Resolution Signal Analyzer (Oscillographic method) for the measurement purpose. She made the following observations:

(a) the ratio between the duration of short and long vowels in Kannada language was 1:1.6, their duration being 76 & 120 m.secs respectively.

(b) in the word or sentence end, the vowels were lengthened. The short vowels were lengthened by 62 m.sec and the long vowels were lengthened by 370 m.secs. The ratios of their durations in non-word-end word-end were 1:1.8 for short vowels and 1:1.4 for long vowels respectively.

(c) Vowels preceding voiced stops were longer than those preceding the voiceless. The mean duration of short and long vowels preceding voiced stops were 75 and 132 m.secs and those preceding voiceless stops were 66 and 123 m.secs respectively. However, the vowels /a/ and /u/ were exceptions for these.

(d) The short vowels preceding nasal continuants were shorter than those preceding voiced stops but were longer than those preceding the voiceless stops. Among the long vowels, those preceding the voiced stops were longest followed by those preceding voiceless stops and nasal continuants.

(e) Vowels preceding the semivowels /r/, */i/ ,/v/* were the longest followed by those preceding fricatives and stops.

(f) Vowels preceding the palatal stops were the longest. These were followed by the vowels preceding dentals, bilabials, velars and retroflexes. However, there were no significant difference in the duration of vowels.

Place of Articulation	Velars VL	VD	Palatals VL	VD	Retroflexes VL	VD	Dentals VL	VD	Bilabilals VL	VD
Vowel Duration	64	67	74	76	54	62	69	76	62	67
Mean	65.5		75.5		60.5		72.5		64.5	

Table 2.3: Vowel duration as a function of the place of articulation of the post-vocalic stop consonants in m.secs (Savithri, 1989)

From the review of literature it is evident that vowel duration is one of the powerful factors to determine both the phonetic and phonemic quality of the vowels. It is an important parameter which provides information on the prosodic as well as linguistic aspects of speech.

Word duration:

Umeda (1975) determined that unusual, unexpected words have longer duration than more frequent anticipated words. The same effect could be occurring in children's speech. New vocabulary item showed longer duration than older, more familiar words. Klatt (1976) examined the factors affecting segmental duration in adult speakers of English. He noted that increased duration in the syllables in final position of the utterance and before a pause.

In studies on language acquisition, it is observed that a young child's first words tend to have much longer duration than later productions. Tingley & Allen (1975) tested the timing control of 5-, 7-, 9- & 11 year old children in sentence repetition and finger tapping. In this experiment the variability of segment length decreased with age. Similar decreases in variability were obtained in the finger tapping task, suggesting that all motor control improves with age. Smith (1978) examined several temporal parameters in two year olds, four year olds and adults who were asked to give ten repetition of various nonsense syllables. Average word duration was greatest for the two years old, with word duration 31% longer than for adults. Four year olds had average word duration 15% greater than did adults. The same trend was seen in segment length. In addition the youngest age group had the greatest variability in word duration. Kent & Forner (1980) obtained similar results from groups of four- year olds, six- year olds, 12- year olds and adults.

Kubaska and Keeting (1981) conducted a study to investigate further the patterns of word duration in child's speech thorough a longitudinal study of a set of frequently occurring words for three subjects. Results indicated that although some words showed significant decrease in duration over time, most did not. In fact, the average duration of two words increased over time. The hypothesis that duration is affected by the child's familiarity with a particular word was also tested. The results were insignificant, suggesting that familiarity has little effect on duration in child's speech. Another hypothesis was that position in utterance has an effect on word duration of children as well as adults. The tests of position in utterance effects across early and late samples indicated that generally tokens in a non-final position are shorter than either isolated or utterance final tokens. Also, there was often no difference between isolated and utterance final tokens. The major influence appears to be whether a word was followed by a pause or not. The results can be summarized as follows:

a) For some but not the majority of the words studied, duration decreased over time.
b) Decreases do not appear to be due to increased familiarity with individual lexical items.
c) Word duration variations with the tested time ranges appear to be largely attributable to the effect of position in the utterance. Isolated and utterance final tokens of words were longer than non-final tokens.

In conclusion, the most interesting result of this study was that from the time a child first combined two words into a single phrase, a non-final word was produced with a shorter duration than it would have in isolated or final position in an utterance. Average word duration may decrease as the child grows older partly because a larger percentage of tokens appear in non-final position.

Various studies of speech production development have observed that duration and temporal variability tend to decrease as children get older. Because both of these factors are commonly viewed as general indicators of neuro motor maturation of children's speech skills, it would seem reasonable to assume that they should be rather closely correlated with one another. But, an examination of a variety of temporal data from children ranging between approximately 2 ½ & 9 ½ years of age indicated that there was not necessarily a close correspondence between these two variables as might be expected. It also appeared that speech duration measures of children tend to be more adult like than measures of their intra subject variability.

Several other acoustic studies have also observed that children's speech segments, syllables, words etc., tend to decrease in duration and also become less variable from younger to older groups of subjects (eg. Chermak & Schneiderman, 1986; Kent & Forner, 1980; Smith 1978, 1992, 1994; Smith et. al., 1983; Tingley & Allen 1975). Although both duration and variability have commonly been observed to continue to decrease until as late as 10-12 years of age before reaching adult like levels (Kent & Forner, 1980; Smith et. al., 1983), the basis of such changes is not clear. They are typically assumed to be due to 'neuro muscular maturation' **and** greater experience with the process of speech production or to a combination of both maturation and experience.

A fairly consistent result of studies on children's speech production was that children younger than about six years had longer speech segment duration, than adults and older children (Naeser, 1970; Hawkins, 1973; Di Simoni, 1974a, b, c, Gilbert, 1977 & Smith (1978). Smith (1978) reported that duration of nonsense utterances were 15% longer for four years old than for adults and 31% longer for two years old than for adults. Because few data have been reported on the duration of segments in children's connected meaningful speech, it is not clear at this time if lengthening of segments is a uniform property of children's speech. This issue is of interest for at least two reasons. First, reduction of segment duration with age may be a consequence of neuromuscular maturation; therefore, durational measurements may be one way of characterizing a child's developmental progress in attaining adult like speech motor control. A second reason is that developmental patterns in the control of duration are a necessary substrate for research on the acquisition of phonological process. Another developmental pattern emerging from studies of children's speech is an age-dependent decline in variability of performance (Eguchi & Hirsh, 1969); Di Simoni, 1974a, b, c; Tingley & Allen (1975).

Kent & Forner (1980) addresses the possibility of developmental effects on segment durations of connected meaningful speech. Spectrograms were used to study speech segment duration in recitation of three simple sentences by 10 adults and by 10 children in each of 3 age groups; 4, 6 & 12 years. The results are in agreement with earlier results reviewed earlier showing that young children at least younger than about 6 years, tend to have longer speech segments than adults. Also, these mean segment duration often were accompanied by a greater variability in repeated productions of the segments. From the results it appeared important to investigate how the variability of segment duration interacts with various segmental and suprasegmental characteristics. Their data indicated that both lengthening of mean segment duration and increased variability of segment duration was more likely to occur under some segmental - suprasegmental combinations than others. For eg. the increased mean and variability of VOT seen for children's productions of /k/ in cat, but not /t/ in 'took', might be related to the fact that 'cat' was a stressed, utterance final word containing a vowel of inherently long duration. Kent & Forner (1980) observed that four and six years old children showed longer and more visible productions than 12 years old and adults. Smith et al (1983) observed that when five, seven and more older children spoke at faster than normal rates and there by produced duration quite comparable to those of adults, children's variability typically was still greater than that of adults.

Smith, Sugarman & Lang (1983) found that children ranging from five to nine years of age exhibited sentence duration that were 36% greater than those of adults when both groups were speaking at fast rates. In addition, although 3 and 4 year olds segments have been found to be 30-35% longer than those of adults at normal speaking rates (Smith, 1978; Kent & Forner 1980), it has been observed that adults maximum syllable repetition rates were approximately 50% faster than those of even seven years old children (Jenkins, 1941, Lundeen 1950). Thus it appeared that speech segment durations might be affected to a greater extent when children were required to perform at maximal vs sub-maximal levels.

Smith (1992), in his study, a subset of the data collected in two previously reported experiments (Smith, 1978; Smith et. al., 1983) was used to investigate duration and variability issues more carefully. Previous research had commonly noted general decreases in both duration and variability when comparing groups of adults or older children with groups of younger children. But little has been mentioned in these studies concerning the nature of the relationship between duration and variability in children's speech. This issue was the primary focus in Smith's (1992) study. It has been suggested that variability in children's speech may merely be a function of duration (Kent & Forner 1980). Findings from Smith's analysis suggest that these assumptions are not entirely accurate. His findings also suggest that it may be possible to draw at least some conclusions about the speech motor control development of individual children on the basis of duration and variability measures. Earlier studies showed a general tendency for decrease in duration and variability to occur when groups of younger children were compared with groups of older children and adults. However in the present analysis the correlation between these two variables were generally found to be relatively modest. This rather moderate relationship between duration and variability thus suggested a need for caution in considering these two measures as equivalent indicators of children's speech.

Smith (1992) concluded by stating that although it can safely be said that both duration and variability generally tend to decrease with increasing age across groups of children and that such decreases were probably at least general indications of increasing speech motor control, what can be said at this point when considering duration and variability measures as they pertain to individual subjects with a group was not particularly clear. Additional research particularly of a longitudinal nature might be more beneficial in dealing with issues concerning the topic. In summary, utilizing a different perspective to reanalyze data from two previous studies (Smith 78, Smith et. al., 1983), it was determined that there seems to be only a moderate correlation between duration and variability in the speech of children. It was concluded that variability was thus not simply an epiphenomenon that was secondary to the development of duration. Further more, although group data indicated that both duration and variability generally tend to become more adult like as children get older, these two measures were not found to necessarily be congruent indicators of the degree to which the speech of an individual child might be approaching adult levels of performance. It appears instead that duration tends to reach adult like levels earlier in the process of development than variability.

The investigation by Smith & Hussain (1996) is a longitudinal analysis of several temporal characteristics of the speech of twelve children of various ages who were seen twice, approximately 1½ years apart. For the group, duration decreased on an average from the initial to the follow up recordings by approximately 10% and temporal variability decreased by about 40%. For the individual children however it was found that some of them showed few, if any, changes in some of the temporal measurements made at two different times whereas others showed substantial differences. Younger children also did not necessarily show longer duration or greater variability than older children nor did younger children always show greater changes across time than older children. Thus, although cross sectional studies indicated that there was a general tendency when comparing group for increased age to be associated with shorter duration and reduced variability, individual children may not evidence such patterns or changes across time. In at least certain instances, some of the younger children showed little difference between the two time periods for one or both of the temporal parameters of interest, whereas some older children showed rather substantial decrease across time compared to certain younger children. This study also revealed that there was a tendency for children whose duration were longer or whose variability was greater at time one to also show longer duration or greater variability at time two . This suggested that there might be a certain amount of learned and or inherent aspects of children's speech production that do not change substantially over time relative to other children within a group. Thus the generalization often made on the basis of cross sectional data that duration and variability decreased with increasing age must be made somewhat cautiously given the longitudinal patterns shown by individual children.

Robb, & Tyler (1995) examined the duration of word and non word forms in the monthly vocalizations of seven children between 8 and 26 months of age. The word forms and non word forms occurring in each child's consonant + vowel (CV) vocalization were measured. The results were that word duration significantly decreased as a function of increasing chronological age. On the other hand non-word duration were not correlated with increasing age. The meaningfulness corresponding to word forms was hypothesized to account for the results.

Katz, Beach, Jenouri & Vema (1996) examined how children and adults produced acoustic correlates for phrase boundaries during speech. Adults and children (ages 5 & 7) were asked to describe groupings of colored block, first in a relatively spontaneous manner and next under more structured conditions. Acoustic analysis indicated that adults reliably control both duration and fundamental frequency (TO) to signal phase boundaries, where as children of both age groups demonstrate little evidence of either type of information being used. Authors conclude suggesting that children as old as age seven do not produce prosodic cues for this type of standing ambiguity in their every day speech, eg: (The old men) and women sat of the bench. (The old men and women) sat on the bench.

If durational differences between adult's and children's speech were greater for maximal speaking rates, it is also possible that their duration differ by varying amount at normal speaking rates as a function of intrinsic durational characteristics of specific segments. That is, children might produce inherently longer segments with more adult like duration, where as inherently shorter segments, may be more demanding of children's speech motor control capabilities and may therefore be produced with less adult like duration. For eg: their stressed vowels are inherently longer in duration than consonants (Lehiste,1970), vowels may be produced by children with duration that are more comparable to adults. In contrast, their consonants tend to require more skilled artciulatory performance , they may show less adult like in duration than other types of segments, then flaps might be least adult like in duration of all segments produced by children learning American English.

Rimac & Smith (1984) studied whether all types of segments produced by children and adults show the same durational relationships or whether intrinsically short segments produced by children are less adult like than intrinsically longer segments. The second purpose of the study was therefore to determine whether the relationship between children's and adult speech segment duration could be more accurately represented by absolute or relative increments. Subjects were children ranging for 7.9 years to 8.5 years and adults 28 to 40 years who were native speakkers of American English. Results showed that the adults produced 90% of the flaps with in the 20-50 ms range, while the children produced 90% of their flaps in the 20-90ms range for all tokens. Children's flap productions averaged 61 ms and the adults flaps averaged 36 ms in duration. Thus the adults produced not only shorter duration for the flaps but also a narrower distributional range than that of the children. Children's stressed vowel duration was 13% greater than those of adults. The other segment types were non flapped consonants preceding stressed vowels (29%greater), unstressed vowels (33% greater) non flapped consonants preceding unstressed vowels (43% greater) and flaps (68% greater). They concluded that shorter intrinsic segments (such as flaps) show greater proportional differences between children and adults while longer intrinsic segments (such as stressed vowels) show smaller, proportional differences. It appears that the development by flap productions by children is a gradual process. In part, speech motor control and neuromuscular development may some what restrict children's fine motor movements and the precise timing control necessary to produce alveolar flaps.

To summarize the review on word duration, it can be stated **that all motor** control improves with age and variability on word duration decreases with age. Adults also showed a narrower distributional range than that of the children.

Formants:

As the tone produced by vocal fold vibration passes through the vocal tact, certain frequencies get damped and certain other frequencies get amplified. The frequencies which are nearer to the resonant frequencies of the cavities in the vocal tract get amplified. These amplified frequencies are seen as peaks in the spectrum of vowels. The regions of the spectrum in which the frequency corresponds to the relatively large amplitude are known as formants. The formant frequencies of a speech sound are directly dependent on the shape and size of the vocal tract. They are largely responsible for the characteristic quality of the speech sound. It is the presence of formants that enable us to recognize different speech sounds which are associated with different positions of the vocal tract (Ladefoged, 1962).

Fant (1960) defined formants as "the spectral peaks of the sound spectrum". Singh and Singh (1979) defined formant frequency as "the frequency region that is significantly amplified for a continuous period of time". The lowest band of continuous stretch of darkness at the lowest end on a spectrogram or the first spectral peak is called as the first formant and is denoted by Fl. The next higher band with a noticeable stretch of darkness or the second spectral peak is the second formant, denoted as F2. Third higher band or the third spectral peak is the third formant, denoted by F3 and so on". In the literature the term formant has been used principally to indicate a concentration of spectral energy in a narrow frequency region of a speech signal. Further more, it generally has been applied only to those portions of the speech signal called voiced, that is, characterized by glottal excitation. For any vocalic sound, a number of formants may occur in the frequency range 0 to 4000 cps, but attention is usually focused on the lowest two or three.

The term formant, a German word, was used first by a physicist Hermann in the second half of the nineteenth century. A formant is a range of frequencies, but since a formant must give rise to a peak in the spectrum of sound produced, the term formant is commonly applied to the frequency at which the peak occurs (Fry, 1979). Formants are the most significant earmarks of sound and every vowel is formed by two or more formant changes (Bunch, 1982). The most significant features of the vowel spectrum are the frequencies, bandwidths and amplitudes of various formants. These correspond to the resonance of the vocal tract, and they produce peaks in the speech spectrum (Denes & Pinson, 1963).

The formant frequencies of a vowel provide a description that is relatively compact, and that is known to bear a reasonably direct relation to observable features of the acoustic waveform and spectrum of the vowel and to the articulatory activity used in the generation of the vowel. In the past, various attempts have been made to show that the formant frequencies are sufficient to provide unambiguous identification of the vowels of a given dialect. These attempts have generally been inconclusive for several reasons, i.e;

a) the same vowel generated by different talkers is characterized by different formant frequencies, b) the phonetic context of a vowel has an influence on the values of the vowel formant frequencies, c) the formant frequencies usually vary as a function of time throughout a vowel in a word or sentence, and hence specification of the frequencies at one instant of time provides only a partial description of the vowel.

Two theories have been proposed regarding the vowel production i.e., Cavity Tone Theory and Harmonic Theory. According to cavity tone theory'proposed by Wills (1829), "the sound identified as a vowel was dependent only upon the length of the resonating tube and its resonances and the vowel tone was completely independent of reed tone (fundamental frequency)". According to Whaetstone (1837), the proponent of harmonic theory of vowel production, "the vowel heard was the result of an augmentation of certain of the harmonic components of the reed tone". Scripture (1902) on the basis of a review of literature and his own experiments concluded that, the vowel production was not a function of the over tones or harmonics but rather a function of the natural resonance of supra glottal resonators. Thus the cavity tone theory was more widely accepted than the harmonic theory. As the vocal tract assumed different shapes and sizes for the production of different vowels, the formant frequencies also changed for different vowels and this led to the perception of different vowel qualities.

According to Fant (1960), Fl of the vowels /e/, /i/, and / i̱ / was almost completely determined by the back cavity volume and the narrowest section of the mouth cavity. Vowels /u/, /o/ and /a/ were somewhat more dependent on the front cavity constriction. The contribution to Fl for the vowel /u/ from the back cavity volume was somewhat larger than that from the front cavity. The second formant F2, only in the case of the vowel /i/, the mouth cavity with associated orifices were found to be the essential determinants of F2. F2 of /i/ was clearly a half wavelength resonance of the back cavity. There was a similar but not so apparent tendency of F2 of /e/, it was influenced more by the back than by the front cavity. The second formant of the back vowels /u/, /o/ and /a/ was somewhat more dependent on the front cavity than on the back cavity. However, the cavity volume changes were introduced on a constant percentage basis, this tendency was apparent, but where the volume changes were performed by means of a constant length reduction, there was an equal dependency of F2 on the two cavities for /u/ and also for /a/. In case of /u/, F2 was dependent much more on the relative dimensions of the tongue mass than on the lip section. These two parts of the compound resonator system had about the same effect on F2 of both /a/ and /o/. The lip section was of practically no importance for F2 of /i/ and did not have a very marked influence on F2 of /e/ either (Fant, 1960).

Stevens & House (1961) has outlined an acoustic theory of vowel production and certain implications of the theory are discussed. The theory considers a vowel sound to be the result of excitation of a linear acoustic system by a quasiperiodic volume velocity source. The transfer function of the acoustic system is completely described by a number of poles whose frequency locations depend on the vocal tract configuration. It is shown that the over-all intensity of vowels, amplitude relations within syllables, and questions of balance in the vowel spectrum. Finally it is proposed that the traditional term formant be restricted to mean a normal mode of vibration of the vocal system.

Sundberg, (1969) opined that the alteration in the configuration of the vocal tract gave rise to variations in ranges of formant frequencies. Combinations of variations in the shape and extent of opening of lips, the position of the tongue, mandible and soft palate have been considered to contribute to the changes in the responses of the cavities in the vocal tract to different frequencies and thus change the formant frequencies.

Fl varies mostly with tongue height and F2 varies with tongue advancement. That is with variations in the antero-posterior position of the tongue. In general low vowels have a high Fl frequeuency and high vowels have a low Fl frequency. Back vowels have a low F2 and typically a small F2-F1 difference, whereas front vowels have relatively high F2 and a larger difference. Therefore the vowel's formants can be used to identify a vowel and even to establish relationships between acoustic and perceptual parameters. Vowels are described in terms of formant frequencies, bandwidths and amplitude. Bandwidth and amplitude interact with each other in a given vowel. Bandwidth is related to damping which is the rate of absorption of sound energy. Greater the damping, greater the bandwidth of the sound. Sounds that are greatly damped tend to die out quickly. And sounds associated with very little damping tend to be sustained. If the human vocal tract were a hard walled tube its damping would be considerably less. Because the vocal tract is composed largely of soft, moist tissues an appreciable amount of the sound produced in speech is absorbed by these tissues. Formant band widths increase with formant change. So the higher formants have larger bandwidths than Fl. Experiments have shown that changing bandwidth of formants has very little effect on vowel perception. Increasing formant bandwidth in speech synthesis can reduce the distinctiveness of vowels, because the energy of different formants overlap. Vowels which are nasalised shows this effect.

Formant changes based on vocal tract changes given by Fant (1973) is presented in the following table.

Table: 2.4 Segmental pattern features (Fant 1973)

ARTICULATION	SPEECH WAVE - SPECTRUM
1. Tongue fronted	F2-F1 large
a) Prepalatal position	F2 high, F3 maximally high
b) Midpalatal position	F2 maximally high and close to F3.
2. Tongue retracted	F2 - Fl small. Fl comparatively high.
3. Mouth-opening (including tongue section and lip) narrow.	Fl low.
4. Lips relatively close and protruded (Small lip opening area)	F1+F2+F3 lower than with a larger lip opening and the same tongue articulation a progressing lip closure alone causes a decrease in each of Fl, F2 and F3 but with varying amounts depending on the particular tongue position. The effect of F3 is pronounced in case of prepalatal tongue positions
5. Retroflex modification	
a) Alveolar articulation	F4 low and close to F3
b) Palatal articulation	F3 low and close to F2
6. Bilabial labiodental Closure	F2 in the region of approximately 500-1500 c/s depending on the tongue location of the associated vowel or vowel like segment. A palatal tongue position favours high F2. The noise spectrum of the fricative /f/ is essentially flat and of low intensity.

7. Interdental articulation	F2 1400-1800 c/s. Fricative noise of /o/ much weaker than for /s/ and with a more continuous spectrum. Center of gravity is higher than for the labiodental fricative /f/.
8. Dental or prealveolar Articulation	F2 in the region of 1400-1800 c/s F3 high. Fricative noise strong. The main part of the /s/-energy is above 4000 c/s. This cut off frequency is lower for alveolar than for dentals.
9. a) Palatal retroflex articulation	F3 low. The fricative nose of /s/ is of high intensity and is carried by F3 and F4.
b) Palatal articulation with tip of tongue down	F2 and F3 high, Strong fricative noise centered on F3 and F4 and also on F2 providing the tongue pass is sufficiently wide. The lower frequency limit of/s/ noise is higher than for retroflex sounds.
10. Velar and pharyngeal Articulation	F2 medium or low. A large part of the fricative noise is carried by F2. The F pattern except of Fl is clearly visible.
11. Glottal source	The entire pattern including Fl is visible.

Vowel sounds have been traditionally classified along several dimensions like height, backness, tenseness etc. The formant frequencies of vowels have been widely used as acoustic parameters representing different dimensions for eg: it is considered that the first fomant frquency (Fl) has been related to vowel height and the second formant frequency (F2) to vowel backness. Stevens & House (1955) related the acoustic event described by a high first formant with the articulatory event characterized by a narrow tongue constriction a few cms above the glottis and an unrounded large mouth opening and low Fl values with small rounded mouth opening or with a narrow tongue constriction near the mouth opening. For vowels characterized by high Fl values for eg; /a/, the tongue body position is low, and for vowels characterized by low Fl values for eg: vowel /i/, the tongue body position is high. For vowels characterized by intermediate values of Fl for eg: vowel /E/, the tongue body position is neither high nor low.

Di Benedetto (1989a) investigated the possibilities of Fl to classify vowels according to vowel height. In their study five vowels of American English , the high vowel /I/ two low vowels /a, ae/, and two mid vowels /*E*, ^/ were considered. The speakers were asked to pronounce the sentences carefully and clearly. If a mistake occurred, the sentence was repeated. The sentences were pronounced in a random order, using the following procedure. The CVC syllables were written in phonetic symbols on cards, one on each card, which were than shuffled. The 3 speakers uttered the sentences reading from the card, the appropriate CVC syllable. This procedure was repeated three times. Thus three tokens of each vowel in each consonantal context was available. A record of the sentence orders was kept after each repetition. Results of the acoustic analysis in the Fl Vs F2 space of five vowels of American English /I, E, ae, ^, a/ have shown that overlapping occurred between vowel areas in the Fl dimension when the formants were sampled at the time where Fl reached its maximum. For a single speaker, the first vowels /I, E, ae/ were well separated from the back vowels /a, ^/. These results showed that Fl could not accurately classify vowels along a dimension height if, over the whole Fl trajectory, one considered only the Fl value at the time where F1, reaches its maximum.

Earlier studies of consonant context and lexical stress involved only isolated words or words in a carrier phrase, and the studies of continuous speech did not consider each consonant context separately. Huang, (1989) in his study measured the formant frequencies in vowels taken from a read story that was well controlled with respect to consonant context and lexical stress. The vowels carry primary or secondary lexical stress. The same vowels and consonants were elicited in a retold story and in nonsense words spoken in a carrier phrase. Preliminary results from one speaker indicated that consonant context and lexical stress do affect vowels in continuous speech as expected. The results also showed no gross differences in the effects of these factors on vowels in continuous speech and in the isolated words studied previously.

Speaking rate has been considered to affect the spectral features of vowels. Disagreement exists regarding the effects of rate of speech and of segmental duration in vowel formant frequency values. Tiffany, (1959) & Miller, (1981) noted that as speakers read from text at a conversational speaking rate, reduced contrast among vowel formant frequency characteristics distinguished their productions from those observed when they read single words in isolation. Lindblom (1963) described a tendency for text - read speech uttered at various rates to be characterized by undershoot of vowel formant frequency values (centralization) as rate increased and concluded that vowel duration seems to be the main determinant of the reduction. Delattre (1969) performed cross linguistic analysis of vowel reduction and suggested that data from languages other than English indicate that stress, rather than duration, might be the factor primarily responsible for changes in vowel formant frequency characteristics in varying contexts. Gay, Ushijima, Hirose & Cooper (1974) noted significant vowel undershoot at proximately induced rapid rates of speech.

Gay (1978) studied the effects of change in speaking rate on both the attainment of acoustic vowel targets and the relative time and speed of movements toward these presumed targets. Four speakers produced a number of CVC and CVCVC utterances at slow and fast speaking rates. Spectrographic measurements showed that at the mid point formant frequencies of the different vowels did not vary as a function of rate. For fast speech the onset frequencies of second formant transitions were closer to their target frequencies while CV transition rates remained essentially unchanged, indicating that movement toward the vowel simply began earlier for fast speech, i.e., the study showed that differences in vowel duration due to changes in speaking rate do not seem to have a substantial effect on the attainment of acoustic vowel targets. The formant frequencies of these presumed targets remained essentially unchanged across changes in speaking rate.

A number of studies have suggested that vowel duration and formant frequency characteristics do not appear to be systematically related. Gay (1978) found that, when speakers were instructed to change speech rate but maintain phoneme identities (be clear), vowel formant frequencies remained relatively stable, though vowel duration were compressed. Verbrugge, Strange and Shankweiler (1977) noted a similar finding from their study. Although vowel duration decreased during fast speech conditions formant frequencies were only slightly centralized. Picheny (1981) found that formant frequency characteristics of vowels contributed to intelligibility ratings, duration characteristics apparently did not and that no systematic relationship could be observed between vowel duration and vowel formant frequency values. Berstein-Ratner, (1985) compared the formant frequency characteristics of vowels in mother to child and mother to adult samples. Findings suggested that no simple relationship exists between the length of vowel segments and their formant frequency characteristics in spontaneous conversational speech. The findings were in concordance with those obtained by Verbrugge, Strange and Shankweiler (1977) and by Gay (1978), whose subject's vowel productions during fast reading showed little effect of duration on formant frequency characteristics.

To test the effect of speaking rate on spectral features, Van Son & Pols (1990) conducted a study where in a meaningful Dutch text of about 850 words was read twice by an experienced news caster, once at a normal speaking rate and once as fast as possible. The first and second formant values of 7 out of 12 vowels in Dutch were measured. No spectral vowel reduction was found that could be attributed to a faster speaking rate, neither was a change in co-articulation found. The only systematic effect was a higher Fl value in fast-rate speech irrespective of vowel identity. This possibly suggests a generally more open articulation of vowels, speaking louder or some other general change in speaking style by the speaker when he speaks fast. From the studies on speaking rate it appears that speaking rate tends to affect the spectral features and significant vowel undershoot has been noticed at induced rapid rates of speech.

The relationship between speaker fundamental frequency (FO) and first formant frequency (Fl) was investigated by Syrdal & Steele (1985). A wide FO range was studied in each of two sentence positions using representative high and low vowels (/i/ & /ae/) in two phonetically controlled inter changeable key words. Data were collected from four women and four men and processed with a 14th order LPC analysis using a correlation pitch tracker. The bark transformed FO ranges were equivalent for women and men. The relationship between FO and Fl were similar for both sexes, although women consistently adjusted Fl frequency in *HI* to closely approximate FO in their higher FO range, where as men typically did not. It was found that Fl increased significantly with increasing FO. Although the difference between bark transformed Fl and FO decreased significantly as FO increased, a three bark critical distance consistently separated *I\J* & /ae/ throughout the FO range.

Diehl, Lindblom, Hoemake & Fahey (1996) supported the assumption of the sufficient contrast hypothesis that higher fundamental frequencies may interfere with vowel identification because of poorer definition of spectral envelopes. Hanson (1997), in his study suggests that a more open glottal configuration results in a glottal volume-velocity waveform with relatively greater low frequency and weaker high frequency components, compared to a waveform produced with a more adducted glottal configuration. The more open glottal configuration also leads to a greater source of aspiration noise and larger bandwidths of the natural frequencies of the vocal tract, particularly the first formant.

Vowels have traditionally been described acoustically in terms of static spectral characteristics, often refereed to as acoustic 'targets' (Joos, 1948, Ladefoged, 1967). These targets are a product of the resonance characteristics of the vocal tract configuration assumed when vowels are produced as sustained steady-state sounds. These formant targets are not in variant across different speakers and major differences exist between the average values for men, women and children (Peterson & Barney 1952). Furthermore, target formant frequencies are often not reached when vowels are co-articulated with consonants in natural speech, a phenomenon known as "target undershoot" (Lindblom 1963). The extent of undershoot varies with consonantal context, speaking rate, and individual speaker differences (Stevens & House 1963; Lindblom, 1963; Gay, 1978).

Vowel reduction refers to the tendency for the obtained formant frequencies of a vowel to fall short of the idealized target values from that vowel- »• values that would be obtained if the vowel were produced in isolation - resulting in overall shrinkage of the vowel space. Consonantal context, stressing and rate of speech (tempo) contribute to this kind of vowel reduction. Fourakis (1991) aimed to determine the extent to which phonetic vowel reduction , brought about by desstressing and increased tempo , affects the nine monophthongal, non reflex vowels of American English. Subjects were four female and four male native speakers of Mid Western American English. They ranged in age from 18-60 years. The results showed that tempo and stress were not major factors in determining the occurrence and extent of phonetic vowel reduction in mid Western American English and that context variation played a role in phonetic vowel reduction.

In a study by Stevens & House {1963), the effects of different talkers and different phonetic contexts were examined by obtaining data for a small number of (3) talkers with different physical characteristics and by selecting speech materials that provided example of each vowel in each of a number of consonantal contexts. The speech material included eight common vowels and 14 consonants that could appear both initially and finally in American English. Nasal consonants were not included because of the difficulties of measuring formant frequencies for nasalized vowels. The measurements of formant frequency and bandwidth were performed using a spectrum matching procedure. The results indicated that the shifts in Fl were in general small. For front vowels, the consonantal environments caused F2 to shift down ward and the shift was larger for lax (Short) vowels than for tense vowels. In the case of back vowels, the consonantal environments cause an upward shift in F2 and the shift is particularly large for rounded vowels. Also significant differences existed in the vowel formant frequencies for one talker to another when the vowels were in the 14 consonantal environments. Acoustic theory predicts that systematic differences should be obtained for utterances of vowels by talkers with different overall, vocal tract lengths. The percentage differences in vocal tract lengths are roughly comparable to the percentage differences in formant frequencies

According to Stevens & House (1963), when they studied the effects of consonantal context on the vowel formant frequencies two general observations emerged: a) the extent of which various consonantal contexts influence the formant frequencies of a vowel differs considerably for one vowel to another b) the consonantal context causes systematic shifts in the vowel formant frequencies depending upon the place of articulation of the consonant, its manner of articulation and its voicing characteristics.

The effect on the vowels of place of articulation in the consonantal context showed that the average shift in Fl for different places of articulation of the consonant was in general small. The effect of F2 was often appreciable and depends strongly on the place of articulation of the consonant as well as on the vowel. The consonantal context always had the effect of shifting F2 from a value appropriate for the null environment toward a more central position, for front vowels with high F2 the shift was downwards and for back vowels with low F2 the shift was upwards. For front vowels the shift was least for the velar consonants and greatest for the labials and post dentals; for the back vowels the labials cause only a small shift in the vowel while the post dentals often cause an appreciable shift as much as 350 cps for the rounded vowel /u/.

On the whole the study suggested that two types of displacements existed, i.e. some articulatory parameters of the vowel shift toward values for a neutral configuration and some shifted toward values for the adjacent consonants. The manner and voicing characteristics of the consonantal environment as well as the place of articulation of the consonant, exerted an influence on the formant frequencies of the vowel. One feature of the data was that tendency for F2 values for vowels in the environments of fricative consonants to be lower for front vowels and higher for back vowels relative to corresponding values for stop consonantal environments. This difference was most evident for /I/., */ae/* & /u/. This data indicated that the vowel tended to approach its ideal target configuration more closely when the consonantal environment was a stop than when it was a fricative in spite of the fact that vowel duration for stop consonantal environments are shorter than those for fricative environments.

Strange (1989) has stated that the co-articulated vowels were differentiated acoustically by dynamic information defined over the entire CVC syllable. Listeners utilize this dynamic information in identifying vowels spoken rapidly in CVC syllables in sentence context. The representation of vowels as static points in an F1/F2 space or indeed in any static spectral space (Syrdal & Gopal, 1986) failed to capture perceptually critical aspects of the signal that allowed listeners to disambiguate vowels.

The purpose of the study by Gay, Boe & Perrier (1992) was to use vocal tract stimulation and synthesis as means to determine the acoustic and perceptual effects of changing both the cross sectional and location of vocal tract constrictions for different vowels. Results showed that formants for each of the vowels were more sensitive to changes in constriction in cross sectional area than changes in constriction location. Vowel perception, however was highly resistant to both types of changes.

Studies have been carried out to obtain data on formant frequencies in the speech of male and female speakers and sometimes also for children speaking various languages: American- English (Peterson & Barney, 1952; Eguchi & Hirsh, 1969 and Strange, Verbrugge, Shankweiler & Edman., 1976); Swedish (Fant, 1959); Danish

(Frokjaer-Jensen, 1967); Dutch (Pols, Tromp & Plomp, 1973 and Koopmans, 1973); Estonian (Liiv & Remmel, 1970); Serbo-Croatian (Lehiste & Ivic, 1963); Japanese (Suzuki, Kasuga and Kido, 1967); Italian (Ferrero, 1968): German (Hess, 1972); Polish (Majewski & Hollien, 1967) and Hungarian (Tarnoczy & Radnai, 1971). The results of all these studies have revealed that there were systematic differences between the average formant parameters of male and female speakers. Acoustic theory predicted this on the basis of the different overall vocal tract lengths (Fant, 1960).

Adult female vocal tract tend to be shorter than those of adult males and accordingly in the speech of females, formants tend to be higher in frequency. One might naively assume that if a given female vocal tract were, say 20% shorter than a given male's then her formant frequencies would be uniformly scaled upward by about 20% relative to his. According to Chiba & Kajiyama (1941), the total length of an average female vocal tract is about 15% shorter than an average male vocal tract. The higher formant frequencies found in females may be due to the shorter vocal tract in females, when compared to males. However, as Fant (1966, 1975) and others have shown, the scale factor relating female and male formant values was decidedly non-uniform across different vowel categories and across formants. Moreover this non uniform scaling appears to be fairly consistent across languages (Fant 1975).

Formant frequencies of vowels produced by an adult males and females were compared by means of scale factors based on the ratio as followed by Fant (1966).

1. First formant scale factor

$$K1 = \frac{F1 \text{ of female}}{F1 \text{ of male}} - 1 \times 100$$

2. Second formant scale factor

$$K2 = \frac{F2 \text{ of female}}{F2 \text{ of male}} - 1 \times 100$$

Fant (1966) concluded based on his calculations that the scale factors relating male and female data varied with the class of the vowels, with the average scale factor being about 18%. In addition, he determined that the scale factors for both Fl and F2 were low for rounded back vowels. The scale factor for Fl was low for any close or highly rounded vowels and the scale factor for Fl was high for very open, front or back vowels. Fant (1966) pointed out that these differences were consistent with differences in vocal tract anatomy between males and females in so far as males had a greater relative length of the pharynx than females.

Pols, et.al (1973) studied the format frequencies in males and females; producing Dutch vowels in a h/ vowel /t context: A significant difference between male and female formant frequencies were observed. There were considerable individual spectral variations within different vowel phonemes, even when they were all produced in a neutral context. This individual variation was not randomly distributed over all vowels, but that speaker normalization procedures could effectively be used to considerably reduce the individual differences (Pols, et.al, 1973).

Kent (1976) has drawn the tentative conclusions on child -adult scale factors. They are :

1. The scale factors for Fl was large for the high vowels but small for the low vowels.
2. The scale factor for F2 was large for the front vowels but small for the close back vowels.

Yang (1996) made a comparative study of American English and Korean vowels produced by male and female speakers. Fl to F3 and FO of 10 Korean vowels and 13 American English vowels produced by 10 male and 10 female speakers of each language group were studied while holding dialectal factors as homogeneous as possible in each group. With in and across language comparisons of the collected data revealed considerable variation in vocal tract length between male and female speakers and between Korean and American English speakers. He opined that the main acoustic correlates of vowel quality are formant frequencies. However, vowels spoken by different speakers showed great variations in formant values.

In the study conducted at Bell Telephone Laboratory by Peterson & Barney (1952) on ten vowels in the /hvd/ context, the most important limitation is that their database consists exclusively of acoustic measurements taken at a single time slice. Duration measures were not made and no information is available almost the pattern of spectral change over time. There is now a solid body of evidence indicating that dynamic properties such as duration and spectral change play an important role in vowel perception.

Zahorran & Jagharghi (1993), in their study, automatic vowel classification experiment was used to compare formants and spectral shape features for monopthongal vowels spoken in the context of isolated CVC words, under a variety of conditions. The roles of static and time verifying information for vowel discrimination were also compared. Under almost all conditions investigated in the absence of FO information, automatic vowel classification based on spectral shape features was superior to that based on formants. If FO was used as an additional feature, vowel classification based on spectral shape features was still superior to that based in formants, but the differences between the two feature sets were reduced. It was also found that the error patterns of perceptual confusions was more closely correlated with errors in automatic classification obtained from spectral shape features that with classification error from formants. Therefore it was concluded that spectral shape features were a more complete set of acoustic correlates for vowel identity than were formants. In comparing static and time verifying features, static features were the most important for vowel discrimination but feature trajectories were valuable secondary sources of information.

The study by Hillinbrand & Getty, Clark & Wheeler (1995) represents an attempt-to address these limitations. Recordings were made of /hvd/ utterances spoken by a large group of men, women and children and measurements were made of vowel duration, FO contours and formant frequency contours. The results showed differences between these measurements of formant patterns and those of Peterson & Barney's (PB) study. One possible explanation of these differences has to do with the use of LPC as opposed to the more direct spectrum analysis method used by PB. Another reason is that little is known about the dialect of the PB talkers. Perhaps more important than potential differences in regional dialect is the passage of some 40 years or more in the times at which the two sets of recordings were made. It is well known that significant changes in speech production can occur over a period of several decades.

The first three formants have been the most commonly used acoustic cues for vowels ever since the work of Peterson and Barney (1952). However, spectral shape features which encode the global smoothed spectrum provide a more complete spectral description and therefore must be even better acoustic correlates of vowels. Watrous (1991) has reported that of two machine readable versions of the Peterson-Barney formant data currently in use, one was incomplete and both contained minor errors. An on line version of the data has been established that was verified against a listing of the original data.

Miller, Engebreston and Vemula (1980) using the data of Peterson and Barney (1952) have sought transformation of the frequency scale (Eg. Mels) and rules of combination of values of the fundamental (F0) and the formants (Fl, F2 & F3) (Eg., F2/F1, F3/F2) that will eliminate differences between talker groups (children, women and men) while maintaining differences between vowel categories. The study suggested that vowels were characterized by their spectral shapes when plotted on log axes. Thus the usual range of differences between children, women and men in the absolute location of the spectrum along the log frequency axis appeared unimportant.

Several perceptual studies on formants also have been reported in the literature. Performance on perceptual tasks is often better for vowels in consonantal contexts than for vowels spoken in null contexts, even though formant frequencies of different intended j vowels overlap more for the former than the latter (Strange et al., 1976; Gottfried & Strange, 1980; Gottfried, Jenkins and Strange, 1985; Strange et al., 1979; Macchi, 1980; Diehl, Custer and Chapman, 1981, Assmann, Nearey and Hogan, 1982; Rakerd, Verbrugge and Shankweiler, 1984, Strange, 1989 & Nearey, 1989).

Di Benedetto (1989) carried out perceptual experiments using consonant vowel consonant (CVC) syllables to examine the perceptual relevance of the first formant frequency (Fl) tragectory in the perception of high vowels versus non-high vowels. Results showed that stimuli characterized by a higher onset frequency and Fl max at the beginning of the vocalic portion were perceived as lower vowels than stimuli with a lower fl onset frequency and Fl maximum toward the end of the vocalic portion. Perceptual experiments which were carried out on American, Italian & Japanese subjects, showed that stimuli that were characterized by a higher Fl onset frequency and Fl maximum at the beginning of the vocalic portion were perceived as lower vowels than stimuli in which the Fl maximum was reached towards the end of the vocalic portion and the Fl onset value was lower.

Study by Strange, Verbugge, Shankeveiler & Edman (1976) showed that vowel produced in isolation and in a filled CVC context by the same talkers demonstrated that providing a consonantal environment increased the likelihood of correct identification of the intended vowel. This time both when talker variation was present and when it was not of the two factors investigated consonantal context was much more important than talker variation in determining listener's identification of vowels. The increment in error for isolated vowels in comparison with the medial vowels was more than three times greater than the increment attributable to unpredictability of talker. The study also showed that consonantal context and vowel identification even when the consonant frame varies unpredictably. Vowels produced in randomly varying stop consonant environments were identified more accurately than were isolated vowels both when the talker was fixed with in a text block and when talkers, as well as context, varied unpredictably. Despite the lack of invariance in static spectral parameters, perceptual studies have shown that more listeners could identify co-articulated vowels with remarkable accuracy even when they are produced by several speakers with no possibility of normalization from prior context (Verbrugge et al, 1976; Macchi, 1980; Assmann et al 1982) and in varying consonantal context (Strange et al, 1976).

Formant frequencies in several Indian languages have also been extensively studied. Acoustic parameters of Hindi vowels have been studied by Ganesan, Agarwal, Ansari and Pavate (1985). The study was carried out on eleven speakers using ten Hindi vowels, which in turn were embedded in four different phonetic contexts. The results revealed that the fundamental frequency, formant frequency and amplitude of the vowels varied with respect to vowels. Jha (1986) carried out acoustic analysis regarding the nasal vowels in Maithili language (Indo- Aryan language spoken in the state of Bihar in India and in the Tarai district of Nepal). The results strengthened the fact that each nasal vowel in Maithilli was one single speech sound, and not a sequence of an oral vowel plus a nasal consonant.

Formant frequencies of eleven Telugu vowels in CNC context and their variation as well as distribution in different frequency planes were studied by Majumder, Datta and Ganguli (1978). This study was carried out on three subjects in the age group of thirty to thirty-five, chosen from twelve amateur actors and a total of six hundred Telugu words were used. The results revealed that the shorter vowels /i/ and *Id* had a tendency towards centralization in the high tongue position than their corresponding longer counterparts / i:/and/e:/

Rajapurohit (1982) carried out a study using Kannada vowels regarding the formant frequencies and their structure on the basis of spectrograms. It was generally observed that higher the vowel, lower was the Fl and conversely lower the vowel, higher was the Fl. With this rule, it was possible to determine the quality of vowels. The variation of formants was by about ±100 to 150 cps. If the phonetic environment was responsible for this shift, then those sounds could be established as allophones. In the absence of such evidence, they were treated fluctuations of the same vowel. The fluctuations were normalized by averaging. The long vowels showed their formants 100 to 150 c/s higher than their short counterparts. Same was the case when the vowels were pronounced with emphasis. Though the frequencies of Fl of /e/ and /a/ were around 500 cps and 800 cps respectively, in certain cases the vowels showed Fl at 600 or 650 cps. It meant that a vowel with the tongue height in between *lad* and /a/ was possible to identify, it could be /^/. It occurred before the geminated velar voiceless stop. But the phonetic environment of its other occurrences could not be ascertained. The vowel *Id* in the final position showed Fl with 500 cps, as against 400 cps elsewhere. Similarly, /o/ when followed by /a/ in a syllable showed Fl with 600 cps, as against 500 cps elsewhere. Most of the vowels showed fast declining intensity in the final position. The spectrograms showed very weak F2 and F3. In case of final /u/ only Fl and F2 were seen, /y/ and /v/ showed formant structures comparable to /i/ and *lul* respectively. The vowel released between the consonants in cluster had very weak formants. Since its Fl appeared at higher level than that of/a/, the released vowel was of/a/ quality.

Rajapurohit (1982) analyzed the speech of only one subject and had not controlled the environment of the vowel and the length of the word in which the vowel occurred. Further the subjects in the study was exposed to three different dialects of Kannada language and the probability of high influence of his native dialect (Dharwad dialect) could not be ruled out. Formant structures of short vowels in Kannada language were also studied by Savithri, (1989). She had stated that vowels were characterized by well defined formants with high Fl in /a/, high F2 in /i/ and /e/. She observed closer Fl and F2 in /u/ and /o/.

Venkatesh (1995) studied all the 10 vowels in Kannada and reported that the formant frequencies were higher in females than in males in all the ten vowels. T test showed that the mean difference between males and females in terms of formant frequencies was highly significant. The results were in agreement with the studies carried out by Peterson & Barney (1952) and Fant (1973). The average scale factors (female/male frequency percentage) for the first four formants were 18.06%, 15.66%, 14% and 20.61% respectively. Fant (1966) found the scale factor to be around 18% in case of Swedish speakers. According to Chiba & Kajiyama (1941), the total length of an average female vocal tract is about 15% shorter than an average male vocal tract. The higher formant frequencies found in females may be due to the shorter vocal tract in females when compared to males. Study by Venkatesh showed that in both males and females, Fl was highest for the vowel /a:/and lowest for the vowel / I:/, F2 was highest for *fl:/* and lowest for /u:/ and F3 was highest for *fl:/* and lowest for *lot.* F4 was highest for the vowel *l\l* in males and for the vowel *fl:/* in females. It was lowest for /o:/ in males and for /u:/ in females. In case of F3 and F4 values many vowel combinations did not show any significant difference when compared to the results of Fl and F2. Earlier Fairbank & Grubb (1961) and Pols, Tromp and Plomp (1973) also observed a similar finding. Fairbank & Grubb state that although acoustic vowels are specified by combinations of formant frequencies, it is commonly understood that these frequencies varied considerably from utterance to utterance. Vowels selected for their study were / i, I, E, ae,A , a,(), U, u/. Results indicated that F3 is a much less powerful determinent of acoustic vowelness than either of the lower two formants. Pols, et.al, (1973) measured the frequencies and levels of first three formants of 12 Dutch vowels in 50 male speakers in h/ vowel /t context. Analysis showed that Fl & F2 were the most appropriate two distinctive parameters for describing the spectral differences among the vowel sounds.

Ganguli (1996) studied the formant frequencies of nonnasal Assamese vowels. Spectrographic analysis of 330 commonly used multi syllabic Assamese words spoken by male subjects (30 to 55 years) provided the basic data for this study. Only the first three formant freuqnecies were considered. The analysis of the results confirmed the existence of seven Assamese vowels with an additional compromised vowel. A comparative study of Assamese vowels with cardinal vowels indicated that Assamese vowels had a tendency towards centralization. Assamese back vowels were found to be more centralized than front vowels.

To conclude the review on formant frequencies, it can be stated that the alteration in the configuration of the vocal tract gave rise to variations in ranges of formant frequencies. Fl varies mostly with tongue height and F2 varies with tongue advancement. Higher formants have larger bandwidth than lower formants. Speaking rate tends to affect the spectral features and significant vowel undershoot has been noticed at induced rapid rates of speech.

Fundamental frequency:

Vowels are the result of the interaction of minimally obstructed vocal tract and the vocal fold vibration, following the escape of pulmonary air stream. The voicing nature of the vowel is due to the vocal fold vibration. The vowel quality is attributed not only to the acoustic modulation by the vocal tract but also to the vocal fold vibration. The acoustic correlate of the frequency of vocal fold vibration is the fundamental frequency of voice. The frequency at which the vocal folds vibrate determines the fundamental frequency of voice, in this case the vowels. Acoustic analysis facilitates the study of vocal fold vibration and acoustic modulation of pulmonary air at different stages. It is reported by Ohala (1973) that the vowels in a language, when produced, present differentially distributed energy across different frequencies due to the varying acoustic modulation by the vocal tract. But interestingly, the energy distribution lies within a range of frequencies and this is true for all the distribution including fundamental frequency, vocal tract resonance and other harmonics (Ohala, 1973).

The range of fundamental frequency of a given vowel is more or less constant and is called intrinsic fundamental frequency of that vowel (Ohala, 1973). The differences between vowels in terms of the intrinsic FO were in the order of one or two semitones; e.g. typical F0 differences between /u/ and /a/ reported by Peterson (1978) for Danish vowels were between 10 and 30 Hz. Vilkman, Analtonen, Laine and Raimo (1989) defined the intrinsic pitch or fundamental frequency of vowels as the systematically varying F0 values in comparable environments. Studies on intrinsic

FO revealed that it was dependent upon the vowel height, place and quality. It was also dependent upon various linguistic and nonlinguistic factors such as phonetic, phonologic, semantic and syntactic and supra segmental factors. The environmental factors, physical and psychological status of the speakers, were crucial among the nonlinguistic factors (Steele, 1986 and Fischer-Jorgensen, 1990).

The earliest documentation of the existence of the study of intrinsic FO was traced to 1925 by Crandall (as cited in Shadle, 1985). Several attempts have been made to study the relationship between intrinsic FO and other parameters like tongue height, lip rounding, formant structure, vowel duration, jaw opening, glottal airflow and others (Mohr, 1971; Ohala, 1973; Neweklosky, 1975; Peterson, 1978, Rossi & Autesserre, 1980; Antoniades & Strube, 1981; Honda, 1982; Nataraja & Jagadish, 1984; Shadle, 1985; Iivonen, 1989; Zwadski & Gilbert, 1989; Fischer-Jorgensen, 1990; Zhi & Lee, 1990; and Honda & Fujimura, 1991). Although most researchers assume that IFO was an automatic consequence of vowel production, others hold that IFO was a deliberate enhancement of the speech signal by the speakers (Diehl & Kluender, 1989, Diehl, 1991, Kingston, 1993).

The mechanism of this 'intrinsic FO' or 'intrinsic pitch' has been the subject of great dispute. IFO has been found not only in languages such as English and French that use FO primarily for stress and intonation, but also in tone languages such as Mandarin (Shi & Zhang, 1987) that use FO changes to distinguish word meaning. IFO seem to be insensitive to the size of vowel inventory as well, since both small (eg.: Japanese with 5 vowels) and large (eg.: German with 14) systems show similar effects (Whalen & Levitt, 1995).

The consistency of the effect across the world's languages can provide some indication of whether an automatic or deliberate process is more likely. If differences among the different languages are found, it would be likely that the degree of IFO is another variable that languages choose. If on the other hand there seems to be a little change in the size of IFO, then one can expect that whatever mechanism is responsible, it is truly intrinsic and occurs as part of the production of vowels in any language.

This intrinsic FO effect (IFO) has been found in the speech of children at various stages of development. With such universality IFO has typically been assumed to be an automatic consequence of vowel articulation. In these circumstances, it is of great interest whether the vowels of babbling will show this effect, since the babbling child presumably has no vowel categories per se, but simply vocalic articulations. The infant vocal tract is markedly different for the older child and mature adult human (Crelin 1987).

Bauer (1988), conducted a study to determine if the IP phenomenon in adults also occurs in immature infants at 9 to 13 months. Vowels were put into one of four broad classifications - high front, high back, low front or low back. Bauer (1988) found no effect of height, but did find an effect of front back. He attributed.

this to the high position of the larynx in the infant. That is , the FO results for the advancement feature supported the hypothesis that IP initially is related to vacant advancement in the one tube infant vocal tract. Gradually the IP shifts to being related to height in the mature, two tube human vocal tract. Thus the acoustics of vocal tract reconfiguration can be mapped. In summary the findings were: 1) advanced tongue rather than heightened tongue position was associated with the IP phenomenon in three infants at 13 & 9-12 months of age. 2) The IP phenomenon may be tied to the gradual reconfiguration of the infant's one tube vocal tract into a two tube mature vocal tract.

If IFO is universal, then one would expect to find similar patterns in the babbling of infants from any language environment. If IFO is deliberate enhancement, one might expert: that different languages would use the enhancement to different degrees. These differences might then appear as a difference in the babbling behavior of children in different language communities.

Whalen & Levitt (1994) summarized that the proposal IFO is a deliberate enhancement of the speech signal seems somewhat tenuous. Even when FO is used extensively for other purposes and vowels occur with the whole range of FOs, as in tone languages, IFO persists. IFO disappears at the lower range of FOs. It appears that IFO is truly intrinsic and not a deliberate enhancement of the speech signal. If a speaker's jaw is fixed to a more open position than is normal for vowels, then it will compensate with an exaggerated tongue movement. A stronger pull of the tongue should result in a larger IFO difference. Another instance of an exaggerated effect is found in the speech of the deaf. Bush (1981), found larger IFO differences for deaf children, compared to normal controls. Hence, there seems to be an element of exaggerated articulation that by itself also increases the IFO effect. Perkell, Lane, Svirsky and Webster (1992) also found an exaggerated difference for subjects prior to receiving a cochlear implant and this exaggeration disappear after the implantation.

Whalen, Levitt, Hsiao Pai - Ling and Smorodinsky (1995) studied IFO in six French and six English learning infants at the ages of six, nine and & 12 months. It was found that IFO appeared in babbling. There was no indication of a developmental trend for the effect or a difference due to the target language in this data. These results supported the claim that IFO was an automatic consequence of producing vowels. . These results were most compatible with the hypothesis that IFO was an automatic consequence of vowel production. These results were at odds with the study by Bauer(1988). The difference is most likely due to the difference in sample size.

There does not appear to be a developmental trend in IFO. Even infants babbling at six months show IFO (Whalen, Levitt, Hsiao & Smorodinsky (1995). Whalen & Levitt (1994) concluded that IFO appeared to be universal. Their sampling of 31 languages while far short of the 6000 or so total languages, covers a fairly wide range of families (11 of 29) and language types (tone, pitch, accent and stress). It can be concluded that IFO is not a deliberate enhancement of the signal but rather a direct result of vowel articulation.

In babbling, there is no communicative intent and thus no distinctions to enhance. So that enhancement account should predict that IFO will not appear in babbling. If IFO is fundamental frequency of babbling, the most likely explanation is that it is not only conversational but also automatic.

Intrinsic Fundamental Frequency and Tongue Height of Vowels has been extensively studied . The relationship between vowel height and fundamental frequency (FO) has been noted for at least 60 years (Taylor 1933) and attempts have been made to explain this relationship. There are four theories which attempt to account for the intrinsic frequency of vowels. They are:

1. The dynamogenetic theory (Taylor, 1973)
2. The aerodynamic theory (Mohr, 1971; Neweklowsky, 1975)
3. The theory of acoustic coupling between the vocal tract and the
4- Vocal cords (Lieberman, 1970; Atkinson, 1972; Gueria, 1978).
5.. The tongue-pull theory (Ladefoged, 1964; Lehiste; 1970)

In every language so far examined, high vowels such as /i/ and /u/ have shown the tendency to have higher fundamental frequencies (FOs) than low vowels such as /a/ & /ae/. It is well known that high vowels tend to have a higher FO than low vowels (Peterson & Barney, 1952). All investigations on the phenomenon of intrinsic fundamental frequency (IFO) agree that a vowel with a high tongue position has a higher FO than a vowel with a low tongue position. Various theories have been advanced to explain intrinsic fundamental frequency.

The most significant factor influencing IFO, reported was the tongue height (O'Shaughnessy, 1976; Thorsen, 1976; Pierrehumbert, 1980). Findings from these studies, revealed that a direct and positive correlation was present between these two. IFO refers to the observation that high vowels, with the tongue position being high in the oral cavity tend to have a higher fundamental frequency than the low vowels, (Peterson & Barney,1952). Other than the recent investigators noted earlier, this tendency has been reported as early as 1949 for English vowels by Black, followed by Peterson & Barney (1952), House & Fairbanks (1953), Lehiste & Peterson (1961), Peterson (1961), Mohr (1971).

According to one explanation, raising the tongue for high vowels increases the tension on the extrinsic laryngeal muscles, which results in greater vocal fold tension and thus a higher fundamental frequency (Ladefoged, 1964). An acoustic hypothesis maintains that the relationship between the laryngeal source and the vocal tract is important. If the sound source and the resonance cavities are closely coupled, the two are not independent. A change in one can cause a change in the other. This effect is greatest if the F0 falls close to the resonant frequency.

Ladefoged (.1964) advanced a theory based on tongue pull. He suggested that the tongue, when elevated for the articulation of high vowels, would pull the hyoid bone and larynx upward via the hyoglossus muscle. This upward pull would be transformed into an increased tension of the vocal folds. Ladefoged (1964) later abandoned this explanation because he found that the correlation between tongue height and hyoid/larynx position was completely or partially inverse. Ohala (1973) put forward another explanation in which the increased tongue pull during the high vowels was believed to give rise to an increased vertical tension in the vocal folds. The vertical tension was established through the mucous membrane and other soft tissues without involving the hyoid bone or any hard structures of the larynx. In support of the explanation Ohala referred to data from Vanden' Berg (1955) and Shimizu (1961) concerning the size of morgagni's ventricles. The latter found, by means of radiography, a lack of correlation between larynx height and IFO, but a positive correlation between tongue height, ventricle size and IFO. Vanden Berg's (1955) tomograms showed corresponding relationship between ventricle size and IFO. Ohala thought that a high tongue position resulted in a vertical enlargement of the ventricles which in turn resulted in an increased vertical tension of the vocal folds and consequently an increase in FO. Tomograms from study by Vanden Berg (1955) showed that the ventricular folds were more rounded, i.e., compressed during the production of low vowels than during high ones.

Mohr (1971) assumed that a constriction in the pharynx as found in a low back vowel would result in a rise of pressure behind the constriction which in turn would reduce the air flow through the glottis and decrease the rate of vocal fold vibration. A constriction as found in a high front vowel would not have the same effect because of the greater cavity behind the constriction. According to this theory the greater the distance between the constriction and the glottis the longer it will take for the air pressure to build up behind the constriction and consequently for FO to drop. If this is true, a higher IFO would be expected in *I'll* than in /u/; however, it is the opposite relationship that is generally found. Further more, for front vowels of medium tongue height should have the highest IFO, because their constriction is less narrow than that of /i/ but no data seem to confirm this.

Ewan (1979) added to the tongue pull theory by suggesting that in order to get a sufficiently low Fl in /u/, the supra laryngeal cavities are expanded actively by a down ward pull of the larynx. This seems to explain the low larynx position in /u/. According to Evan the lowering of the larynx may stretch the soft tissues of the larynx; in combination with the increased tension from the tongue pull this may account for the fact that /u/ which generally has a higher IFO than /i/.

Ewan (1979) reports that the nasal consonant */m/* was produced with a higher fundamental frequency during the utterance /umu/ than during /amu/. If the observed change in FO can be attributed to the acoustic coupling hypothesis, then differences in first formant frequencies of nasal sounds should also be observed. Fujimura (1962) found that there were no changes in first formant frequencies of nasals corresponding to co-articulatory effects of adjacent vowels.

Another theory is based on the assumption that the glottis impedance is sufficiently low for some acoustic coupling to occur between the vocal folds and the supra laryngeal cavities. Referring to this Atkinson (1973) suggested that closer the first formant (Fl) is to the FO, the greater the tendency to increase FO. Consequently the low Fl in high vowels will influence FO more strongly than the high Fl in low vowels. Thus according to this theory it is resonance frequency of Fl that seems to account for intrinsic FO. Beil (1962) found that vowels produced in a helium rich atmosphere raised all formant frequencies by about 100% and FO for all vowels about 10% as compared to vowels produced in normal atmosphere. However, the IFO effect was identical under both conditions.

According to Ohala (1973) & Di Cristo (1978) the tongue pull theory is the most plausible even though the explanation of the intrinsic frequency of [u] and of nasal vowels is unsatisfactory. Reinholt Peterson (1980) observed that the pitch of V2 in a V1CV2 paradigm was significantly influenced by the height of VI even though the influence of the VI resonance on V2 was not significant. The acoustic theory therefore cannot account for the changes observed by Ewan (1979). Instead, it appeared that the most plausible explanation of Ewan's (1979) observations was that the differences in tongue height during the production of nasal sounds directly affected laryngeal tension and raised FO, as proposed by the tongue pull hypothesis. While the evidence may support an articulatory rather than an acoustic explanation, much remains to be learned about the nature of this hypothesis. Ohala & Eukel (1987) measured FO when the jaw was held in place with bite blocks, but the tongue was allowed to move freely during the production of different vowels. They hypothesized greater changes in FO due to the expected greater tongue dorsum movements needed to compensate for the lack of jaw movements. Ohala & Eukel (1987) reported that they did find greater FO differences between high and low vowels when compared to normal speech to speech using bite blocks. It is always difficult to speculate about normal speech articulatory patterns from studies of speech produced in unnatural circumstances. However it can be inferred from the increased FO changes with restricted jaw movements that tongue activities are more important than the mandible in affecting FO. Lubker, Mc Allister and Lindblom(1977) reported findings from an experiment similar to that of Ohala & Eukel (1987). While they did find the usual correlation between FO and vowel height, they did not find any greater effect during the bite block condition. Thus it is difficult to make any claims about the relative contribution of the tongue and mandible on FO from available data.

Gandour & Weinberg (1980) observed that oesophageal speakers with excised larynges had the same IFO differences as normal speakers. They were able to rule out any kind of tongue pull explanation, because there existed no connection through which the tongue position could influence the voice source (the pharyngo-esophageal sphincter). They concluded that during the articulation of high vowels the oesophageal speakers must actively increase their respiratory drive or speech/vocal effort.

Rossi & Autesserre (1981) used the technique of xeroradiography to study the horizontal and vertical movements of the hyoid bone and the larynx. The results indicate that the vertical movements of the hyoid varied from one subject to another for the same vowels. The vertical movements of the larynx were relatively independent of those of the hyoid, in particular they contributed to the adjustment of the length of the vocal tract. For all the subjects the larynx was high for /i/, mid for /a/ and low for the nasal vowels.

Honda & Baer (1981) and Honda (1983) suggested that "contraction of the geniohyoid muscle pulls the hyoid bone forward and tilts the thyroid cartilage down to increase the antero-posterior tension of the vocal folds". Honda (1983) has put forward an explanation focusing on the horizontal tongue pull. He found a positive correlation between the posterior fibers of the genioglossus muscle and IFO. This suggested that a contraction of this muscle pulled the hyoid bone forward, rotating with thyroid cartilage forward/downward, thus increasing the horizontal tension of the vocal folds.

Steele (1986) reported that a substantial portion of her data on IFO of vowels could not be accounted for by changes in vocal fold tension alone. She suggested that differences observed were caused by an interaction of vocal fold tension and subglottal pressure. Ewan (1979) has further suggested that tongue compression or pharyngeal constriction may be more important factor in lowering FO than tongue dorsum stretching may be in increasing FO. He proposed this by observing lower FOs produced by an Iraqi Arabic speaker following pharyngeal consonants. Since the tongue should have greater retraction during the pharyngialized sounds, this observation supported a tongue compression' theory. Zawadzski & Gilbert (1989) attempted to obtain additional information concerning this mechanism by comparing articulatory positions observed through cineradiography with FO measurements. The major finding of this study was that mandible position was more closely related to fundamental frequency than its tongue position. The study indicated that mandible position was more important than 'tongue compression' in determining fundamental frequency. Previous investigations had proposed that higher fundamental frequencies associated with high vowels may be due to tongue dorsum 'pull' or tongue root compression. Data from Zawadzki & Gilbert (1989) contradict both the tongue pull (vertical as well as horizontal) and the tongue retraction theories.

Pettorino (1987), showed similar results in esophageal speech from one laryngectomized Italian speaker. He rejected explanations based on tongue pull and acoustic coupling and concluded that the results could be explained aerodynamically. Most investigators have explained IFO merely as passive influence from the articulation, or as expressed by Silverman (1984) as an artifact of articulation. Honda (1983) performed a correlation analysis between the EMG activity from the pars recta and pars obliqua of CT muscle and EFO during the articulation of/pip/ and /pap/. The pars obliqua of the CT muscle showed a relatively good correlation with IFO in both vowels, where as the pars recta of the CT muscle showed a positive correlation with IPO in /i/ but a very weak negative correlation in /a/. He assumed that the negative correlation in /a/ could be the result of actively reducing the back vowel effect on FO. His final conclusion was that the results implied a synergistic relationship between the tongue and larynx.

According to Fischer - Jorgensen (1990) "the.direct positive correlation between IFO and vowel height or tongue height does not hold good if short lax vowels are considered. It is reported that short lax vowels have considerably lower tongue height but practically same FO as their corresponding tense counterparts" (Fisher-Jorgensen, (1990). According to Fischer - Jorgensen (1990), other factors such as duration, jaw opening etc, play.a role in determining the IFO.

Dyhr (1990), investigated the relationship between EMG activity of the cricothyroid muscle (CT) and the intrinsic fundamental frequency (IFO) in high and low vowels in Danish . The results which were based on visual inspection of average EMG and FO curves, showed a positive correlation between the CT activity and IFO, more specifically that the CT activity rise related to the high vowels starts earlier and in most cases more steeply than the CT activity related to the low vowels. However, a drop in FO at the beginning of the low vowels could not be accounted by CT activity. This FO drop was believed to be the result of either tongue retraction during the articulation or influence from the preceding consonants. The study concluded that the CT muscle was a major factor in controlling IFO in stressed high and low vowels in Danish.

Effect of consonantal context and connected speech on intrinsic pitch has also been extensively studied. The literature indicates that in isolated or carrier phrased utterances, the FO of a vowel following a voiceless stop starts high and drops sharply, but when the vowel follows a voiced stop, FO starts at a relatively low frequency followed by a gradual rise (Hombert and Ladefoged, 1977; House and Fairbanks, 1953; Lea, 1973; Lehiste and Peterson, 1961; Maeda 1976; O'Shanghnessy 1976). Previous studies have also indicated that the peak FO during the vowel was quite high after voiceless consonants and considerably lower after voiced ones.

Almost all the studies on IFO were limited to the use of either isolated words (eg: hud, heed, who'd as in Peterson & Barney, 1952) or words in a set carrier phrase. Umeda (1981) reported that there were no consistent IFO effects in readings by two speakers. She controlled the consonantal contexts but had not controlled a range of intonational effects, such as lexical stress, sentence stress, or declinatioa Umeda (1981) measured FO in a large number of vowel tokens, approximately 200 vowels in various consonantal environments, taken from reading of a 20 min connected text. She found no evidence of IFO and concluded that it was not present in running speech and that vowel height had no consistent effect on FO in connected speech. However, there were a great many factors that influence FO in speech and they were not controlled in her study. Her finding was questionable because she apparently made no attempt to control the prosodic environment of the vowels she measured. Since the range of FO differences attributable to intonational features was considerably larger than that ascribable to intrinsic pitch, intonational effects could have earlier overridden the intrinsic pitch effect Umeda was looking for.

The segmental factors which determine the fundamental frequency, FO of vowels in stressed syllables in fluent readings were studied by Umeda (1981). The paper described five characteristics of FO in the following vowel for different preceding consonants 1) the direction of FO change at the vowel onset 2) the frequency at voice onset 3) the peake FO during the vowel. 4) the amount of FO increase and 5) the tone required to reach the peak. Two speakers showed similar consistent tendencies for all the fundamental frequency characteristics. The results were similar to those reported with isolated or carrier phrased utterances. Evidence for the intrinsic fundamental frequencies for different vowels were not observed in the data.

Both the data from isolated utterances (Lehiste & Peterson 1961; Lea 1973) and fluent reading (Umeda 1981) showed statistically about the same range of FO variability in the initial and the peak FO values of the vowel depending on preceding stressed consonants. However, there were many differences in details of the results in these two situations. For eg: in Umeda's data on voiceless fricatives as a group did not show as high post consonantal FO as voiceless stops did, but in isolated or carrier-phrased data, voiced fricatives were followed by an FO which was same as or even higher than the FO after voiceless stops. The differences between FO following voiceless VS voiced fricatives were for smaller than those of voiceless VS voiced stops in this data, but the situation was opposite in isolated utterances. In the reading of extended meaningful text, the direction of FO movement at the onset of a vowel was not as reliable as a voicing indicator of the preceding consonant as it was in isolated utterances.

Umeda (1981) stated that the differences in results between the two kinds of studies (one based on isolated or carrier phrased utterances and the other on fluent readings) might be explained as follows: In isolated short four uniform utterances, the speaker has plenty of time to make himself psychologically and physiologically ready for the utterance. However, in continuous speech where many words run together in a breath and content processing is necessary, it is not possible for him to supply the same amount of energy and attention to words and phrases as he does in the isolated situation. Nevertheless the segmental effect of consonants upon FO of the following vowel is retained strongly in continuous speech. This suggests that a proper FO control of segmental factors in speech production models would help in the intelligibility of consonants

The earlier studies of intrinsic pitch phenomena concentrated on elicited speech in test situations. In contrast, two studies addressed the question, does the intrinsic pitch phenomenon generalize to connected speech?. A comparison in four sentence positions of connected speech was carried out for contextual correlates of the intrinsic pitch effect (Shadle, 1985). A significant fO effect was found in all four positions for three of the four speakers who had a significant interaction between FO and sentence final position, indicating that vowel context modified the intrinsic pitch effect (Shadle, 1985).

High vowels have a higher intrinsic FO (IFO) than low vowels. This phenomenon has been verified in several languages. However, most studies of IFO of vowels have used words either in isolation or bearing the main phrasal stress in a carrier sentence. As a first step towards an understanding of how the IFO of vowels interacts with intonation in running speech, Shadle (1985) examined FO of the vowels /i, a, u,/ in four sentence positions. The four speakers used for this study showed a statistically significant main effect of IFO (high vowels had higher FO). Crandell's study of English (1925) appears to be the earliest documentation of the existence of the IFO effect. Di Cristo et al (1979), Ohala (1973) & Mohr (1971) cite numerous studies showing that the effect appears in English as well as in various other European, African, and Asiatic languages. To their lists may be added a later study in German by Antomadis & Strube (1981) and research on Taiwanese & Chinese by Zee (1978). Study by Zee & one by Hombert (1977) on Yoruba language show that the effect also appears in the tone languages and that its magnitude was less for lower tones. Deaf speakers often exhibited a higher than normal IFO, which may be related by a higher than normal average FO and exaggerated articulatory posture (Bush 1981). Finally, House and Fairbanks (1953), Mohr (1971) & Hombert (1978) have shown that the IFO was lower when the preceding consonant was voiced or when the final consonant was velar or palatal. Shadle's (1985) study supported the conclusions that IFO of vowels existed in sentence context and that the magnitude of the effect interacted with sentence position. Changes in method were necessary to make the intonation pattern and semantic effects the same for the vowels being compared (target words were embedded in sentence in initial, near initial, final, and near final positions).

Intrinsic pitch (IP) effects in connected speech was investigated by Ladd & Silverman (1984). Fundamental frequency differences between German high and low vowels were measured in two different experimental conditions. 1) a typical laboratory task in which a carrier sentence served as a frame for test vowels. 2) a paragraph reading task in which test vowels occurred in a variety of prosodic environments . By comparing test vowels in comparable segmental and prosodic environments, it was shown that the IP effect does occur in connected speech but that the size of the differences between high and low vowel fundamental frequency was somewhat smaller than in carrier sentences. Ladd & Silverman (1984) in their study in German controlled the phrase position and stress. Unlike Umeda (1981) they found evidence for intrinsic FO with sentence position.

In 1985, Steele chose a less natural corpus in order to control for semantic, syntactic, prosodic and contrastive stress in a single sentence in one experiment and observed the interaction of IFO with sentence position. A second experiment using a different sentence with no contrastive stress separated the variables of FO and stress, leading her to conclude that prominence was the main parameter affecting the magnitude of the IFO difference. Shadle (1985) established that three out of the four subjects showed a large main effect of IFO that lessened in final position. However, evidence from several sources indicated that sentence final position need not reduce the IFO difference. Ladd & Silverman (1984) have reported a phrase final accented/unaccented comparison in which only the accented case had a normal IFO difference. These studies establish that both FO and accent affect the amount of IFO.

The main goal of Ladd & Silverman (1984) was to study IP effects in connected speech while at the same time controlling for differences of prosodic environment. The results showed that IP effect was clearly present in connected speech as well as in carrier sentences. However, the IP differences were smaller in the connected speech conditions than in the carrier sentence condition. At least two explanations for these differences are possible. One is in effect that Umeda (1981) is partly right and that IP differences though not absent are generally reduced in connected speech. The second possible explanation was that the smaller overall IP effects in the connected speech conditions was due to the averaging together of very small IP effects in certain prosodic environments with normal (that is carrier sentence signal) effects in other environments.

The effects of prosodic environment on intrinsic pitch have also been examined extensively as it is known that prosodic and segmental environments affect the size of IP differences. Reinholt Peterson (1979) has reported that IP was smaller in unstressed syllables than in stressed syllables and the size of effect also appeared to decrease during the course of an utterance. Steel & Godfrey (1982) and Shaddle (1983) found that various prosodic differences such as degree of stress affect the size of IP differences.

Sorenson (1981) found that FO peaks on stressed syllables at various locations with in sentences were generally higher in sentences produced at faster rates than at normal or slow rates by the same speakers. The higher FO at faster rates was attributed to the general increase in muscular tension of the vocal folds at faster rates.

Cooper, Soares, Ham & Damon, (1983) conducted a study to examine the influence of speaking rate and emphatic stress on patterns of fundamental frequency (FO) and palatalization across word boundaries. Two groups of speakers exhibiting characteristically fast and slow rates of speech, uttered presented sentences at normal fast and slow rates. Acoustic analysis of FO showed some what higher FO peaks for characteristically fast speakers and for fast rates of speech. Emphatic stress was accompanied by a typical heightening of FO on the emphasized word and by a lowering of FO and on a neighbouring word. Palatalization across word boundaries was more frequent among characteristically fast speakers and at fast rates of speech. The study led to the conclusion that the influence of emphatic stress on FO could be attributed to an increase in tension of the vocal folds accompanying the production of stress. The inhibition of palatalization produced by such stress could be attributed to the speakers desire to clearly articulate the emphasized word, particularly the word initial phoneme. This interpretation was consistent with perceptual data showing that listeners were better at detecting mispronunciations of word-initial Vs word final phonemes (Cole,Jakimik and Cooper 1978).

Speaking fundamental frequency has been studied by Hollien & Shipp (1972). They studied the mean speaking fundamental frequency (SFF) of 175 male speakers ranging in age from 20 to 89 years. Mean frequency levels by age decade showed a progressive lowering of SFF from age 20 to 40 with a rise in level from age 60 through the 80's. Results showed that mean SFF for the 20 to 29 your old group was 119.5 Hz, 112.2Hz for the 30-39 year old group and 40-49 group old group had a mean SFF of 107.1 Hz. Fundamental frequency for the 50-57 year olds was 118.4 Hz and for the 60-69 year olds 112.2 Hz. The 70-79 year olds (132.1Hz) and the 80-89 year olds (146.3Hz) had the highest mean fundamental frequencies.

There are several studies comparing F0 across adult males and females. Monsen and Engbreston (1977), in an attempt to compare the male and female speakers, a reflection less metal tube (Sondhi's tube) which can act as a pseudo infinite termination of the vocal tract was used to collect glottal volume-velocity waveforms produced by 10 male and female adult subjects. From each subject glottal samples were collected of normal, loud and soft voice, falsetto and creaky voice; monosyllables with rising and falling intonation; and three syllable utterances containing primary lexical stress on one of the three syllables. Analysis of the data indicated a wide variation of the glottal waveform shape, its RMS intensity and fundamental frequency, phase spectrum, and intensity spectrum.

Results further showed that for both male and female speakers, the spectrum falls more steeply above 1200Hz than below 1200Hz and shape of the spectrum changed from octave to octave; a note worthy exception was the spectrum of falsetto voice. The wave shape produced by male subjects was typically asymmetrical and frequently showed a prominent hump in the opening phase of the wave. The closing portion of the wave generally occupied 20% - 40% of the total period and there may not be an easily identifiable closed period. The female waveform tended more toward symmetry. There was seldom a hump during the opening phase, and both opening and closing parts of the wave occupied more nearly equal proportion of the period.

The female voice was also slightly weaker than the male voice; on the average the RMS intensity of the glottal periods produced by female subjects was - 6 dB relative to the average male samples. A most striking characteristic of the male and the female glottal spectra was that the harmonic relations in each were typically different. For both male and female subjects the slope of the glottal spectrum increased in steepness with each successive octave, but the slope of the spectrum for males was less steep than that of the females. For the male subjects the first two octaves fell off at about -10dB octave; for the female speakers, the slope of the first two octaves was -15dB/octave. The slope of the female glottal spectrum at any octave was steeper than that of the male.

In human voice, at least three registers, or noticeably different modes of phonation, are recognized; chest voice (model register) falsetto and breathy voice (vocal fry). In Monsen & Engbretson's (1977) study, the modes of phonation included soft and loud voice also. The male voice was lower in frequency and more intense than the female voice in all the five modes considered . For most subjects there were spectral and waveform differences between loud, normal and soft voice in addition to the intensity and fundamental frequency differences. Soft voice had a more symmetrical waveform and a more steeply declining spectrum. For loud voice, the closing portion of the wave was brief and abrupt, and time was a consequent increase of energy particularly in the higher frequencies. For a male subject the closing portion of the waveform was 32% of the total period for normal voice but only 27% for loud voice and nearly 50% for soft voice. For a female subject the closing portion of the waveform was 33% for normal'voice, 23% for loud voice, and 47% for soft voice. For some subjects only soft voice had a markedly different spectrum and wave shape.

The spectrum of falsetto voice in both male and female was similar. It fell off steeply at the rate of about -20dB per octave. However, the spectral envelope of falsetto voice was different from that of normal voice in that the spectrum did not fall off sharply above 1200 Hz. For the male subjects falsetto voice had a characteristic phase reversal in the waveform. It was the opening portion of the wave that is shorter and more abrupt.

As the slope of the glottal spectrum became steeper with rising F0, corresponding changes might be observed in the appearance of the glottal waveform itself. At the lower fundamental frequencies, the closing portion of the glottal wave was short and steep, and as the F0 increased, the closing portion of the wave occupied a proportionately longer segment of the total period. For example in one male subject the closing portion of the wave form increased from about 32% at 183-260 Hz to 46% at 280-300 Hz. For the male subjects, the asymmetrical hump in the opening portion of the wave gradually disappears as the phonation progressed from a low to a higher F0. The appearance of the male waveform at higher F0 was thus like the female waveform in normal voice phonation.

In the normal or chest register, the fundamental frequency of phonation for both male and female speakers varied more than one octave in the production of stressed and unstressed syllable or in syllables with declarative (falling) or interrogative (rising) intonation. Across this change of FO, the glottal wave appeared to range in two different ways. In the interrogative glide, the closing time of the glottal period became proportionately longer as the fundamental frequency increased. In this type of FO change, the harmonic relations in the glottal spectrum become increasingly steep along with increasing FO, and the overall spectral envelope remained relatively constant. In contrast to this, glottal periods spanning a smaller but comparable FO range taken from either stressed and unstressed syllables or from syllables with falling into nation, contained constant harmonic relationship and therefore as FO increased the entire spectrum was shifted along the frequency axis. In this type of FO change, the closing time of the glottal wave varied slightly. These two types of change in the glottal wave suggested that with in the normal chest register, the mechanism of raising or of lowering FO may involve a different manipulation of sub glottal air pressure and of vocal fold tension depending upon the linguistic context.

To summarize the review of fundamental frequency of speech, various studies have shown that it was dependent upon the vowel height, place and quality. It was also dependent upon various linguistic and nonlinguistic factors such as phonetic, phonologic, semantic and syntactic and supra segmental factors. Sex of the speakers, physical and psychological status of the speakers, were crucial among the nonlinguistic factors.

Intensity:

There are very few studies on vowel intensity. This may be due to its limited role in vowel identification and vowel synthesis or due to the difficulty in the measurement of absolute vowel intensity. However, investigators have observed that open vowels have higher intensity than the closed vowels. They also found that unrounded vowels were louder than the rounded vowels. There, were no studies available on intrinsic fundamental frequency and intensity of the vowels in Indian languages.

Stathopoulos & Sapienza (1993) in their study made simultaneous aerodynamic, acoustic and kinesmatic measurements from the laryngeal and respiratory systems in order to study mechanisms for changing vocal intensity. Adults were used as a control group to 20 four year olds and 20 eight year olds. Laryngeal and respiratory results indicated that speech production differences between the children and adults were based both on size and function. Results showed that at the comfortable and loud vocal intensity levels, children produced significantly higher tracheal pressures than adults. The smaller surface area of children's sub glottal tract presented greater mechanical impedance to airflow and thus results in greater pressures than adults. In this study all subjects phonated in chest register at three different intensity levels. For the intensity change from soft to loud, F0 increased; this was true for all children and all adults. But F0 increased when vocal intensity decreased from comfortable to soft speech for both women and men. These data agree with Holmberg et. al. (1988) whose data also showed that some adult subjects increase F0 when pressure decreased from comfortable to soft speech. The lung volume measures showed that at soft, comfortable and loud speech, adult lung volume initiations were significantly higher than the four year olds and eight year olds. Testing across intensity for each of the age groups indicated that adult initiations were significantly higher for loud speech as compared to soft speech. There were no differences in lung volume initiations for the four year olds or eight year olds across intensity levels. The smaller volumes during speech for children as compared to adults could be explained based on differences in lung and vital capacity sizes (Simon et. al.,1972; Polgar & Promadhat, 1971). Another observation was that both four and eight year old children used a higher percentage of their vital capacity than adults during speech utterances (four year olds: 40.95, eight year olds: 33.48; adults : 23.74).

Hoit, Hixon, Watson and Morgan (1990) found a similar trend in their data, but explained the larger expenditures for younger children by dysfluencies during reading. Statistical analysis of ribcage terminations showed a main effect for age with the four year olds and eight year olds terminating at significantly lower rib cage displacements than adults. In summary straight forward quantitative differences were found between children and adults. For eg. the differences were found in tracheal pressure , alternating glottal airflow, maximum flow declination rate, lung, ribcage and abdominal volume excursions likely relate to speech mechanism size differences. Also several qualitative functional differences were uncovered. For eg. The amount of time the vocal folds are closed, the percentage of vital capacity used during speech, the rib cage excursion range and abdominal displacement at utterance termination were functionally different for the children compared to adults. Because there were both quantitative and qualitative differences, it is concluded that using an adult mechanism model for describing children's speech production was essentially uninformative.

The effect of vocal intensity on vocal efficiency (VE) for children as compared to adults was investigated by Tang & Stathopoulos (1995) leading to the conclusion that children have different VE values than adults. 60 subjects participated in the study including 20 subjects with 10 males and 10 females in each of the three age groups: 4 year olds, 8 year olds and adults. The speech tasks were produced at soft, comfortable and loud levels. Vocal efficiency measurements were made and were compared for age, intensity and gender differences. The results indicated that four year olds and eight year olds have lower vocal efficiency values than adults. Vocal efficiency increased with vocal intensity for all the age groups and no significant differences were found for females as compared to males. Maturation of the vocal ligament, amplitude of vocal fold vibration, fundamental frequency and tracheal pressure are considered to be the factors influencing the vocal efficiency. Hence, results indicated that vocal efficiency was affected by vocal intensity and age, but not by gender.

METHODOLOGY

CHAPTER 3

METHODOLOGY

The objective of the study was to determine the developmental changes in the spectral and temporal characteristics of vowels in Kannada language (Mysore dialect) used by normal children, adolescents and adults. For this purpose the acoustic analysis of vowels in Kannada language in /CVCV/ environments was carried out.

The following spectral parameters which were considered to be reflecting changes related to age (Eguchi and Hirsh,1969; Kent, 1976), in terms of the volume of the supraglottal resonators (Peterson & Barney, 1952; Fant, 1960; Rajapurohit, 1982; Savithri, 1986, 1989; Venkatesh, 1995), the laryngeal system (Eguchi and Hirsh,1969; Rashmi, 1984) have been considered. Several studies have indicated that duration of the vowel and the word vary with age and attempts have been made to explain the same based on neuromuscular changes with age. Hence it was decided to consider these parameters which would reflect changes related to development.

1. Temporal parameters
   a. Duration of the vowel (VD)
   b. Duration of the word having the test vowel (WD)
2. Spectral parameters
   a. Formant frequency 1 (Fl)
   b. Formant frequency 2 (F2)

c. Formant frequency 3 (F3)

d. Fundamental frequency at the mid point of the vowel (IFO)

e. Intensity at the mid point of the vowel (10)

Subjects

Ten subjects in each of the three age groups, 7-8 years (children-Group 1), 14-15 years (adolescents-Group 2) and 20-30 years (adults- Group 3) were considered for the present study. Each group had five male and five female subjects. These 30 subjects were selected on the criteria that they:

a. had normal speech, language and hearing function and did not have any earlier history of speech and hearing problems.

b. were natives and residents of Mysore and had Mysore dialect of Kannada as their mother tongue.

c. had Kannada as their dominant language. However all the 30 subjects were exposed to some amount of English and the adults had reasonable fluency in English (this was because it is difficult to find a monolingual in an urban literate population).

Test material

According to Upadhyay (1972) Schiffman (1979) and Andronov (1982) there are only ten vowels in this dialect of Kannada. They are /a, a:, I, I:, u, u:, e, e:, o, o:/. In the present study these ten vowels were intended to be analyzed. They were:

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

Venkatesh (1995) studied these ten vowels in a single consonant environment i.e., /k/. It is a well established fact that the temporal and spectral characteristics of the vowel gets affected by the preceding and following sounds. Therefore in this study, it was decided to study the vowels in different consonantal environments so as to represent the speech development. Therefore a word list consisting of all the ten vowels with 12 different consonants were prepared. The words were in the form of $C_1V_1C_2V_2$ where C_2V_2 remained constant. C_1 varied according to the consonant considered and Vi (test vowel) varied as one of the ten test vowels forming a meaningful word. C_1 included /k, g, t, d, t, d, t, d, p, b, m, n/. Semivowels and aspirated consonants were excluded. Totally 73 test words with each of the above listed 12 consonants as C_1 and the ten vowels as V_1 were prepared.

Thus the test material consisted of a list of 73 meaningful bisyllabic words. Each test word consisted of one of the 12 consonants as C_1 and one of the ten vowels as V_1. Following are few examples of the bisyllabic words selected for the present study.

./kasu/= strength /chi:la/ = bag /jo:di/ = pair /pudi/ = powder

(List of all the words used in the study is presented in Appendix - 1)

These 73 test words were embedded in the medial position of a three word carrier phrase. The test word was embedded in the medial position of the sentence so as to keep the phonetic environment (i.e, the following and preceding speech sounds) of these test vowels constant. The carrier phrase used was "/I: pada__________a:gide/" (This word is___________). Thus a list of 73 sentences were prepared. Using these 73 sentences, three different sets of the material consisting of 73 sentences each were prepared by arranging these sentences in a random order. Each of these sentences were written on a flash card of size 12X8 cms.

Procedure

Instrumentation: Recording and analyses:

The following instruments were used for the recording and analysis of speech samples:

a. Sony cassette deck (TC-FX 170)

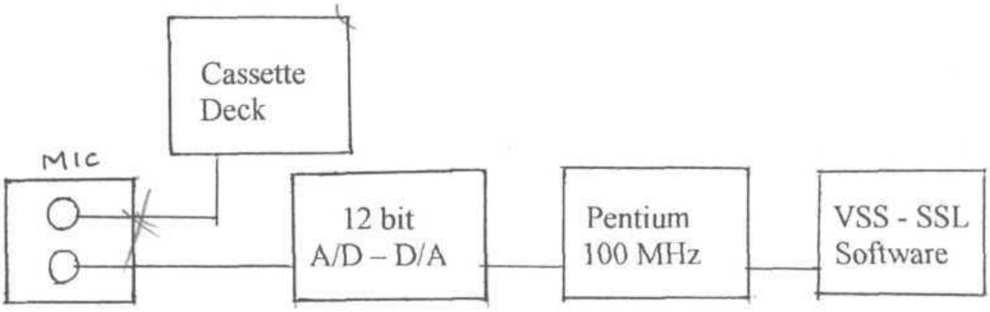
b. Pentium computer (100 Mhz)

c. Speech Interface Unit having 12 bit ADC & DAC card

d. Speech editing analysis software - VSS-SSL (developed by Voice and Speech Systems, Bangalore, based on LPC-Auto correlation, FFT algorithms).

Test environment

/The recordings were done in a sound treated room.The overall noise level was measured using B & K sound pressure level meter at the beginning of the recording of each session. The average noise level measured was 32 dB A.



Block diagram showing the arrangement of the instruments for recording and acoustic analyses

Recording of speech

The subject was seated comfortably in the sound treated room of the Speech Science Lab. The subjects were instructed in Kannada as follows for the recording:

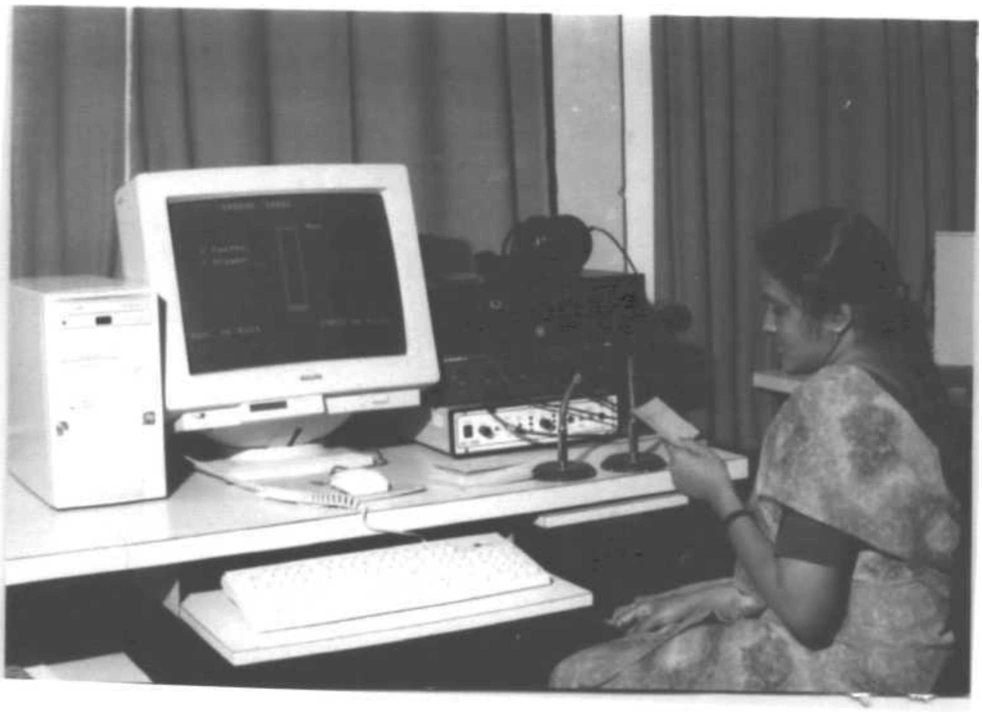
ಈ ಕಾಡಿ ೯ ನಲ್ಲಿ ಬರೆದಿರುವ ವಾಕ್ಯವನ್ನು ನೀವು
ಸ್ಪಷ್ಟವಾಗಿ ಮಾಮೂಲಿಯಾಗಿ ಓದುವ ರೀತಿಯಲ್ಲಿ ಓದಿರಿ.

("As the flash card is presented, read the sentence written on that silently and later say that at comfortable loudness level and as naturally as possible").

The recording was done for individual subjects by presenting one flash card at a time. Two Cardioid dynamic microphones (AKG d-222) were kept in front of the subject at a distance of about 15cms from the mouth of the subject. The output from one microphone was fed to a Hi-Fi cassette Deck (Sony TC-FX 170) with Hi-Fi CRO_2 cassette for recording the speech. The second microphone was connected to the speech interface unit (VSS-SIU), which in turn was connected to the Computer (Pentium). Low pass filtering and analog to digital conversion of the speech were carried out using the Speech Interface Unit. The speech signal was directly digitized using VSS-SIU, using a 12 bit AD converter at the sampling frequency of 16KHz. The speech recorded on cassette tape were used for perceptual evaluation. The digital recording on the computer was used to extract the acoustic parameters of the speech. During recording the VU meter deflection on the tape deck was used to monitor the intensity level and precaution was taken to avoid clipping of the signal (Photograph 1).

For the purpose of calibration, a calibration tone of 1 kHz at 60 dB SPL and the phonation of vowels /a/ and / \l by the subjects were used at the beginning of each recording. The subjects were instructed to phonate /a/ and l\l at a comfortable loudness. This was done to set the input gain to the optimal level of recording. During recording the VU meter deflection on the tape deck was used to monitor the intensity level and precaution was taken to avoid clipping of the signal, by instructing the subject to vary the intensity of speech as required.

The list of 73 Kannada sentences on flash cards were presented and the recording was repeated three times for each subject with different randomized sentence lists. The flash cards were presented to the subjects with an interval of approximately lOsecs between each presentation. On presentation of the flash cards, the subjects uttered the sentences as naturally as possible at comfortable loudness. As stated earlier the uttered sentences were recorded on both cassette tape Deck and on the secondary memory of the computer simultaneously. Whenever the target words were not produced correctly by the subjects, the investigator provided the required target word until the words were produced correctly. This was done more specifically with children. Only when the production of the target words were satisfactory, the recording was done. Each subject was presented with the flash cards by the investigator in the order of one of the predetermined randomized set. Thus all the three randomized sets were used for the subjects of the three groups. Using this procedure, recordings were carried out for each of the 30 subjects. Thus a total of 6570 sentences (73X3X30) were recorded.



PHOTOGRAPH 1: RECORDING OF TEST MATERIAL

Three speech pathologists served as judges to evaluate the correctness of the vowels uttered with reference to target vowel of the thirty subjects. The judges were native speakers of Kannada language (Mysore dialect). The recorded material on the cassette tape were presented in a sound treated room through a speaker, an judges were requested to identify the vowels produced, in each test word. The judges were asked *to* mark whether the uttered vowel was the same as the expected target vowel or a different vowel. The identification of the test vowels by the judges were expected to be same as the target vowel. Based on the judgement the sentences were selected for the analysis. Only those words which were identified as having the vowels same as that of the target ones were selected for the analysis. Even when one judge differed in the identification of the test vowel, that sentence was rejected and a new recording of the rejected sentences were done using the same subjects. Out of 6570 test words recorded, 200 words were rejected based on the evaluation of judges. The subject's whose utterances were rejected by the judges were identified and the re recording of the rejected sentences were carried out and the re-recorded sentences were subjected to perceptual evaluation by the judges as explained earlier.

The waveform of the digitized acoustic signal of the sentences uttered by each subject was displayed on the computer screen using VSS-DISPLAY (Speech waveform editing program). This program had facilities to mark the desired portion of the waveform and listen to the marked portion. Using the same program the waveforms representing each test word was segmented and stored as a separate file. Thus a total of 6570 files were created which were used for further acoustic analysis.

Acoustic analyses

The following temporal and spectral parameters were extracted using VSS-DISPLAY, VSS-SPGM and VSS-FOFNT programs.

Temporal parameters

1. Vowel duration was defined as the duration of the waveform from the onset of voicing to the offset of voicing of the first vowel in the test word /C_1 V_1 C_2 V_2/.
2. Word duration was defined as the duration of the waveform from the region of its to its offset.

Spectral parameters

3. FO of the vowel was defined as the fundamental frequency at the mid point of the vowel.
4. Intensity of the vowel was defined as the RMS intensity at the midpoint of the test vowel.
5. Formant frequencies were defined as the first three well defined spectral peaks which represented concentration of energy at the mid point of the test vowel.

Measurement procedure

The vowel duration and word duration were extracted from the DISPLAY (VSS) program which had facilities for zooming in and out.

For measurement of vowel duration, the vowel onset and offset were identified using the following criteria. Onset of voicing was defined as the beginning of the periodic portion of the waveform. Vowel offset was defined as the vowel to consonant transition region of the test word /C_1 V_1 C_2 V_2/ in the waveform, where there was discernable cessation of the acoustic energy of the test vowel and onset of the aperiodic energy of the following consonant (C_2).. The boundaries for the onset and offset of the vowels were marked by looking at the waveform displayed on the screen of the computer and the boundaries were further confirmed by listening to the marked portion of the speech waveform.

Word duration was defined as the duration of the waveform from the region of its onset to its offset. The onset and offset of the test word were defined using the criteria that the beginning of aperiodic energy (burst in case of voiceless plosives) and the beginning of voicing / murmer (in case of voiced plosives and nasals) in the initial portion of the test word waveform as word onset and the discernable cessation of acoustic energy after the final vowel of the test word as word offset. The boundary portions for the beginning and ending of the words were aided by looking at the waveform displayed on the screen of the computer and by listening to the speech wave form. In case of waveforms, which did not show a clear burst for plosives, the boundaries were marked by listening to the word repeatedly until the investigator had identified the word boundaries satisfactorily.

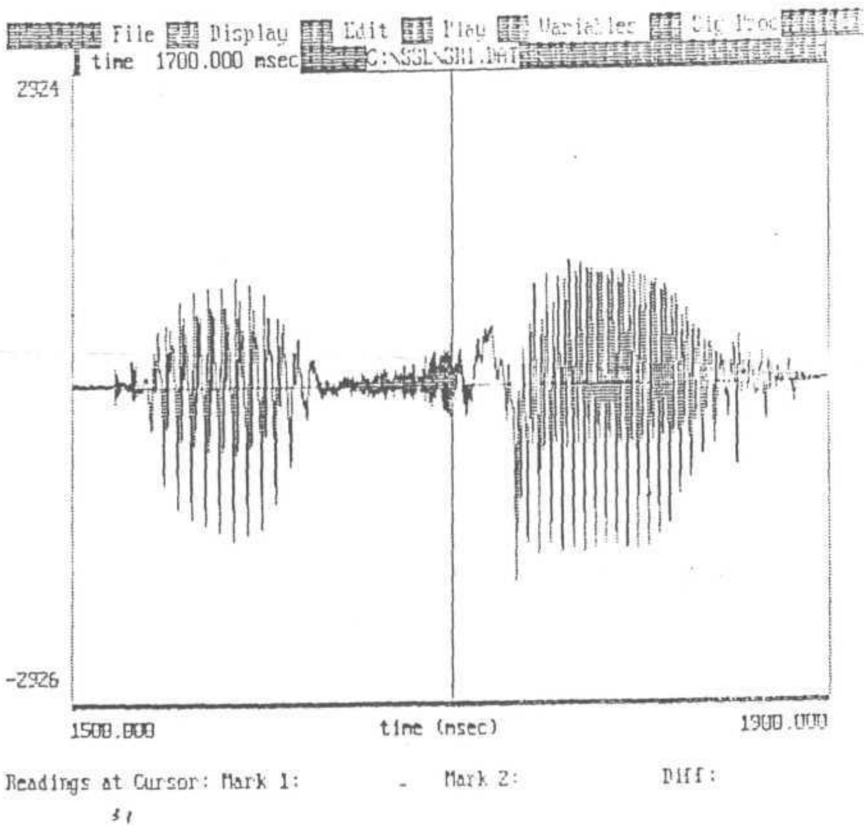


Fig. 3.1: Speech waveform of the segmented test word

The IFo & Io were extracted using the program POINT (VSS). In this program the speech signal from the specified file is read in blocks or frames of 40 msec duration each. Auto correlation technique is used to estimate the average F0 over this block of 40 msec. Intensity is measured as the RMS value in dB. The onset and offset of the target vowel duration which was obtained using the DISPLAY program was fed in F0INT program for processing. From the following display, the fundamental frequency and intensity curves of the target vowel could be visualized. The cursor was moved to the mid point of the target vowel and the corresponding values of IFo & Io were noted down.

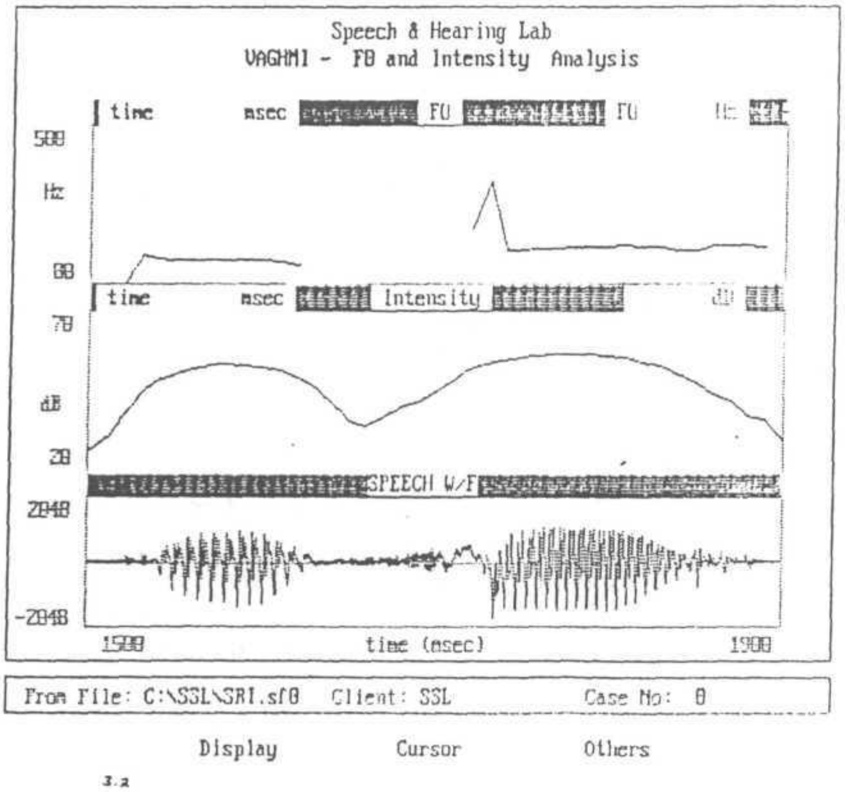


Fig 3.2: Fundamental frequency and intensity curves for the test vowel.

The formant frequencies were extracted using SPGM program (VSS-Bangalore). The following procedure was used. As described earlier, the DISPLAY (VSS) program provided the target word duration which was measured by marking the onset and offset of the waveform or the word The word duration was analyzed in the SPGM (VSS) program to obtain a wide band (with a filter frequency of 300 Hz) spectrogram. SPGM program had facilities for obtaining section type of spectrogram also. The section type of spectrogram displayed the energy concentrations at different frequencies. The formant frequencies were identified as the peaks showing the increased intensity at those frequencies. By moving the cursor to the peak on the section, the formant frequency could be read digitally on the screen of the computer. The frequency regions which had maximum darkness representing the increase in intensity were shown as peaks in the section display and these peaks were seen corresponding to the dark portion on the spectrogram and thus the first three formant frequencies (Fl, F2 & F3) were noted down. A filter band width of 300 Hz was used for the analyses. A window size of 30m.secs with 10m.secs resolution were used in case of the speech samples of males. In female subjects and children, a window size of 15m.secs with a resolution of 5m.secs were used for processing (photograph 2).

To check the reliability of the measurements made , 5% of the total words recorded were selected randomly and the temporal and spectral parameters were extracted from the test vowels present in these words, using the procedures explained earlier. The values were tabulated and there was no statistically significant difference between the values measured first and the repeated measurements. There was also a high degree of correlation between them. Hence the measurements made were considered to be reliable.

The mean and standard deviation of all the parameters for both males and females of each of the three age groups were calculated using SPSS program. The significance of difference in tenns of these parameters across the three age groups, across gender, across the various consonantal contexts and across the three trials were determined using the One Way Anova Test of the SPSS statistical package. The comparisons were made in the following way:

1. Males of group 1 vs group 2
2. Males of group 1 vs group 3
3. Males of group 2 vs group 3
4. Females of group 1 vs group 2
5. Females of group 1 vs group 3
6. Females of group 2 vs group 3
7. Males vs females of group 1
8. Males vs females of group 2
9. Males vs females of group 3

The results are presented in the following chapter.

RESULS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

The objective of the study was to determine the temporal and spectral characteristics of vowels of Kannada language (Mysore dialect) uttered by groups of normal children, adolescents and adults to note the changes in these parameters with age. For this purpose the acoustic analysis of vowels in Kannada language in a /CVCV/ environment was carried out to obtain the following parameters as explained in the previous chapter.

1. Temporal parameters

a. Duration of the vowel (VD)
b. Duration of the word having the test vowel (WD)

2. Spectral parameters

a. Formant frequency 1 (Fl)
b. Formant frequency 2 (F2)
c. Formant frequency 3 (F3)
d. Fundamental frequency at the mid point of the vowel (FO)
e. Intensity at the mid point of the vowel (Io)

The mean, standard deviation and range of all the above parameters in each of the three age groups were calculated. The significance of difference across the three age • groups, across gender, across the different consonantal contexts and across the three trials in terms of these parameters have been determined using ANOVA .

1. Temporal parameters:

The vowel duration and the word duration from the utterances of children (Group 1), adolescents (Group 2), and adults (Group 3), with ten subjects in each group were obtained. These 30 subjects produced 73 sentences with ten Kannada vowels in the context of 12 consonants that were embedded in a carrier phrase. This resulted in a total of 6570 utterances which were recorded and analyzed. From these utterances the vowel duration, word duration were measured as described earlier.

l.a Vowel Duration

The vowel duration was defined as the duration of the waveform from the onset of the vowel to the offset of voicing of the first vowel in the test word /$C_1V_1C_2V_2$/. Onset of voicing was defined as the beginning of the periodic portion of the waveform. Vowel offset was defined as the vowel to consonant transition region of the test word /C_1 V_1 C_2 V_2/ in the waveform, where there was discernable cessation of the acoustic energy of the test vowel and onset of the aperiodic energy of the following consonant (C_2). The results are presented in the following order of I, I:, e, e: (front vowels), a, a: (central vowels) and u, u:, 0, o: (back vowels). As stated earlier, one way ANOVA was used to determine the significance of difference across different age groups and across the genders for the ten vowels.

Vowel /i/: Table 4.1 showed that the mean duration of vowel *IV* in males of group 1 was 103.3msecs and the SD and range were 29.16 and 172msecs respectively. The mean, SD and range for females of group 1 were 99.6 msecs, 23.4, and 125msecs respectively. Similarly the mean, SD and range for males of group 2 were 81.9 msecs, 15.6, and 75 msecs respectively. For females of group 2, they were 99.9msecs, 25, and 125 msecs respectively. In case of males of group 3, the mean, SD and range were 82.1 msecs, 20.2, and 128 msecs respectively. The mean, SD and range for females of group 3 were 94.5 msecs, 22.8, and 137 msecs respectively.

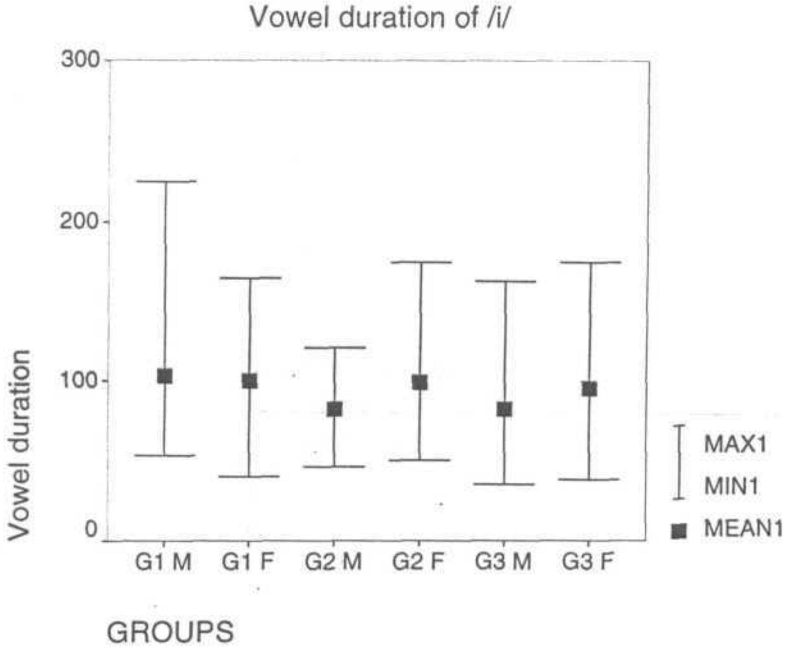
The inspection of Table 4.1 and Graph 1 showed that both in case of males and females the values of vowel duration for /i/ which decreased from group 1 to group 3. It was found that the SD also decreased with age in males nonlinearly i.e., it was higher in group 3 than in group 2. SD reduced from group 1 to group 3 in females also, but again group 2 had higher SD than the other two groups. The range of duration for the vowel /i/ in males was highest in group 1 followed by group 3 and group 2 . In females the range was highest in group 3. Group 1 and group 2 females had an identical range of 125 msecs.

	/i/		/i:/		/e/		/e:/	
	M	F	**M**	F	M	**F**	**M**	F
Group 1 Mean	103.3	99.6	156.8	175	102.4	105.4	176.4	193
SD	29.16	23.4	36.89	37.1	29.65	23.36	35.19	32.5
Range	172	125	210	188	137	94	114	175
Group 2 Mean	81.9	99.9	141.5	156.5	85.9	101.1	141.8	172.8
SD	15.6	25.0	33.1	37.2	17.6	24.2	20.95	30.5
Range	75	125	147	178	87	87	106	177
Group 3 Mean	82.1	94.5	146.2	178.9	82.7	98.6	157.1	194.6
SD	20.2	22.8	26.12	43.35	20.9	24.8	24.97	40.78
Range	128	137	113	182	143	153	157	165

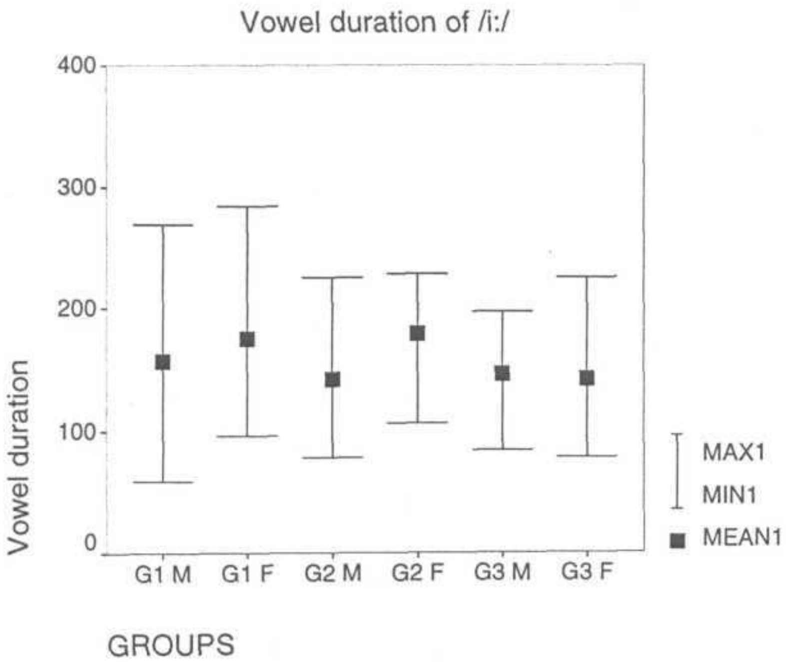
Table 4.1: Mean, SD and Range of Vowel Duration (msecs) for front vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

The statistical analysis of scores of males of different groups using ANOVA showed that males of group 1 had significantly longer vowel duration than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /i/ in Kannada" was rejected. When males of group 2 were compared with males of group 3, it was found that there was no significant difference in the duration of the vowel *l\l*. Therefore the hypothesis stating that "that there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /i/ in Kannada" was accepted.

Similarly in case of females on comparisons using ANOVA, it was found that there were significant differences between groups 1 and 2 and between groups 1 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel *l\l* in Kannada" were accepted. But there was significant difference between females of group 2 and group 3 with group 2 having the lead. Hence the hypothesis stating that "there is no significant



Graph 1



Graph 2

difference between females of groups 2 and 3 in terms of the duration of the vowel *IV* in Kannada" was rejected.

When the males and females of group 1 were compared, the duration of vowel *l\l* was significantly longer in males. Hence the hypothesis stating that "there is no significant difference between males and females for vowel duration of /i/ in group 1 in Kannada" was rejected. But in groups 2 and group 3, females had significantly longer vowel duration for /i/ than their male counterparts. Thus the hypothesis stating that "there are no significant differences between males and females for vowel duration of *l\l* in group 1, group 2 and group 3 in Kannada" were rejected.

Vowel /I:/: On examination of Table 4.1, the mean duration of vowel /I:/ in males of group 1 was 156.8msecs and the SD and range were 36.89 and 210msecs and in females of group 1 they were 175 msecs, 37.1, and 188msecs respectively. The mean, SD and range for males of group 2 were 141.5 msecs, 33.1, and 147msecs respectively. Similarly the mean, SD and range for females of group 2 were 156.5 msecs, 37.2, and 178 msecs respectively. Males of group 3 had a mean of 146.2 msecs, SD of 26.12 and range of 113 msecs. The mean, SD and range for females of group 3 were 178.9 msecs, 43.35, and 182 msecs respectively.

It was seen from Table 4.1 and Graph 2 that only males showed vowel duration of /I:/ to be decreasing from group 1 to group 3. The decrease was linear even though group 3 had longer vowel duration than in group 2 as it was statistically non significant. In females, group 3 had the longest duration and group 2 the shortest duration. Group 1 females had an intermediate value. It was found that the SD also decreased with age in males. In females, SD reduced from group 3 to group 1. The range of vowel duration for /I:/ also decreased with increase in age in males. In females, the range was highest for group 1 followed by group 3 and group 2.

On comparison of male groups, it was observed that there was significantly longer vowel duration in males of group 1 than in males of group 2 and group 3. Therefore the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /I:/ in Kannada" was rejected. When males of group 2 was compared with males of group 3 there was no significant difference in the duration of the vowel /I:/. Thus the hypothesis stating that "there was no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /I:/ in Kannada" was accepted.

When the females of different groups were compared it was observed that there was no significant difference between females of group 1 and group 3 for the duration of vowel *I'vJ.* Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the duration of the vowel /I:/ in Kannada" was accepted. But there was significant difference between females of groups 1 and 2 with group 1 having significantly longer duration. Also on comparison between females of groups 2 and 3, group 3 showed significantly longer vowel duration. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of duration of the vowel /i:/ in Kannada" was rejected.

When males and females of group 1, group 2 and group 3 were compared, it was found that the duration of vowel /I:/ was significantly longer in females of all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of /I:/ in groups 1, group 2 and group 3 in Kannada" were rejected.

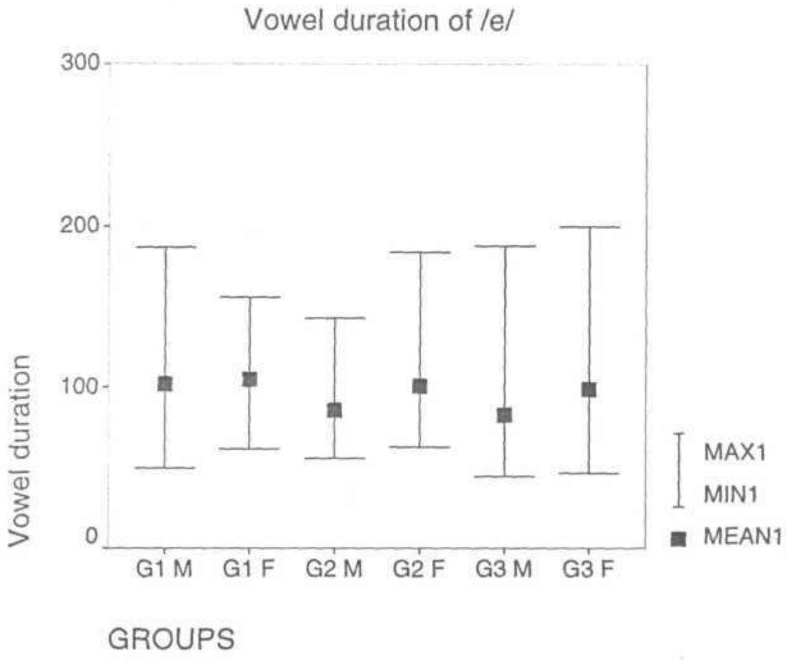
Vowel *Id:* Table 4.1 depicted that the mean duration of vowel /e/ in males of group 1 was 102.4 msecs and the SD and range were 29.65 and 137 msecs respectively. Also the mean, SD and range for females of group 1 were 105.4 msecs, 23.36, and 94 msecs respectively. For males of group 2 , the mean, SD and range were 85.9 msecs, 17.6, and 87msecs and for females they were 101.1 msecs, 24.2, and 87 msecs respectively. The mean, SD and range for males of group 3 they were 82.7 msecs, 20.9, and 143 msecs and for females of group 3 they were 98.6 msecs, 24.8, and 153 msecs respectively.

It was evident from Table 4.1 and Graph 3 that in both males and females vowel duration of /e/ decreased from group 1 to group 3 linearly. Group 1 had the longest duration and group 3 had the shortest duration. SD decreased nonlinearly with age in males as group 2 had a lower SD than group 3. In females, .SD reduced from group 3 to group 1. The values of range of vowel duration for /e/ in both males and females, was highest for group 3 and then decreased to group 1 and then to group 2.

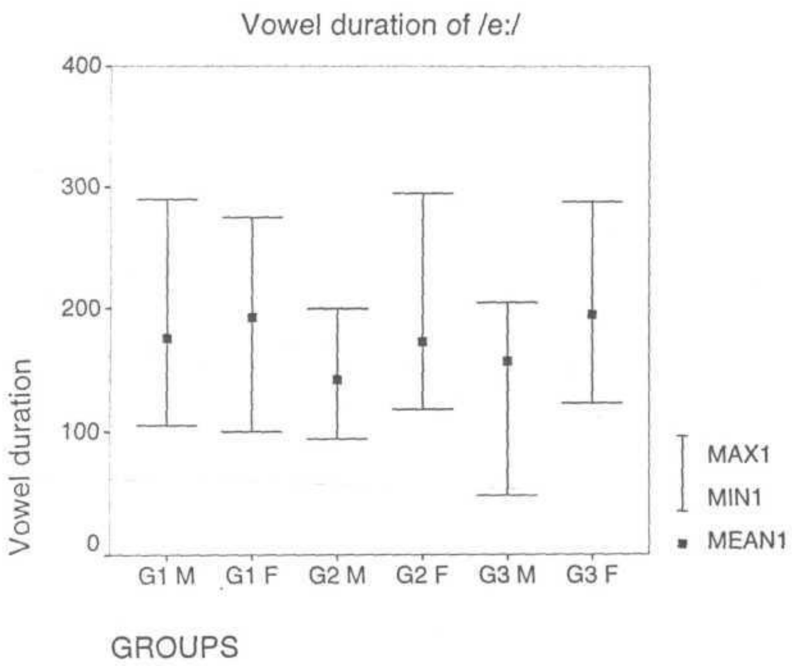
On comparison across the three groups of males, the males of group 1 had significantly longer vowel duration for /e/ than group 2 and group 3 . Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /e/ in Kannada" was rejected. When males of group 2 were compared with males of group 3 there was no significant difference in the duration of the vowel /e/. Therefore the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /e/ in Kannada" was accepted.

The results of ANOVA in females showed that there were no significant differences between group 1 and group 3 and between group 1 and group 2 for the duration of vowel /e/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 1 and 2 in terms of the duration of the vowel /e/ in Kannada" was accepted. Also there was no significant difference between group 2 and group 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of duration of the vowel /e/ in Kannada" was accepted.

When comparisons of males and females of each group were made, it was found that there was no significant difference between males and females of group 1 for duration of vowel /e/. Hence the hypothesis stating that "there is no significant difference between males and females for vowel duration of /e/ in group 1 in Kannada" was accepted. In groups 2 and 3, females had significantly longer duration for vowel /e/.



Graph 3



Graph 4

Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of /e/ in group 2 and group 3 in Kannada" was rejected.

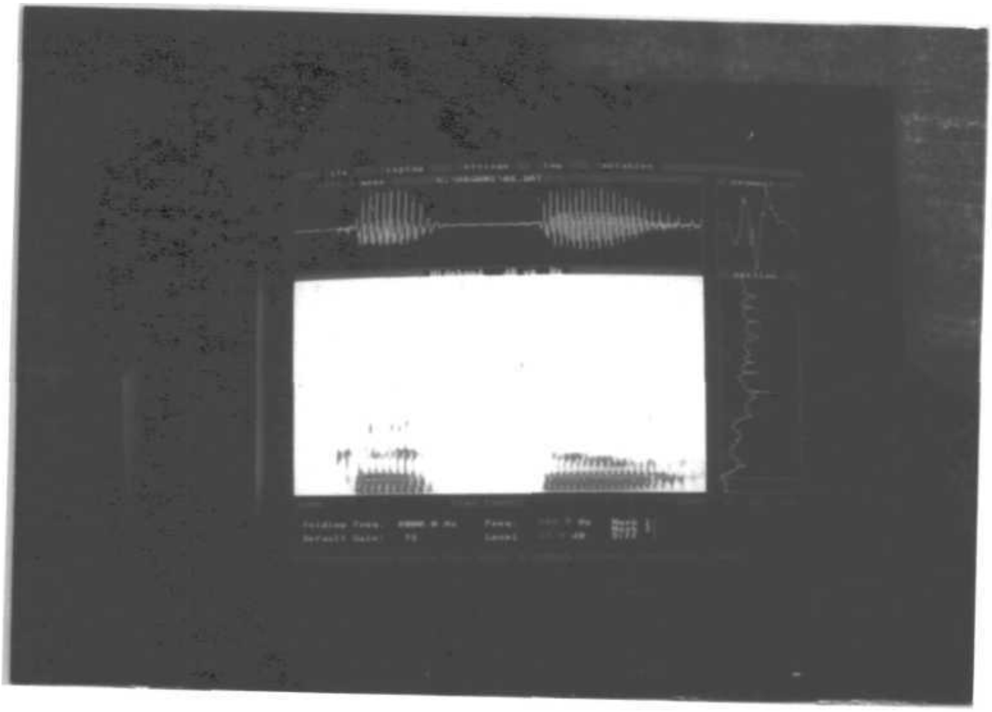
Vowel /e:/: On perusal of Table 4.1, the mean duration of vowel /e:/ in males of group 1 was 176.4 msecs and the SD and range were 35.19 and 114 msecs respectively. The mean, SD and range for females of group 1 were 193 msecs, 32.5, and 175 msecs respectively. Similarly in group 2, for males the mean, SD and range were 141.8 msecs, 20.95, and 106 msecs and for females they were 172.8 msecs, 30.5, and 177 msecs respectively. In group 3, males had a mean of 157.1 msecs, SD of 24.97 and range of 157 msecs and the mean, SD and range for females of group 3 were 194.6msecs, 40.78, and 165 msecs respectively.

It was noticed from Table 4.1 and Graph 4 that only in males vowel duration of /e:/ decreased from group 1 to group 3 though nonlinearly as group 3 had longer duration compared to group 2. In females, group 3 had the longest duration for vowel /e:/ and group 2 had the shortest duration. Group 1 females had an intermediate value. It was found that the SD also decreased nonlinearly with increase in age in males. Group 2 males had lower SD compared to group 3. In females, SD was highest in group 3 and least in group 2 with an intermediate value for group 1. The range of vowel duration for /e;/ was highest for group 3 and lowest for group 2 in males. In females, it was highest for group 2 and lowest for group 3.

The results of comparison across males showed that group 1 males had significantly longer vowel duration for /e:/ than group 2 and group 3 males. Thus the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /e:/ in Kannada" was rejected. When group 2 was compared with group 3, it was observed that males of group 3 had significantly longer duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /e:/ in Kannada" was rejected.

In case of females, comparison of different groups showed that there was no significant difference between group 1 and group 3 in terms of duration of vowel /e:/. So the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the duration of the vowel /e:/ in Kannada" was accepted. But there was significant difference between group 1 and group 2 and also between group 2 and group 3. In both cases, group 2 had significantly shorter duration. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and between groups 2 and 3 in terms of the duration of the vowel /e:/ in Kannada" was rejected.

On comparison across the gender in each group, it was observed that females had significantly longer duration for vowel /e:/ in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of /e:/ in group 1, group 2 and group 3 in Kannada" was rejected.



PHOTOGRAPH 2 : SPECTROGRAM OF THE WORD /KASU/

Vowel /a/: Table 4.2 revealed that in males of group 1, the mean duration of vowel /a/ was 189.6 msecs , SD was 30.83 and range was 144 msecs. The mean, SD and range for females of group 1 were 112.2 msecs, 38.07, and 209 msecs respectively. In case of males of group 2 the mean, SD and range were 87.06 msecs, 16.21, and 92 msecs and for females of group 2 they were 106.91 msecs, 20.47, and 112 msecs respectively. In case of males of group 3 males the mean, SD and range were 82.96 msecs, 17.23, and 104 msecs respectively. Similarly the mean, SD and range for females of group 3 were 103.77 msecs, 23.91, and 153 msecs respectively.

Table 4.2 and Graph 5 depicted that in both males and females duration had decreased from group 1 to group 3 for vowel /a/. It was found that the SD also decreased from group 1 to group 3 and then to group 2. The range of vowel duration for the vowel /a/ in males and females was highest in group 1 followed group 3 and group 2 respectively.

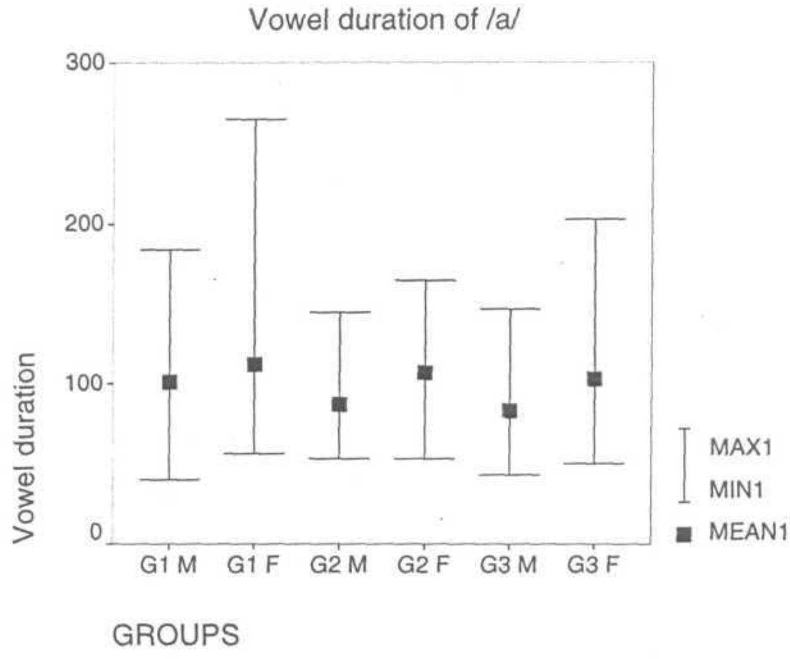
	/a/		/a:/	
	M	F	M	F
Group 1 Mean	101.1	112.2	189.6	207.8
SD	28.3	38.07	30.83	44.56
Range	144	209	156	397
Group 2 Mean	87.06	106.9	158.55	196.4
SD	16.21	20.47	26.07	27.32
Range	92	112	150	159
Group 3 Mean	82.96	103.8	162.27	205.8
SD	17.23	23.9	26.34	44.38
Range	104	153	138	318

Table 4.2 : Mean, SD and Range of Vowel Duration (msecs) for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

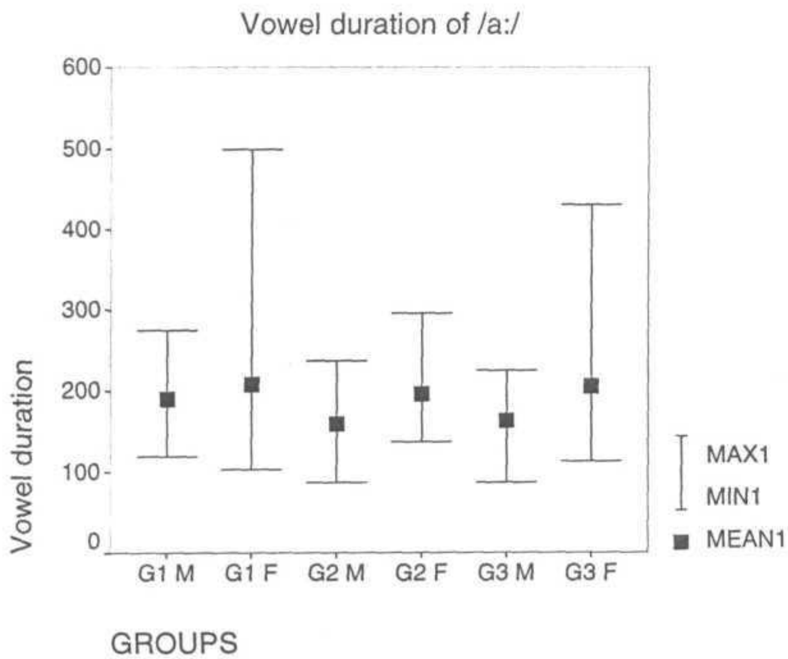
ANOVA showed the males of group 1 had significantly longer vowel duration than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /a/ in Kannada" was rejected. Also when males of group 2 was compared with males of group 3, group 3 showed significantly longer duration for the vowel /a/. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /a/ in Kannada" was rejected.

Using ANOVA comparison of females of different groups were made. It was found that in females of groupl had significantly longer vowel duration than groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /a/ in Kannada were rejected There was no significant difference between females of group 2 and group 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of the duration of the vowel /a/ in Kannada" was accepted.

When the males and females of group 1 were compared in terms of duration of vowel /a/, it was found that the duration was significantly longer in females. Similarly in group 2 and group 3 also females had significantly longer vowel duration than their male counterparts. Therefore the hypothesis stating that "there are no significant differences between males and females for vowel duration of /a/ in group 1, group 2 and group 3 in Kannada" was rejected.



Graph 5



Graph 6

Vowel /a:/: Table 4.2 showed that the mean duration of vowel /a:/ in males of group 1 was 189.6 msecs and the SD and range were 30.83 and 156 msecs and for females they were 207.8 msecs, 44.56, and 397 msecs respectively. Males of group 2 males had a mean of 158.55 msecs, SD of 26.07 and range of 150 msecs and females had a mean of 196.4 msecs, SD of 27.32, and range of 159 msecs . The mean, SD and range for males of group 3 were 162.27 msecs, 26.34, and 138 msecs and in females they were 205.8 msecs, 44.38, and 318 msecs respectively.

It was clear from the study of Table 4.2 that in both males and females vowel duration decreased from group 1 to group 3 and further to group 2 for vowel /a:/ as age increased. It was found that the SD decreased linearly with increase in age in males. In females, SD decreased from group 1 to group 3 and then to group 2. The range of duration for the vowel /a:/ in males decreased from group 1 to group 3. In females the range was highest in group 1 and the decreased to group 3 and then to group 2 .

On comparison across males of different groups it was found that males of group 1 had significantly longer vowel duration for /a:/ than group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /a:/ in Kannada" were rejected. On comparison between males of groups 2 and 3, males of group 3 had significantly longer duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /a:/ in Kannada" was rejected.

In case of females, the results of ANOVA showed that there was no significant difference between group 1 and group 3 for the duration of vowel /a:/. Therefore the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the duration of the vowel /a:/ in Kannada" was accepted. But there was statistically significant difference between group 1 and group 2 with group 1 having longer duration. Thus the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of duration of the vowel /a:/ in Kannada" was rejected. When groups 2 and 3 were compared, it was observed that there was significant difference between them with group 3 having longer duration. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of duration of the vowel /a:/ in Kannada" was rejected.

When males and females of group 1, group 2 and group 3 were compared with in each group, it was observed that duration of vowel /a:/ was significantly longer in females than males in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of/a:/ in groups 1, group 2 and group 3 in Kannada "was rejected.

Vowel /u/: It was seen from the scrutiny of Table 4.3 that the mean duration of vowel /u/ in males of group 1 was 96.5 msecs and the SD and range were 35.3 and 163 msecs and for females they were 88.1 msecs, 27.27, and 129 msecs respectively. The mean, SD and range for males of group 2 were 74.9 msecs, 14.2, and 74 msecs and for females they were 87.9 msecs, 23.4, and 166 msecs respectively. In group 3, the mean, SD and range for males were 70.95 msecs, 17.2, and 109 msecs and for females of group 3 were 80.75 msecs, 22.37, and 150 msecs respectively.

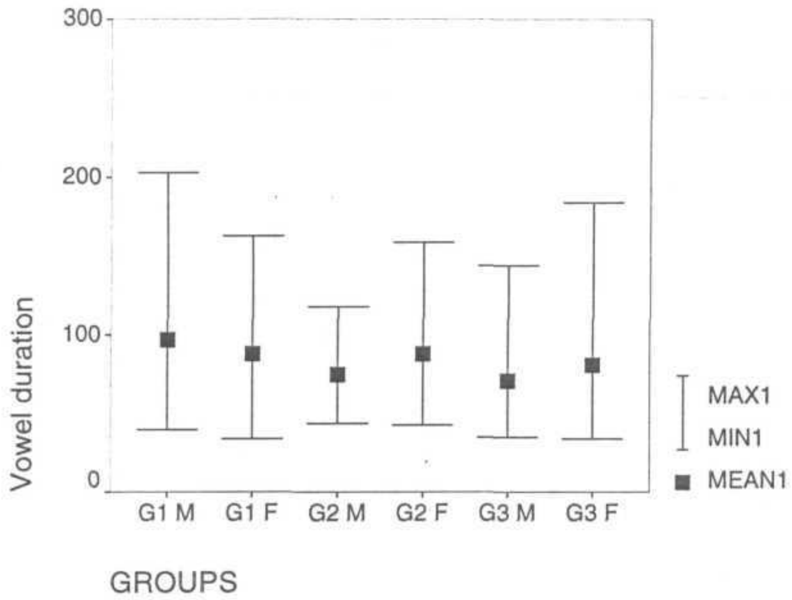
As can be seen from the Table 4.3 and Graph 6, both males and females had the values of vowel duration for /u/ which decreased from group 1 to group 3 for vowel /u/. It was found that the SD also decreased with increase in age in both males and females. But in males of group 2 had slightly lower SD compared to group 3. The range of vowel duration for /u/ was highest for group 1 and lowest for group 2 in males. In females the range was highest for group 3 and lowest was found in group 2. Group 1 showed the value of range in between these two groups

	/u/		/u:/		/o/		**/o:/**	
	M	F	M	F	M	F	M	F
Group 1 Mean	96.5	88.1	148.11	173.4	110.3	106.88	160.19	177.9
SD	35.3	27.27	38.38	34.97	35.7	31.3	28.8	29.9
Range	163	129	172	146	181	165	165	178
Group 3 Mean	74.9	87.9	123.9	154.3	93.8	110.3	131.7	165.5
SD	14.2	23.4	24.79	33.4	22.2	29.7	19.19	27.8
Range	74	116	135	172	140	131	102	122
Group 3 Mean	70.95	80.75	146	173.8	84.4	104.2	152.5	185.2
SD	17.2	22.37	25.1	46.21	20.31	31.4	25.2	34.69
Range	109	150	123	217	94	210	112	137

Table 4.3: Mean, SD and Range of Vowel Duration (msecs) for back vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3) .

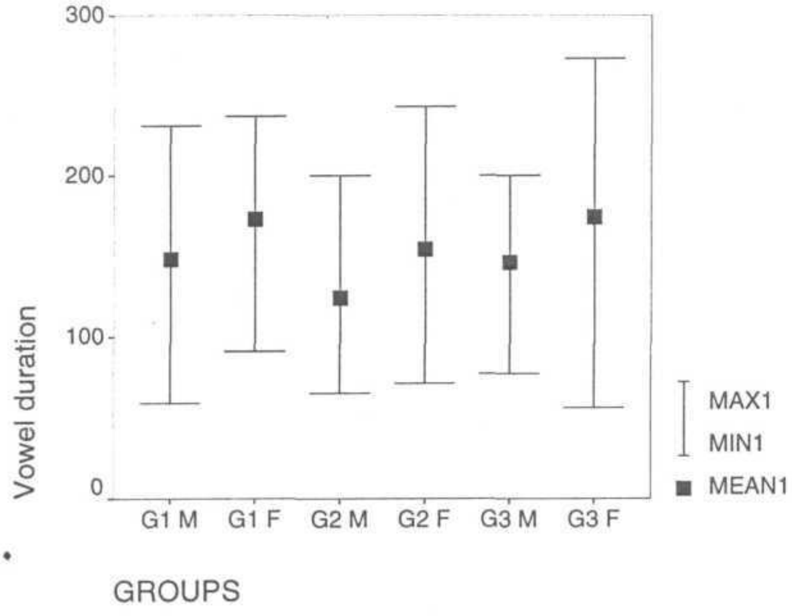
From the comparison of males of three groups it was found that males of group 1 had significantly longer vowel duration for /u/ than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /u/ in Kannada"

Vowel duration of /u/



Graph 7

Vowel duration of /u:/



Graph 8

was rejected. When males of group 2 was compared with males of group 3, it was found that there was significant difference with group 2 showing longer duration for the vowel /u/. Thus the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel *Iwl* in Kannada" was rejected.

Comparison of groups of females, it was revealed that there was no significant difference between groups 1 and 2 and groups 1 and 3 for duration of vowel /u/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /u/ is Kannada" was accepted. Also there was no significant difference between group 2 and group 3. So the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of the duration of the vowel /u/ in Kannada" was accepted.

On comparison between males and females it was found that males of group 1 had significantly longer duration than females of group 1. In groups 2 and 3, females showed significantly longer duration. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of *Iwl* in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /u:/: It is evident from Table 4.3 that the mean duration of vowel /u:/ in males of group 1 was 148.11 msecs and the SD and range were 38.38 and 172 msecs respectively. Females of group 1 had a mean of 173.4 msecs, SD of 34.97 and range of

146 msecs respectively. The mean, SD and range for males of group 2 were 123.9 msecs, 24.79, and 135 msecs and for females they were 154.3msecs, 33.4, and 172 msecs respectively. In males of group 3 the mean, SD and range were 146 msecs, 25.1, and 123 msecs respectively. The mean, SD and range for females of group 3 were 173.8 msecs, 46.21, and 217 msecs respectively.

Table 4.3 and Graph 7 showed that in males duration of/u:/ decreased from group 1 to group 3 and further to group 2 . In females the duration decreased from group 3 to group 1 and then to group 2. SD decreased from group 1 to group 3 and then to group 2 in males. In females SD decreased from group 3 to group 1 and then to group 2. The range of vowel duration for /u:/ decreased linearly with increase in age in males. In females the range increased with increase in age.

The results of comparison in males revealed that males of group 1 had significantly longer vowel duration for /u:/ than males of group 2 . Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 2 in terms of the duration of the vowel /u:/ in Kannada" was rejected. But there was no significant difference between males of groups 1 and 3. Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 3 in terms of the duration of the vowel /u:/ in Kannada" was accepted. When males of group 2 were compared with males of group 3, the latter group had significantly longer duration for the vowel /u:/. Thus the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /u:/ in Kannada" was rejected.

A similar comparison in case of females indicated that females of group 1 had significantly longer vowel duration for /u:/ than group 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of the duration of the vowel /u:/ in Kannada" was rejected. And there was no significant difference between females of groups 1 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the duration of the vowel /u:/ in Kannada" was accepted. When females of groups 2 and 3 were compared, females of group 3 had significantly longer duration than females of group 2. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of the duration of the vowel /u:/ in Kannada" was rejected.

On comparison between the two sexes, it was noticed that females showed longer duration of vowel /u:/ in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of/u:/ in group 1, group 2 and group 3 in Kannada"were rejected.

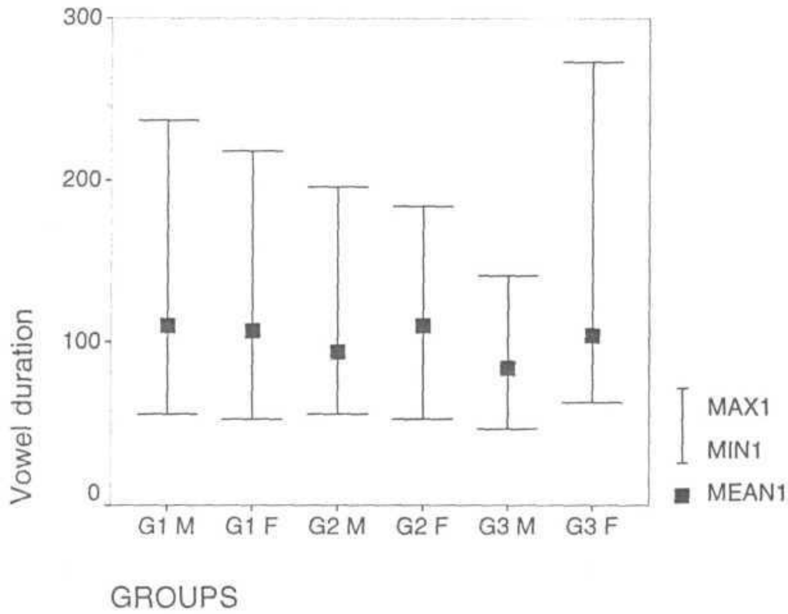
Vowel /o/: On perusal of Table 4.3, it was observed that the mean duration of vowel /o/ in males of group 1 was 110.3 msecs and the SD and range were 35.7 and 181 msecs and for females of group 1, they were 106.88 msecs, 31.3 and 165 msecs respectively. Males of group 2 had a mean of 93.8 msecs, SD of 22.2, and range of 140 msecs . The mean, SD and range for females of group 2 were 110.3 msecs, 29.7, and 131 msecs respectively. Group 3 males showed the mean, SD and range as 84.4 msecs, 20.31, and 94 msecs and for females they were 104.2 msecs, 31.4 and 210 msecs respectively.

It was evident from the study of Table 4.3 and Graph 9 that males had the values which decreased from group 1 to group 3. In females the mean was highest in group 2 followed by group 1 and then group 3 . It was found that the SD also decreased with increase in age in males. Such a decrease in SD was not seen in case of females. The range of vowel duration for /o/ also decreased with increase in age in males. In females the range was highest for group 3 and lowest for group 2 with group 1 showing an intermediate range.

The statistical analysis revealed that the males of group 1 had significantly longer vowel duration for /o/ than males of group 3. Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 3 in terms of the duration of the vowel /o/ in Kannada" was rejected. On comparison between the males of groups 1 and 2, it was found that there was no significant difference between the two. Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 2 in terms of the duration of the vowel /o/ in Kannada" was accepted. When males of group 2 was compared with males of group 3, no significant difference in the duration of the vowel /o/ between the two groups was found. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /o/ in Kannada" was accepted.

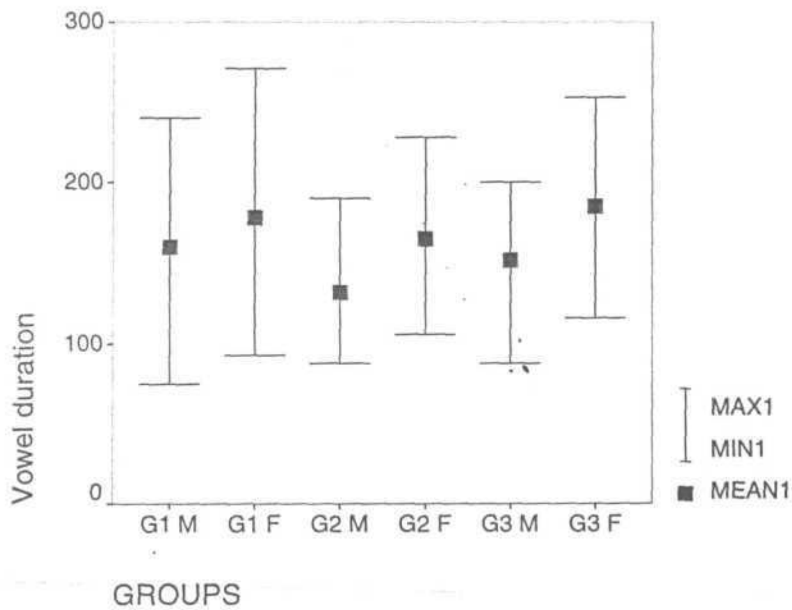
In case of females, the results of ANOVA indicated that females of group 1 had significantly longer vowel duration for /o/ than females of group 3. Hence the hypothesis stating that "there is no significant difference between females of groups 1

Vowel duration of /o/



Graph 9

Vowel duration of /o:/



Graph 10

and 3 in terms of the duration of the vowel *lol* in Kannada" was rejected. On comparison between females of groups 1 and 2 and groups 2 and 3, there was no significant difference. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of the duration of the vowel /o/ in Kannada" was accepted.

Comparison between males and females of each group revealed that there was no significant difference between males and females for duration of vowel *lol* in group 1. Hence the hypothesis stating that "there is no significant difference between males and females for vowel duration of *lol* in group 1 in Kannada" was accepted. There was significant difference between males and females of groups 2 and 3 with females having longer vowel duration. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of *lol* in group 2 and group 3 in Kannada" was rejected.

Vowel /o/*:* On examination of Table 4.3 it was noticed that the mean duration of vowel /o/ in males of group 1 was 160.19 msecs and the SD was 28.8 and the range was 165 msecs. The mean, SD and range for females of group 1 were 177.9 msecs, 29.9, and 178 msecs respectively. In case of males of group 2 the mean, SD and range were 131.7 msecs, 19.19, and 102 msecs and for females they were 165.5 msecs, 27.8, and 122 msecs respectively. The mean, SD and range for males of group 3 were 152.5 msecs, 25.2, and 112 msecs respectively. Similarly the mean, SD and range for females of group 3 were 185.2 msecs, 34.69 and 137 msecs respectively.

From Table 4.3 and Graph 10, it was observed that in males the duration decreased from group 1 to group 3 and then to group 2 for vowel /o:/. In females, the longest duration was found for group 3 followed by groupl and group 2. SD also followed the same pattern as the mean, that is, SD was least for group 2 for both males and females. Both for males and females the range of duration for the vowel /o:/ decreased from group 1 to group 3 and then to group 2.

The results of comparisons across the male groups showed that males of group 1 had significantly longer vowel duration for /o/ than group 2 and group 3 males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the duration of the vowel /o:/ in Kannada" were rejected. On comparison across males of groups 2 and 3, it was observed that the latter group had longer duration. Thus the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the duration of the vowel /o:/ in Kannada" was rejected.

When the females of three groups were compared, it was observed that there was no significant difference between group 1 and group 3 in terms of the duration of vowel *lo'.l.* Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the duration of the vowel /o:/ in Kannada" was accepted. Further it was observed that there was significant difference between group 1 and group 2 with females of group 1 having longer vowel duration. Hence the hypothesis stating that "there is no significant difference between females of groups and 2 in terms of duration of the vowel /o:/ in Kannada" was rejected. When females of groups 2 and 3 were compared, females of group 3 showed significantly longer duration. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of duration of the vowel /o:/ ir Kannada" was rejected.

When males and females of group 1, group 2 **and** group 3 were compared, duration of vowel /o:/ was significantly longer in ferales of all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for vowel duration of /o:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

Tables 4.4 and 4.5 shows the presence and absence of significant difference in **vowel** duration between different age groups.

Males	/i/	/I:/	/e/	**/e:/**	/a/	/a:/	/u/	/u:/	/o/	**/o:/**	**Total**
Gl vs G2	P	P	**P**	**P**	P	P	P	P	**A**	**P**	**9/10**
Gl vs G3	P	P	**P**	**P**	P	P	P	A	**P**	**P**	9/10
G2 vs G3	A	A	**A**	**P**	P	P	P	P	**A**	**P**	6/10

Table 4.4 : The results of test for significance of difference for the three age groups in case of males for vowel duration in Kannada at 0.05 level

Females	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl vs G2	A	P	A	P	P	P	A	P	A	P	6/10
Gl vs G3	A	A	A	A	P	A	A	A	P	A	2/10
G2 vs G3	P	P	A	P	A	P	A	P	A	P	5/10

Table 4.5 : The results of test for significance of difference for the three age groups in case of females for vowel duration in Kannada at 0.05 level

It was evident from Table 4.4 that there was significant difference in vowel duration for nine out of ten vowels between group 1 and groups 2 and 3 in males. Table 4.5 shows that in females the difference in vowel duration was significantly evident between groups 1 and 2 rather than between groups 1 and 3. From the observations made in scaling following the procedure used by Eguchi and Hirsh (1969), the picture became even more clearer (Table 4.6). Males of group 1 had longer short vowel duration than males of groups 2 and 3 by 17% and 21% respectively. Males of Group 2 had longer short vowel duration than males of group 3 by 5%. Similarly in females of group 1 had longer short vowel duration than females of groups 2 and 3 by 1% and 6% respectively. Females of Group 2 had longer duration than females of group 3 by 5%. That is, a linear decrease in vowel duration was observed in case of short vowels as age increased.

In case of long vowels, males of group 1 had longer duration than males of groups 2 and 3 by 16% and 8% and in females they were 1% and 9% respectively. However, in long vowels for both males and females, group 3 had longer duration than group 2 by 9% and 11% respectively. Hence, even though there was a decrease in duration, it was not linear in case of long vowels. However from the vowel duration measurements obtained from both males and females it was concluded that vowel duration decreased markedly from childhood (Group 1) to adolescence (Group 2) after which there was a gradual increase to adulthood (Group 3). Hence a definite developmental trend was seen for vowel duration in both males and females.

Vowel duration	**Group 1 /Group 3**		**Group 1 /Group 2**		**Group 2 /Group 3**	
	M	**F**	**M**	**F**	**M**	**F**
Short Vowel	21 %	6%	**17%**	**1 %**	5%	5%
Long Vowel	8%	**1%**	**16%**	**9%**	- 9 %	- 11 %

Table 4.6 : The percentage by which group 1 is greater than groups 2 & 3 and by which group 2 is greater than group 3 for vowel duration

M vs F	***/i/***	*/I:/*	/e/	**/e:/**	**/a/**	**/a:/**	**/u/**	**/u:/**	*/o/*	**/o:/**	**Total**
G_1	**P**	**P**	**A**	**P**	**P**	**P**	**P**	**P**	**A**	**P**	8/10
G2	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	10/10
G3	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	**P**	10/10

Table 4.7: The results of test for significance of difference between males and females for vowel duration in Kannada at 0.05 level

It was clear from Table 4.7 that there was significant difference in vowel duration across gender for all the three groups. On the average, females had longer vowel duration in all the three age groups. On scaling of vowel duration it was observed that for short vowels there was no durational difference in group 1. Females of groups 2 and 3 had longer short vowel duration than males by 16% and 17% respectively. In case of

	Group 1 M	**Group 1 F**	**Group2 M**	**Group 2 F**	**Group 3 M**	**Group 3 F**
Ratio	1:1.6	1:1.8	1:1.6	1:1.7	1:1.9	1:1.9

Table 4.9: Overall short and long vowel ratios in different age groups in Kannada

The durational ratios of short and long vowels for the five vowel groups obtained in the present study in different age groups are given in Table 4.10. Table 4.11 shows the durational ratios for different vowels in adults in comparison with Venkatesh (1995).

Vowel	Group 1	Group 2	Group 3
i/i:	1:1.63	1:1.64	1:1.83
e/e:	1:1.78	1:1.69	1:1.93
a/a:	1:1.86	1:1.83	1:1.96
o/o:	1:1.55	1:1.46	1:1.79
u/u:	1:1.73	1:1.69	1:2.1

Table 4.10: Short/long vowel ratios in three age groups for different vowels in Kannada

Vowel	Venkatesh (1995)	Present study
i/i:	1: 2.24	1:1.83
e/e:	1:2.02	1:1.93
a/a:	1:2.18	1:1.96
o/o:	1: 1.98	1:1.79
u/u:	1:2.19	1:2.1

Table 4.11: Short/long vowel ratios of present study and Venkatesh (1995) in Kannada

Vowels	Group 1		Group 2		Group 3	
	M	F	M	F	M	F
a	101	112	87	107	83	104
a:	190	208	159	196	162	206
i	103	100	82	100	82	95
I:	157	175	142	157	146	179
u	97	88	75	88	71	81
u:	148	173	124	154	146	174
e	102	105	86	101	83	99
e:	176	193	142	173	157	195
o	110	107	94	110	84	104
o:	160	178	132	166	153	186

Table 4.12: Vowel duration in males and females of different groups in Kannada obtained in the present study

Table 4.12 gives the values of vowel duration for all the ten vowels studied in the three groups in Kannada. Based on the values obtained on vowel duration, following observations have been made:

A) On the whole it was observed that among the five short vowels considered in the study, vowel /u/ had the shortest vowel duration in both males and females of all the three groups.

B) Similarly vowel /o/ was the longest in both males **and** females of all the three groups.

C) Among the five long vowels, /u:/ was the shortest and /a:/ was the longest in both males and females of all the three groups consistently. This observation is in consonance **with** Venkatesh (1995).

Table 4.13 shows that the vowel duration obtained in the present study for adults in comparison with earlier studies in Kannada. The absolute vowel duration obtained in the present study were not exactly in consonance with Rajapurohit (1982) as he had considered only one subject for the purpose of measurement. Some differences were noticed with Venkatesh (1995) also. This may be because he had considered the vowels in the context of only one consonant /k/ where as in the present study of vowels in Kannada 12 consonants have been considered.

Vowels	Rajapurohit (1982) Kannada		Venkatesh (1995) Kannada		Present Study Kannada	
	M	F	M	F	M	F
i	60.77	-	80	78	82	95
I:	136.41	-	166	185	146	179
e	83.16	-	96	97	83	99
e:	151.16	-	176	215	157	195
a	71.84	-	89	92	83	104
a:	157.8	-	178	212	162	206
0	84	-	92	95	84	104
o:	146.22	-	168	197	153	185
u	58.05	-	77	80	71	81
u:	168	-	160	182	146	174

Table 4.13 : Duration of the vowels of Kannada in the present study and other studies

In the present study on vowels of Kannada, the variability and range of vowel duration also decreased from childhood to adulthood. The findings of the present study are in support of earlier studies by Smith (1978) and Kent & Forner (1980) where they have reported that children's speech segments are frequently longer in duration than those of adults and the temporal variability decreased as children get older (Eguchi and Hirsh, 1969, Tingley & Allen, 1975; Di Simoni, 1975; Kent,1976; Smith et. al., 1983). As the young children's speech segment duration are often longer than those of adults, Smith and Gartenberg (1984) hypothesized that at least two factors could be responsible for the temporal differences which have been observed in acoustic measurements of children's and adult's speech.. They state that "it is possible that physical characteristics of children's less mature speech mechanisms might limit the rate at which they perform articulatory movements, due to factors such as development of the nervous system (Crelin,l973; Williams, 1983) and/or growth of the orofacial region" (Subtelney, 1957, Goldstein, 1980). The second factor for children's longer segment durations could be a result of not yet having learned to anticipate and plan sequences of speech gestures in the same manner that adults do (Thompson & Hixon, 1979; Kent & Forner, 1980; Kent, 1983). Smith and Gartenberg (1984) suggested that that the longer acoustic durations on children's versus adult's speech seemed to involve both physical level and organizational level factors. Rashmi (1985) reported that both males and females show a consistent decrease in vowel duration as a function of age from 4 to 15 years. Elizabeth (1998) has reported longer vowel duration in children aged between 7-8 years than in adults of Malayalam language. She attributed the reduction in vowel duration to neuromuscular maturation and progress in speech motor control. Hence the results of the present study of vowels in Kannada are in consonance with similar studies in various other languages.

There seems to be no obvious reason for the longer duration observed in the adult group compared to the adolescent group in the present study. It is possible that a more homogenous group was selected in the 14-15 year group compared to the adults and moreover the rate of speech was not controlled during the recording procedure. Most previous studies have examined the acoustic differences between children and adults. As acoustic data on 14-15 year group is limited, further research should help clarify this finding.

Another finding in the present study was that females had longer vowel duration than males is also in consonance with several earlier reports. Zue and Lafferiere (1979) observed that longer vowel duration characterized female speech. Rashmi (1985) had reported longer vowel duration in female subjects compared to males in the age range of 4 to 15 years. Savithri (1983) in Sanskrit and Savithri (1986) and Venkatesh (1995) in. Kannada, observed that the vowels produced by female speakers had longer duration than the male speakers. Similar results were reported by Elizabeth (1998) in Malayalam for both children and adults. The longer vowel duration in females may be related to the higher fundamental frequency used by them. Further the vowel duration decreased as a function of age in both males and females which may possibly be due to the decrease in fundamental frequency with age. Study by Nataraja and Jagadish (1984) has also shown a relationship between the vowel duration and fundamental frequency, that is the duration of vowels *hi* and /u/ at high and low frequencies were significantly longer than at the normal fundamental frequency in case of males and females.

Based on the results of the study, of vowel durations of Kannada in three different age groups in the present investigation, it was concluded that:

a) Vowel duration decreased from children to adults.

b) Variability and range of vowel duration also followed suit.

c) In all the three groups females had longer vowel duration than their male counterparts.

d) The developmental trend was more stronger in short vowels than in long vowels.

e) Long vowels were almost twice the duration of short vowels in adults.

l.bWord Duration

The word duration was defined as the duration of the waveform from the region of it's onset to it's offset in the test word $/C_1V_1C_2V_2/$. The results are presented in the following order of i, i:, e, e: (front vowels), a, a: (central vowels) and u, u:, o, o: (back vowels).

Vowel /i/*:* Table 4.14 depicted that the mean word duration with vowel *I'll* in males of group 1 was 376.2 msec and the SD and range were 70.8 and 344 msec respectively. The mean, SD and range for females of group 1 were 394.4 msec, 59.7, and 266msec respectively. Similarly in group 2 males the mean, SD and range were 284.5 msec, 41.1, and 192msec and for females of group 2 they were 346.3msec, 57.4, and 291msec. respectively. Group 3 males had a mean of 347.3 msec, SD of 57.1 and range of 261 msec and the mean, SD and range for females of group 3 were 404.1 msec, 75.1, and 319 msec respectively.

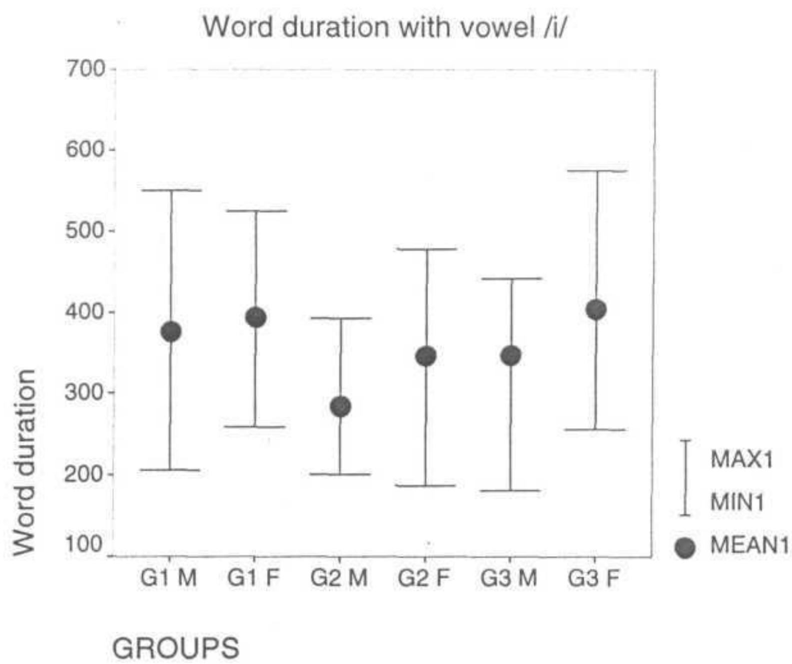
Table 4.14 and Graph 11 disclosed that in males had the values of word duration decreased from group 1 to group 3 and further to group 2. In females, group 3 had the longest word duration followed by group 1 and group 2. SD and range were highest in group 1 then decreased to group 3 and to group 2 in males. In females, group 3 had the highest SD followed by group 1 and group 2. In females, the values of range was highest in group 3 and decreased to group 2 and then to group 1 .

	/i/		/i:/l		/e/		/e:/	
	M	F	M	F	M	F	M	F
Group 1 Mean		394.4	426.7	476	380.6	416.4	443.9	496.3
SD	70.8	59.7	56.3	65.1	58.9	50.9	64.7	62.3
Range	344	266	278	490	265	250	341	337
Group 2 Mean	284.5	346.3	358.5	419.9	305.8	362.6	359.9	419.7
SD	41.1	57.4	41.61	61	38.8	47.2	52.2	57.6
Range	192	291	197	260	181	238	269	272
Group 1 Mean	347.3	404.1	392.6	458.4	332.5	388.1	419.2	491
SD	57.1	75.1	67.9	84.2	53.5	65.1	63.9	92.3
Range	261	319	306	359	334	312	312	370

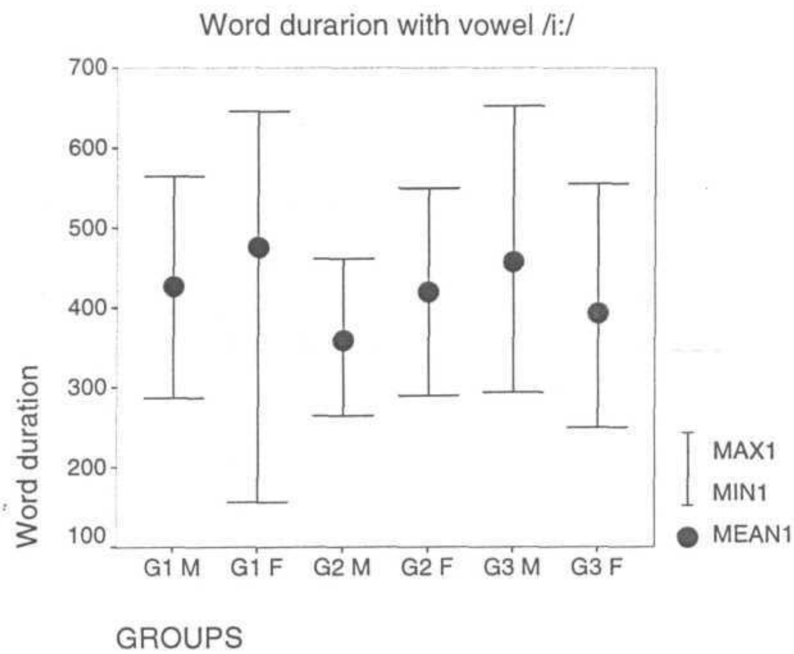
Table 4.14: Mean, SD and Range of Word duration (msec) with front vowels of males and Females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

Statistical analysis using ANOVA showed that in males, group 1 had significantly longer word duration than group 2 and group 3. Hence the hypothesis stating "that there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of word duration for the vowel /i/ in Kannada" was rejected. When males of group 2 was compared with males of group 3, there was significant difference with group 3 having a longer word duration. Thus the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of word duration for the vowel *HI* in Kannada" was rejected.

Similarly in females comparisons across the three groups using ANOVA showed that there was no significant difference between group l and group 3. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and



Graph 11



Graph 12

3 in terms of the word duration for the vowel /i/ in Kannada" was accepted. But there was statistically significant differences between females of groups 1 and 2 and groups 2 and 3. In both cases group 2 showed a shorter word duration. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of the word duration with the vowel *l\l* in Kannada" was rejected.

When the males and females of group 1 were compared, it was found that there was no significant difference in word duration with the vowel /i/ In group 2 and group 3, females had significantly longer word duration than their male counterparts. Hence the hypothesis stating that "there are no significant differences between males and females for word duration for /i/ in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /I:/: On perusal of Table 4.7, it was seen that the mean word duration for vowel /i:/ in males of group 1 was 426.7msec and the SD and range were 56.3 and 278 msec respectively. The mean, SD and range for females were 476 msec, 65.1, and 490msec respectively in group 1. Group 2 males had a mean of 358.5 msec, SD of 41.61 and range of 197 msec and for females, the mean, SD and range were 419.9 msec, 61, and 260 msec respectively. Similarly the mean, SD and range for males of group 3 were 392.6 msec, 67.9, and 306msec respectively. In females of group 3 the mean, SD and range were 458.4 msec, 84.2, and 359 msec respectively.

Inspection of Table 4.14 and Graph 12 show that in both males and females word duration decreased from group 1 to group 3 and then to group 2. SD was highest in group 3 and lowest in group 2. Group 1 had an intermediate value of SD in both males and females. The range of word duration for /I:/ decreased from group 3 to group 1 and then to group 2 in males. In females, the range was highest for group1 and then decreased to group 3 and then to group 2.

On comparison across three groups of males, it was noticed that males of group 1 had significantly longer word duration for /I:/ than group 2 and group 3. Thus the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration with the vowel /I:/ in Kannada" was rejected. On comparison between males of groups 2 and 3, the latter group had longer word duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration of the vowel /I:/ in Kannada" was rejected.

When the female groups were compared it was disclosed that there was no significant difference between group 1 and group 3 for the word duration for vowel /I:/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration with the vowel /I:/ in Kannada" was accepted. But there was significant differences between females of groups 1 and 2 and groups 2 and 3. In both cases, group 2 showed shorter word duration. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of word duration of the vowel /I:/ in Kannada" was rejected.

When males and females of group 1, group 2 and group 3 were compared, with each other, the results indicated that the word duration with vowel /I:/ was significantly longer in females. Hence the hypothesis stating that "there are no significant differences between males and females for word duration with /I:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

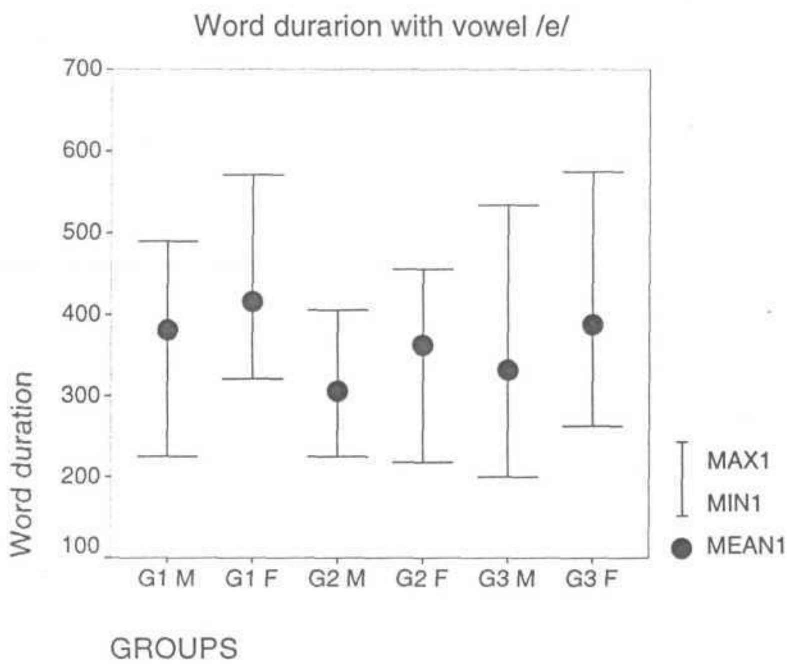
Vowel *Id:* Table 4.14 showed that in group 1 males the mean word duration with vowel *Id* was 380.6 msec, SD was 58.9 and the range was 265 msec. The mean, SD and range for females of group 1 were 416.4 msec, 50.9, and 250 msec respectively. Similarly in group 2 males, the mean, SD and range were 305.8 msec, 38.8, and 181 msec and for females they were 362.6 msec, 47.2, and 238 msec respectively. The mean, SD and range were 332.5 msec, 53.5, and 334 msec respectively for males of group 3. The mean, SD and range for females of group 3 were 388.1 msec, 65.1, and 312 msec respectively.

As it was evident from the Table 4.14 and Graph 13, in both males and females word duration values decreased from group 1 to group 3. In both males and females, group 1 had the longest duration followed by group 3 and then group 2. SD also decreased with age in males but group 2 had a lower SD than group 3. In females, SD reduced from group 3 to group 1 and to group 2. The range of word duration for *Id* in both males and females was maximum for group 3 decreasing to group 1 and then to group 2.

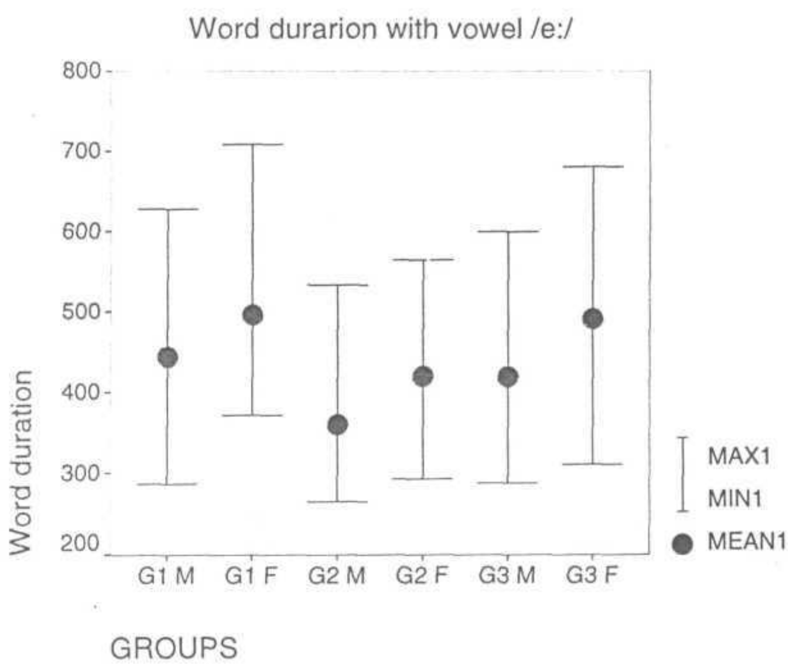
In case of males, it was noticed that group 1 had significantly longer word duration with /e/ than group 2 and group 3 . Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration of the vowel /e/ in Kannada" was rejected. When males of group 2 was compared with males of group 3, it was observed that there was significant difference in the word duration, with group 3 showing a longer word duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration with the vowel /e/ in Kannada" was rejected.

When the female groups were compared, it was found that females of group 1 had significantly longer word duration than groups 2 and 3 . Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of the word duration with the vowel /e/ in Kannada" were rejected. Also there was significant difference between females of group 2 and group 3 with group 3 having the lead. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of word duration with the vowel /e/ in Kannada" was rejected.

When comparisons across sex was made in each of the three groups, it was found that females had significantly longer word duration with vowel /e/ in all the three groups. Therefore the hypothesis stating that "there are no significant differences between males and females for word duration of /e/ in groupl, group 2 and group 3 in Kannada" was rejected.



Graph 13



Graph 14

Vowel /e:/: On examination of Table 4.14, it can be seen that the mean word duration with vowel /e:/ in males of group 1 was 443.9msec and the SD and range were 64.7 and 341msec respectively. The mean, SD and range for females of group 1 were 496.3msec, 62.3, and 337msec respectively. In males of group 2, the mean, SD and range were 359.9msec, 52.2, and 269msec and for females they were 419.7msec, 57.6, and 272msec respectively. Similarly the mean, SD and range for males of group 3 were 419.2msec, 63.9, and 312msec and in females of group 3, the mean, SD and range for were 491msec, 92.3, and 370msec respectively.

It can be noticed from Table 4.7 and Graph 14 that both males and females had the values which decreased from group 1 to group 3. In both males and females, group 1 had the longest duration followed by group 3 group 2 respectively. In males SD and range decreased from group 1 to group 3 and then to group 2 . In females, SD and range reduced from group 3 to group 1 and to group 2.

The results of comparison using one way ANOVA in males disclosed that males of group 1 had significantly longer word duration for /e:/ than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration of the vowel /e:/ in Kannada" was rejected. Males of group 3 had significantly longer word duration than group 2. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration of the vowel /e:/ in Kannada" was rejected.

In case of females, the statistical analysis indicated that there was no significant difference between group 1 and group 3 for word duration of vowel /e:/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration of the vowel /e:/ in Kannada" was accepted. However there were statistically significant differences between females of group 1 and group 2 and also between females of group 2 and group 3. In both cases, females of group 2 showed a shorter word duration than groups 1 and 3. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and between group 2 and 3 in terms of the word duration with the vowel /e:/ in Kannada" was rejected.

The statistical analysis across gender revealed that there were significant differences between males and females for word duration with vowel /e:/ in all the three groups. Females had longer duration of /e:/ in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for word duration of /e:/ in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /a/: On examination of Table 4.15, the mean word duration of vowel /a/ in males of group 1 was 371.5 msec and the SD and range were 56.85 and 294 msec respectively. In females of group 1 the mean, SD and range were 407.5 msec, 69.37, and 456msec respectively. In group 2 males the mean was 293 msec, SD was 44.24 and the range was 325 msec . The mean, SD and range for females of group 2 were 356 msec, 50.1, and 254 msec respectively. Males of group 3 had a mean of 339.5 msec, SD of

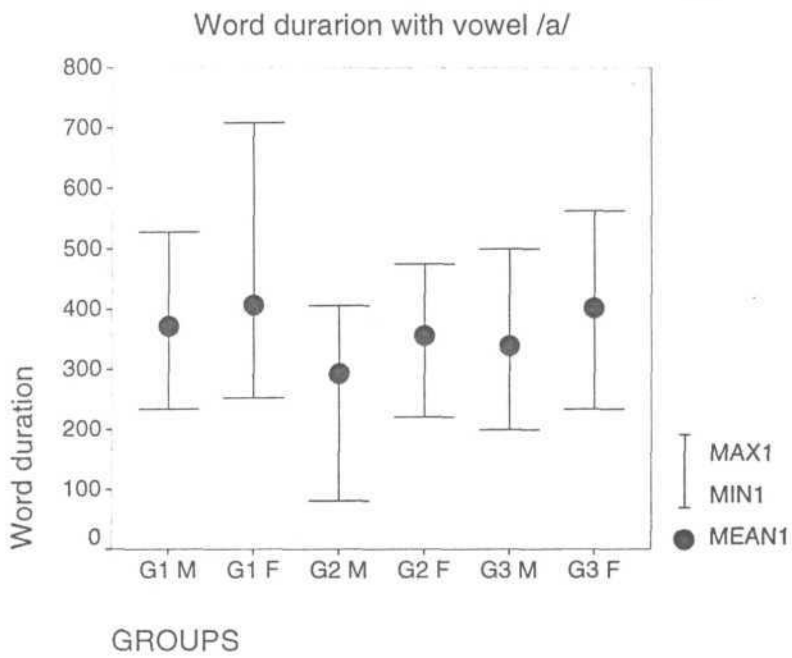
59.19 and range of 300 msec and for females of group 3 they were 402.6 msec, 74.41 and 329 msec respectively.

Table 4.15 and Graph 15 depicted that in both males and females word duration decreased from group 1 to group 3 and then to group 2 for the vowel /a/. In both males and females SD was highest in group 3 followed by group 1 and group 2. The range of word duration in males was highest in group 2 and then in group 3 and group 1 respectively. In females it was highest in group land then in group 3 and group 2 respectively.

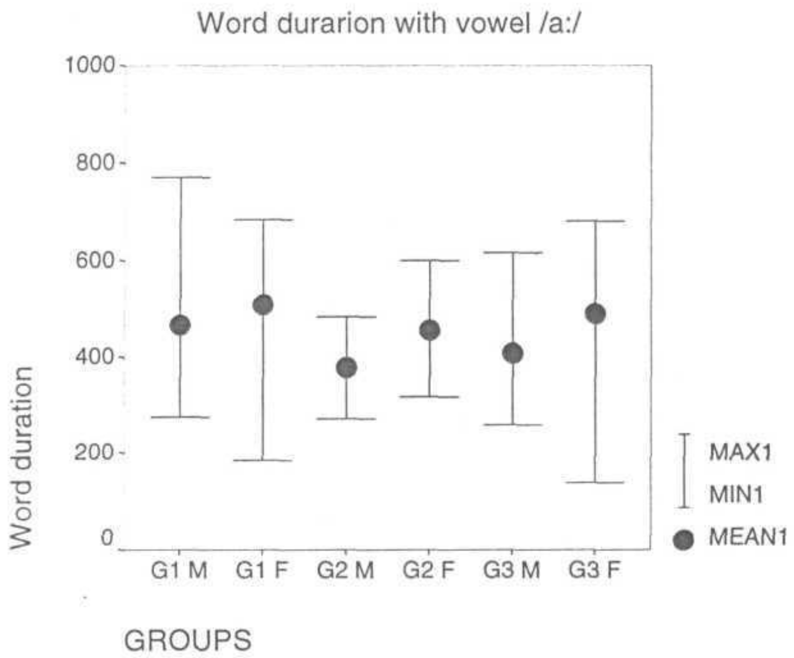
		/a/		/a:/	
		M	F	M	F
Group 1	Mean	371.5	407.5	467	508.5
	SD	56.85	69.37	59.5	75.5
	Range	294	456	496	500
Group 2	Mean	293	356	379	456.3
	SD	44.24	50.1	46.37	54.5
	Range	325	254	213	282
Group 3	Mean	339.5	402.6	408.3	490.4
	SD	59.19	74.41	68.2	90.7
	Range	300	329	357	543

Table 4.15: Mean, SD and Range of word duration with central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

The results of comparisons across males of different groups showed that males of group 1 had significantly longer word duration than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration of the vowel /a/ in Kannada" was rejected. Also when group 2 was compared with group 3, group 3 males



Graph 15



Graph 16

had significantly longer word duration. So the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration of the vowel /a/ in Kannada" was rejected.

On comparisons using ANOVA in case of females showed that there was no significant difference between group 1 and group 3. Hence the hypothesis that "there is no significant difference between females of groups 1 and 3 in terms of the word duration of the vowel /a/ in Kannada" was accepted. There were significant differences between females of groups 1 and 2 and between groups 2 and 3. Group 2 had shorter word duration in both comparisons.' Hence the hypothesis that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of the word duration of the vowel /a/ in Kannada" was rejected.

When the males and females of group 1, group 2 and group 3 were compared, word duration was significantly longer in females of all the three groups. Hence the hypothesis that "there are no significant differences between males and females with word duration of /a/ in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel */a:/:* It was seen from Table 4.15 that the mean word duration of vowel /a:/ in males of group 1 was 467 msec and the SD and range were 59.5 and 496msec and in females they were 508.5 msec, 75.5, and 500 msec respectively. Males of group 2 had a mean of 379 msec, SD of 46.37 and a range of 213 msec . The mean, SD and range for females of group 2 were 456.3 msec, 54.5, and 282 msec respectively. In group 3 the mean, SD and range for males were 408.3 msec, 68.2, and 357 msec and for females they were 490.4 msec, 90.7, and 543 msec respectively.

The study of Table 4.15 and Graph 16 depicted that both males and females had the values of word duration which decreased from group 1 to group 3 and further to group 2. It was found that the SD was highest in group 3 and least in group 2 with group 1 falling in between. The range of word duration for the vowel /a:/ in males decreased from group 1 to group 3 and then to group 2. In females, the values of range was highest in group 3 then decreased to group 1 and then to group 2 .

On comparing the male groups using one way ANOVA, it was noticed that males of group 1 had significantly longer word duration for /a:/ than males of group 2 and group 3. Hence the hypothesis that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration of the vowel /a:/ in Kannada" was rejected. On comparison between groups 2 and 3 there was significant difference in word duration with group 3 having a longer word duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration of the vowel /a:/ in Kannada" was rejected.

In case of female groups using ANOVA it was found that there was no significant difference between females of group 1 and group 3 for the word duration with vowel /a:/. Thus the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration with vowel /a:/ in Kannada" was accepted. But there were significant differences between females of groups 1 and 2 and groups 2 and 3 with group 2 having a shorter word duration in both instances. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of word duration of the vowel /a:/ in Kannada" was rejected.

When males and females of group 1, group 2 and group 3 were compared, word duration with vowel /a:/ was significantly longer in females than in males in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for word duration for /a:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

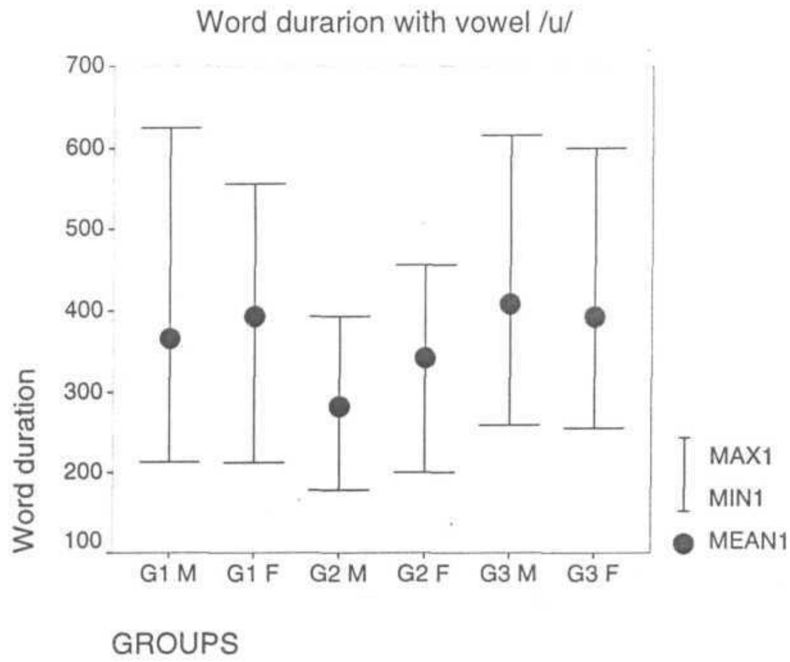
Vowel /u/: Table 4.16 showed that the mean word duration with the vowel *Ixxl* in males of group 1 was 365.6 msec and the SD and range were 67.57 and 412 msec and the mean, SD and range for females of group 1 were 392.9 msec, 68.5, and 344 msec respectively. In group 2 males had the mean, SD and range as 282.1 msec, 44.87, and 215 msec and for females they were 341.5 msec, 56.5, and 256 msec respectively. In males of group 3 the mean, SD and range were 332.8 msec, 60.9, and 300 msec respectively. The mean, SD and range for females of group 3 were 392 msec, 71.2, and 345 msec respectively.

		/u/		/u:/		/o/		/o:/	
		M	F	M	F	M	F	M	F
Group I	Mean	365.6	392.9	434.5	509.5	409.5	439.2	420.2	484.4
	SD	67.57	68.5	65.5	69.2	61.6	48.5	66.73	65.44
	Range	412	344	341	522	295	228	398	315
Group 2	Mean	282.1	341.5	338.5	421	307.7	385.3	351.1	430.7
	SD	44.87	56.5	42.5	53.2	31.4	53.7	43.32	52.87
	Range	215	256	197	271	134	206	225	244
Group 3	Mean	332.8	392	433.2	501.1	367.2	434.4	398.3	477.5
	SD	60.9	71.2	61.9	83.9	57.0	70.9	70.7	91.2
	Range	300	345	285	328	381	294	359	374

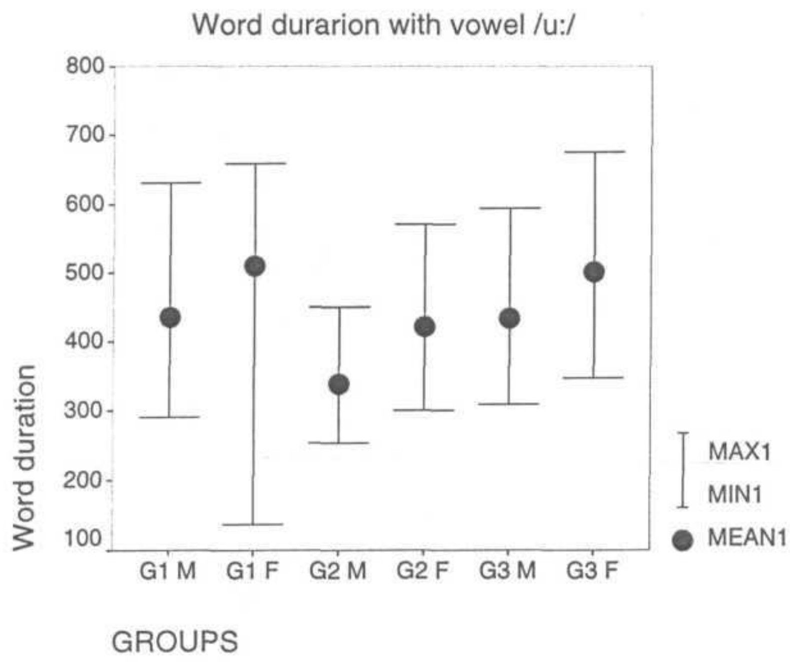
Table 4.16: Mean , SD and Range of word duration (in msec) with back vowels for males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

Table 4.16 and Graph 17 depicted that both males and females had a decrease in word duration from group 1 to group 3 and then to group 2. In males SD and range decreased from group 1 to group 3 and then to group 2. In females, SD and range decreased from group 3 to group 1 and then to group 2.

Using one way ANOVA across the three groups of males, it was seen that, group 1 males had significantly longer vowel duration for /u/ than group 2 and group 3 males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration with the vowel /u/ in Kannada" was rejected. When group 2 males were compared with group 3 males it was found that group 3 had significantly longer word duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration with the vowel /u/ in Kannada" was rejected.



Graph 17



Graph 18

In case of females comparisons across the three groups disclosed that there was no significant difference between group 1 and 3 for word duration of vowel /u/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration with the vowel /u/ in Kannada" was accepted. There were significant differences between groups 1 and 2 and groups 2 and 3 with group 2 having shorter word duration. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of the duration of the word duration with vowel /u/ in Kannada" was rejected.

On comparison across sex in each group showed that there was significant difference between males and females for word duration with vowel /u/ in all the three groups with females having longer word duration. Hence the hypothesis stating that "there are no significant differences between males and females for word duration with /u/ in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /u;/ Table 4.16 showed that the mean word duration with long vowel /u:/ in males of group 1 was 434.5 msec and the SD and range were 65.5 and 341 msec respectively. Similarly the mean, SD and range for females of group 1 were 509.5 msec, 69.2 and 522 msec respectively. Group 2 males showed a mean of 338.5 msec, SD of 42.5 and range of 197msec. The mean, SD and range for females of group 2 were 421msec, 53.2, and 271 msec respectively. The mean, SD and range for males of group 3 were 433.2 msec, 61.9, and 285 msec and for females of group 3 they were 501.1msec, 83.9, and 328 msec respectively.

It was evident from Table 4.16 and Graph 17 that in both males and females word duration decreased from group 1 to group 3 and then to group 2. It was found that SD decreased from group 1 to group 3 and then to group 2 in males. In females, SD reduced from group 3 to group 1 and to group 2. The range of word duration for /u:/ was highest in group 1 decreasing to group 3 and then to group 2 in both males and females.

Using ANOVA, in case of males comparison between group 1 and 3 indicated that there was no significant difference for word duration with vowel /u:/. Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 3 in terms of the word duration with vowel /u:/ in Kannada" was accepted. But there were significant differences between males of groups 1 and 2 and groups 2 and 3. Group 2 males had shorter word duration than groups 1 and 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 2 and 3 in terms of word duration with the vowel /u:/ in Kannada" was rejected.

When comparisons were made across the females of different groups it was found that there was no significant difference between females of group 1 and 3 for word duration with vowel /u:/. Therefore the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration with the vowel /u:/ in Kannada" was accepted. When groups 1 and 2 and groups 2 and 3 were compared, females of group 2 were found to have significantly shorter word duration than groups 1 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of the word duration with the vowel /u:/ in Kannada" was rejected.

Results of comparisons between males and females of each group showed that in all the three groups females had significantly longer word duration with vowel /u:/. Hence the hypothesis stating that "there are no significant differences between males and females for word duration with /u:/ in group 1, group 2 and group 3 in Kannada" was rejected.

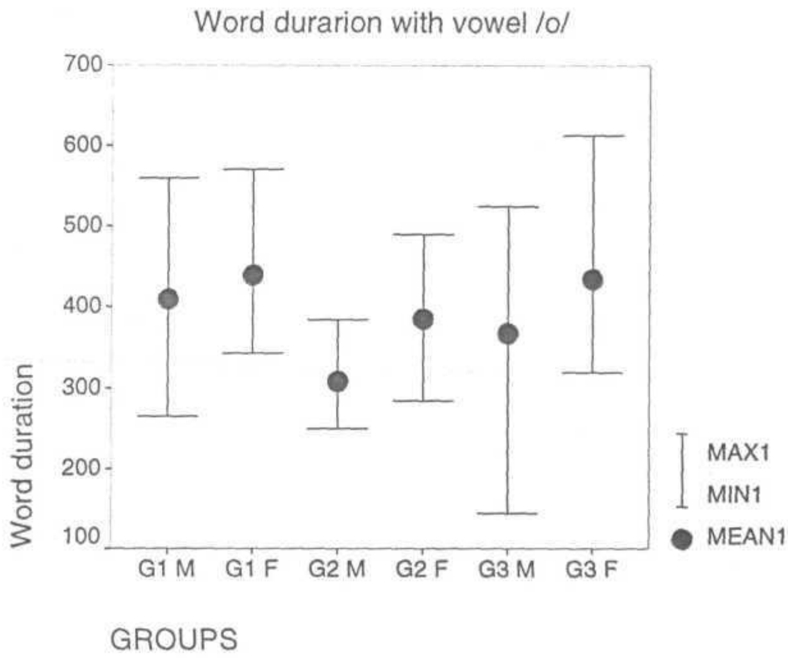
Vowel *lol:* Table 4.16 showed that the mean word duration with the vowel *lol* in males of group 1 was 409.5msec and the SD and range were 61.6 and 295msec respectively. Similarly the mean, SD and range for females of group 1 were 439.2msec, 48.5, and 228msec respectively. In males of group 2, the mean, SD and range were 307.7msec, 31.4, and 134msec and in females of group 2 they were 385.3msec, 53.7, and 206msec respectively. In group 3 the mean, SD and range for males were 367.2msec, 57.0, and 381msec respectively. The mean, SD and range for females of group 3 were 434.4msec, 70.9 and 294msec respectively.

It was evident from Table 4.16 and Graph 19 that both males and females had the values which decreased from group 1 to group 3 and then to group 2. It was found that the SD also decreased from group 1 to group 3 and then to group 2. In females, SD reduced from group 3 to group 1 and group 2 had an intermediate value. The range of word duration with vowel *lol* was highest for group 3 followed by group 1 and by group 2 in males and females.

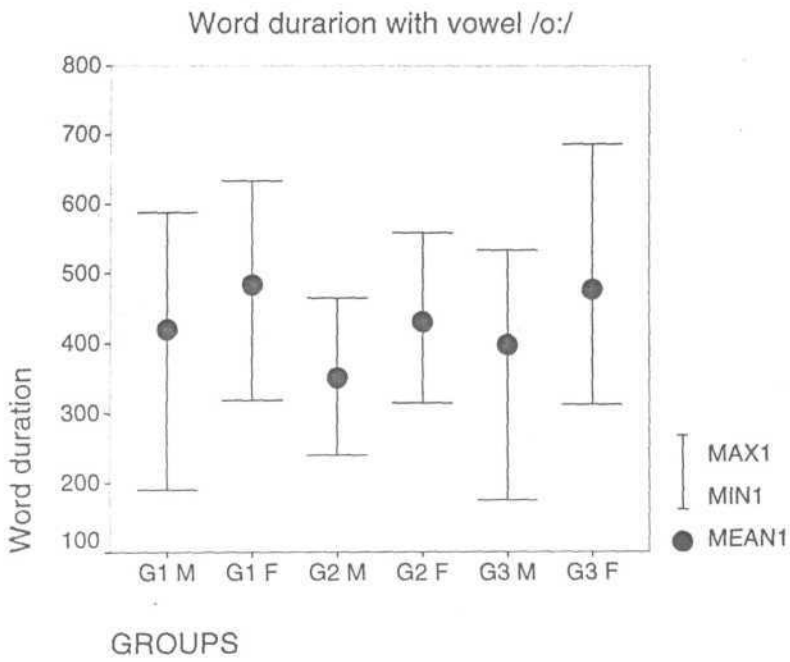
On comparison across males of different groups showed that males of group 1 had significantly longer word duration for /o/ than males of group 2 and group 3 males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration with the vowel /o/ in Kannada" was rejected. When group 2 males were compared with group 3 males, the latter group had longer word duration. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration with the vowel /o/ in Kannada" was rejected.

There were significant differences in terms of word duration between females of groups 1 and 2 and groups 1 and 3 with longer word duration for group 1. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of the word duration with the vowel /o/ in Kannada" was rejected. Further there was significant difference between females of groups 2 and 3 with group 3 showing longer word duration. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of word duration with the vowel /o/ in Kannada" was rejected.

When males and females were compared, females had significantly longer word duration with vowel /o/ in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for word duration of /o/ in group 1, group 2 and group 3 in Kannada" was rejected.



Graph 19



Graph 20

Vowel /o:/: On scrutiny of Table 4.6 and Graph 20 it was observed that the mean word duration with vowel /o:/ in males of group 1 was 420.2 msec and the SD and range were 66.73 and 398 msec respectively. In group 1 females the mean, SD and range were 484.4 msec, 65.44, and 315 msec respectively. Group 2 males had a mean of 351.1 msec, SD of 43.32 and range of 225 msec .The mean, SD and range for females of group 2 were 430.7 msec, 52.87 and 244 msec respectively. The mean, SD and range for males of group 3 were 398.3 msec, 70.7, and 359 msec and for females they were 477.5 sec, 91.2 and 374 msec respectively.

It was seen from Table 4.16 and Graph 20 that in both males and females word duration decreased from group 1 to group 3 and then to group 2 for vowel */o:/.* For both males and females SD was least in group 2, followed by group 1 and group 3. In males the range of word duration for the vowel /o:/ decreased from group 1 to group 3 followed by group 2. In females the range decreased from group 3 to group 1 and to group 2 respectively.

When the three groups of males were compared using one way ANOVA, it was found that males of group 1 had significantly longer word duration with vowel /o:/ than males of group 2 and group 3 . Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of the word duration for the vowel /o:/ in Kannada" was rejected. On comparison between males of groups 2 and 3 it was found that males of group 3 had significantly longer word duration. Thus the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of the word duration for the vowel /o:/ in Kannada" was rejected.

When the female groups were compared with each other it was found that there was no significant difference between group 1 and group 3 for the word duration with the vowel /o:/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the word duration with the vowel /o:/ in Kannada" was accepted. But there were significant differences between females of groups 1 and 2 and groups 2 and 3 with group 2 having shorter word duration than the other groups. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of word duration with the vowel /o:/ in Kannada" was rejected.

Comparison between males and females of each group showed that in group 1, group 2 and group 3, word duration with reference to vowel /o:/ was significantly longer in females. Therefore the hypothesis stating that "there are no significant differences between males and females for word duration of /o:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

Tables 4.17 and 4.18 show the presence or absence of significant difference in word duration between the different age groups.

Males	*IV*	**/I:/**	*/e/*	/e:/	**/a/**	/a:/	**/u/**	**/u:/**	*/o/*	**/o:/**	**Total**
Gl vs G2	P	P	P	P	P	P	P	P	**P**	**P**	10/10
Gl vs G3	P	P	P	P	P	P	P	A	**P**	**P**	9/10
G2 vs G3	P	P	P	P	P	P	P	P	**P**	**P**	10/10

Table 4.17 : The results of test for significance of difference between the three age groups in case of males for word duration at 0.05 level

Females	*/i/*	**/I:/**	/e/	/e:/	/a/	/a:/	/u/	/u:/	*/o/*	/o:/	Total
Gl vs G2	**P**	**P**	P	P	P	P	P	P	P	P	10/10
Gl vs G3	**A**	**A**	P	A	A	A	A	A	P	A	2/10
G2 vs G3	**P**	**P**	P	P	P	P	P	P	P	P	10/10

Table 4.18: The results of test for significance of difference between the three age groups in case of females for word duration at 0.05 level

Inspection of Tables 4.17 and 4.18 depicted that there were significant differences between males and females in terms of word duration for the three groups. Children had longer word duration than adolescents and adults. However in females, the difference between children and adolescent groups was more prominent than between children and adults. The results also showed that adults had significantly longer word duration than adolescents in both males and females. This may be attributed to the fact that the rate of speech was not controlled during data collection as the subjects were asked to read as normally as possible.

On scaling of word duration it was observed that in case of males, group 1 had longer word duration than group 2 and 3 by 20% and 9% respectively. Group 3 males had longer word duration than group 2 by 13%. Similarly in females, group 1 had longer word duration than groups 2 and 3 by 13% and 2% respectively. However group 3 females had longer word duration than group 2 by 11% (Table 4.19).

	Group 1 / Group 3		Group 1 / Group 2		Group 2 / Group 3	
	M	F	M	F	M	F
Word duration	9%	2%	20%	13%	-13 %	-11%

Table 4.19 : Percentage by which group 1 is greater than groups 2 & 3 and by which group 2 is greater than group 3 for word duration

However from the measurements of duration of Kannada words obtained from males and females it can be concluded that duration of Kannada words decreased markedly from childhood (Group 1) to adolescence (Group 2) after which there was a slight increase in the adulthood (Group 3). It was seen that the variability and range of word duration also decreased with increase in age. Hence a developmental trend was seen in terms of r word duration in both males and females with reference to Kannada words studied in the present investigation.

Mvs F	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	lu:l	/o/	/o:/	Total
Gl	A	P	P.	P	P	P	P	P	p	p	9/10
G2	P	P	P	P	P	P	P	P	p	p	10/10
G3	P	P	P	P	P	P	P	P	p	p	10/10

Table 4.20: The results of test for significance of difference between males and females for word duration at 0.05 level

It was clear from Table 4.20 that there was significant difference in word duration across gender for all the three groups. Females had longer word duration in all the three age groups. On scaling of word duration it was observed that in groups 1, 2 and 3 females had longer word duration than males by 9% ,17% and 15% respectively (Table 4.21). Table 4.22 gives the word duration with all ten vowels for the three age groups in Kannada.

	Group 1	Group 2	Group 3
Word duration	**9%**	17%	15%

Table 4.21: Female/male word duration percentage in different groups

Vowels	Group 1		Group 2		Group 3	
	M	F	M	F	M	F
a	372	408	293	356	340	403
a:	**467**	509	379	456	408	490
i	376	394	285	346	348	404
I:	427	476	420	306	396	458
u	365	393	282	342	333	392
u:	435	510	339	**421**	433	501
e	381	416	306	363	333	388
e:	444	496	360	420	420	491
0	410	439	308	385	367	434
o:	420	484	351	431	398	478

Table 4.22 : Word duration in the three age groups in Kannada

On examination of Table 4.22, the results on word duration can be summarized as:

a) On the whole it was observed that among the five short vowels considered in the study, word duration with vowel /u/ was the shortest in both males and females of groups 1 and 2 and with vowel *Id* in group 3.

b) Similarly word duration with vowel /o/ was the longest in both males and females of all the three groups.

c) Among the five long vowels there was no consistent pattern seen for the shortest long vowel. But vowel /a:/ was the longest in both males and females for all the three groups consistently.

The above results are in support of several earlier studies. Smith (1978) examined several temporal parameters in two year olds, four year olds and adults. He reported that average word duration was greatest for two years old with word duration 31% longer than for adults and for four year olds it was 15% longer than adults. Also the youngest age group had the greatest variability as in the present study. Kent and Forner (1980) obtained similar results from groups of four year olds, six year olds, 12 year olds and adults. Several other acoustic studies have also observed that children's speech segments, syllables and words tend to decrease in duration and also become less variable from younger to older groups of subjects (Chermak and Schneiderman, 1986; Kent & Forner, 1980; Smith 1978, 1992, 1994; Smith et al 1983; Tingley & Allen 1975). Kent & Forner (1980) and Smith et al (1983) opine that although both duration and variability have commonly been observed to continue to decrease until as late as 10-12 years of age before reaching adult like levels, the basis of such changes is not clear. They are typically assumed to be due to 'neuromuscular maturation' and greater experience with the process of speech production or to a combination of both maturation and experience. Smith, Sugarman and Lang (1983) found that children ranging from five to nine years of age exhibited sentence duration that were 36% greater than those of adults when both groups were speaking at fast rates. Robb, & Tyler (1995) examined the duration of word and non word forms in the monthly vocalizations of seven children between 8 and 26 months of age. The results were that word duration significantly decreased as a function of increasing chronological age. Elizabeth (1998) has also reported longer word duration in children aged 7-8 years than in adults and also females in both age groups were found to have a longer word duration in Malayalam. Venkatesh (1995) found that adult females had significantly longer word duration than adult males in Kannada. Rathna Kumar (1998) also reported longer word duration in girls aged between 7-11 years than compared to the boys.

Based on the results of this part of the study on word duration it was concluded as:

a) Word duration decreased from child to adult in both males and females.

b) The variability and range also decreased with increase in age. However the mean value of word duration, standard deviation and range were less than adults in the adolescent group.

c) Females had longer word duration in all the three groups.

2.a Formant frequency 1

The formant frequency was defined as the well marked spectral peak which represents concentration of energy at the mid point of the test vowel. First three of them are identified as Fl, F2 and F3. In the test word /$C_1V_1C_2V_2$/, V_1 was the test vowel. The results are presented in the following order of i, i:, e, e: (front vowels), a, a: (central vowels) and u, u:, o, o: (back vowels).

Vowel /i/: Inspection of Table 4.23 showed that the mean Fl of vowel /i/in males of group 1 was 464 Hz and the SD and range were 65.9 and 320 Hz respectively. The mean, SD and range for females of group 1 were 424 Hz, 49.5 and 240 Hz respectively. The mean, SD and range for males of group 2 were 387 Hz, 45.2, and 240Hz respectively. The mean, SD and range for females of group 2 were 401 Hz, 51.7 and 240 Hz respectively. The mean, SD and range for males of group 3 were 375 Hz, 54.1 and 282 Hz respectively. The mean, SD and range for males of group 3 were 423 Hz, 71.3 and 235 respectively.

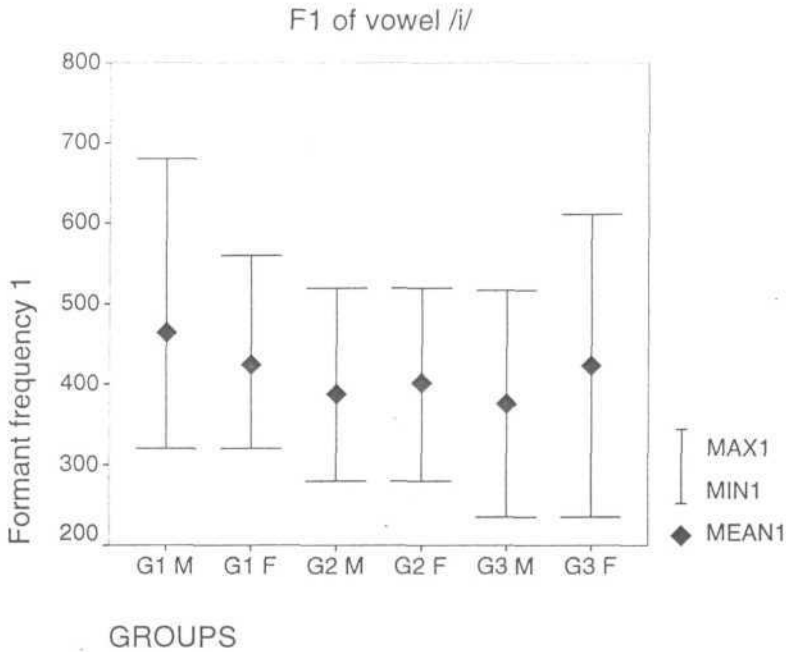
From Table 4.23 and Graph 21, it was seen that both males and females showed the values of Fl which decreased from group 1 to group 3. But in females, group 3 had a higher Fl than group 2. It was found that the SD also decreased with age in males but it was higher in group 3 than in group 2. SD reduced from group 3 to group 1 in females with group 2 having an intermediate value. The range of Fl for the vowel /i/ in males was highest in group 1 and then in group 3 and group 2 respectively. In females the range was same in group 1 and 2. Females of group 3 had a reduced range than the females of other two groups.

		/i/		/i:/		/e/		/e:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	464	424	447	412	510	508.7	492	466
	SD	65.9	49.5	69.3	47.9	77.9	77.9	64.5	50
	Range	320	240	354	200	354 .	320	330	320
Group 2	Mean	387	401	369	383	463	523	401	447
	SD	45.2	51.7	41.7	45.7	80.2	87.2	45.6	48.2
	Range	240	240	200	200	360	440	200	280
Group 3	Mean	375	423	344	393	509	531	424	447
	SD	54.1	71.3	50.1	68.5	90.4	86.7	49.7	69.9
	Range	282	235	259	235	502	376	314	282

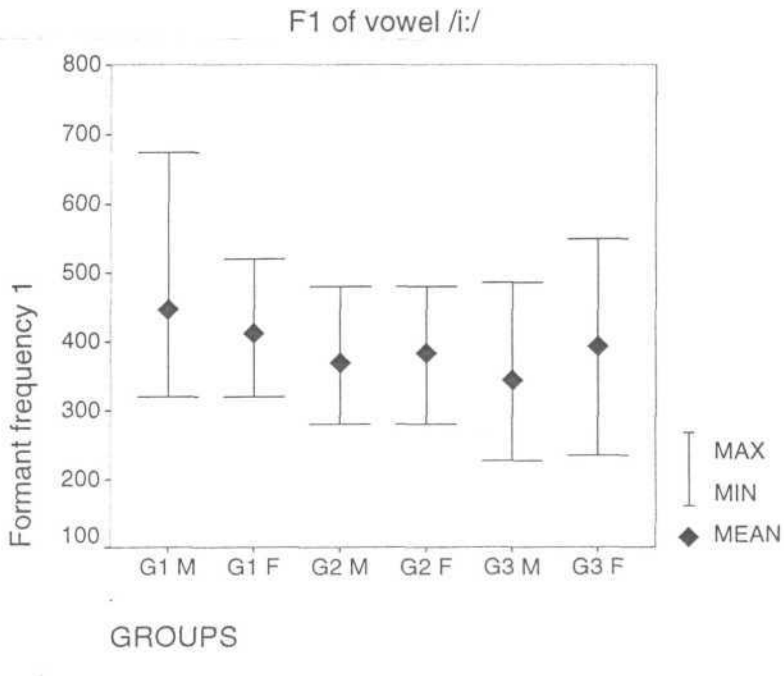
Table 4.23: Mean, SD and Range of Fl for front vowels of males and females in 7-8 yrs (Group 1) , 14-15 yrs (Group 2) and adults (Group 3)

The results of one way ANOVA showed that males of group 1 had significantly higher Fl than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of Fl of the vowel /i/ in Kannada" was rejected. When males of group 2 were compared with males of group 3 there was no significant difference in Fl of the vowel *HI*. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of Fl of the vowel *HI* in Kannada" was accepted.

It was found from the statistical analysis that there was no significant difference between the females of groups 1 and 3 and groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 and 2 and 3 in terms of Fl of the vowel /i/ in Kannada" was accepted. But there was significant



Graph 21



Graph 22

difference between females of group 1 and 2 with females of group 1 showing higher Fl. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of Fl of the vowel /i/ in Kannada" was rejected.

When the males and females of group 1 were compared Fl was significantly higher in males. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of /i/ in group 1 in Kannada" was rejected. In group 2 and group 3, Fl of vowel /i/ was significantly higher in females compared to males. Hence the hypothesis stating that "there are no significant differences between males and females for Fl of /i/ in group 2 and group 3 in Kannada" was rejected.

Vowel /I:/: On examination of Table 4.23 it was found that the mean Fl of vowel /I:/ in males of group 1 was 447 Hz and the SD and range were 69.3 and 354 Hz respectively and for females they were 412 Hz, 47.9 and 200 Hz respectively. The mean, SD and range for males of group 2 were 369 Hz, 41.7, and 200Hz respectively. The mean, SD **and** range for females of group 2 were 383 Hz, 45.7 and 200 Hz respectively. In males of group 3 the mean, SD and range were 344 Hz, 50.1 and 259 Hz respectively and the mean, SD and range for females of group 3 were 393 Hz, 68.5 and 235 respectively.

It can be deduced from Table 4.23 and Graph 22 that both males and females showed the values of Fl for /i:/ which decreased from group 1 to group 3. However in females, group 3 had a higher Fl than group 2. It was found that the SD also decreased with increase in age in males but it was higher in group 3 than in group 2. SD was less in group 3 than in group 2 and in group 2 than in group 1. The range of Fl for the vowel /I:/ in males was largest in group 1 and then in group 3 and group 2 . In females the range was same in both group 1 and 2. Females of group 3 had a higher range than the other two groups.

The results of one way ANOVA in case of males showed that males of group 1 males showed significantly higher Fl for /I:/ than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of Fl of the vowel /I:/ in Kannada" was rejected. When group 2 males were compared with group 3 males there was significant difference in the Fl of vowel/I:/ with group 3 having a lower Fl. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of Fl of the vowel /I:/ in Kannada" was rejected.

It was found from the statistical analysis that there was no significant difference between females of group 1 and 3 for Fl of vowel /I:/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of the Fl of vowel /I:/ in Kannada" was accepted. But there was significant difference between females of groups 1 and 2 and groups 2 and 3. In both cases group 2 showed a lower Fl than group 1 and 3. Hence the hypothesis stating that "there are no significant difference between females of groups 1 and 2 and groups 2 and 3 in terms of Fl of the vowel /I:/ in Kannada" was rejected.

When males and females of group 1, group 2 and group 3 were compared it was found that duration of vowel /I:/ was significantly longer in females. Hence the hypothesis stating "that there is no significant difference between males and females for vowel duration of /I:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

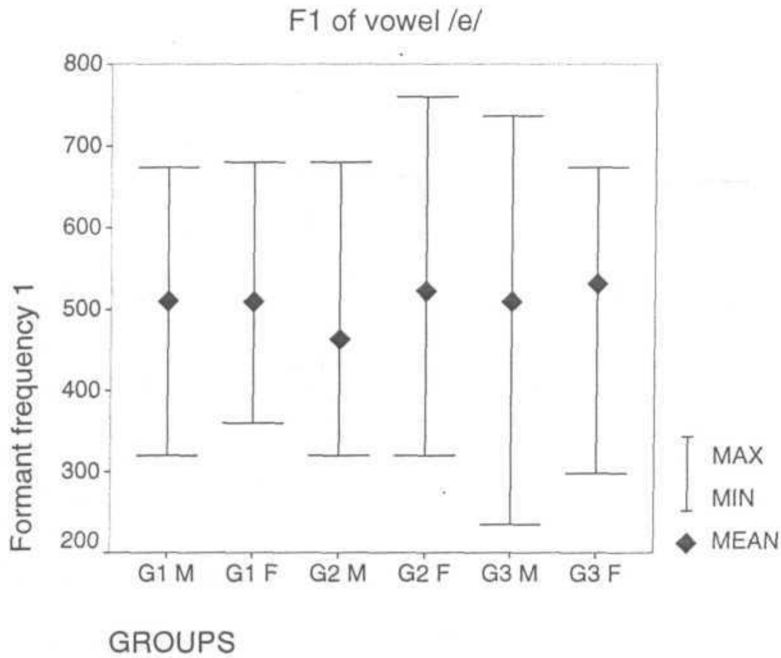
Vowel *Id:* On examination of Table 4.23, the mean Fl of vowel /e/ in males of group 1 was 510 Hz and the SD and range were 77.9 and 354 Hz respectively. The mean, SD and range for females of group 1 were 509 Hz, 77.9 and 320 Hz respectively. Males of group 2 had a mean of 463 Hz, SD of 80.2 and range of 360Hz . The mean, SD and range for females of group 2 were 523 Hz, 87.2 and 440 Hz respectively. In group 3 the mean, SD and range for males were 509 Hz, 90.4 and 502 Hz respectively and for females they were 531 Hz, 86.7 and 376 respectively.

From Table 4.23 and Graph 23, it can be seen that males showed the values of Fl for /e/ which was less in group 2 than in group 3 and in group 3 than in group 1. In females, group 3 had the highest Fl followed by group 2 and group 1 respectively. It was found that the SD also increased with age in males. In females, SD was highest in group 2 followed by group 3 and group 1 respectively. The range of Fl for the vowel /e/ also increased with age in males. In females the range was highest in group 2 and next **in order were** group 3 and 1.

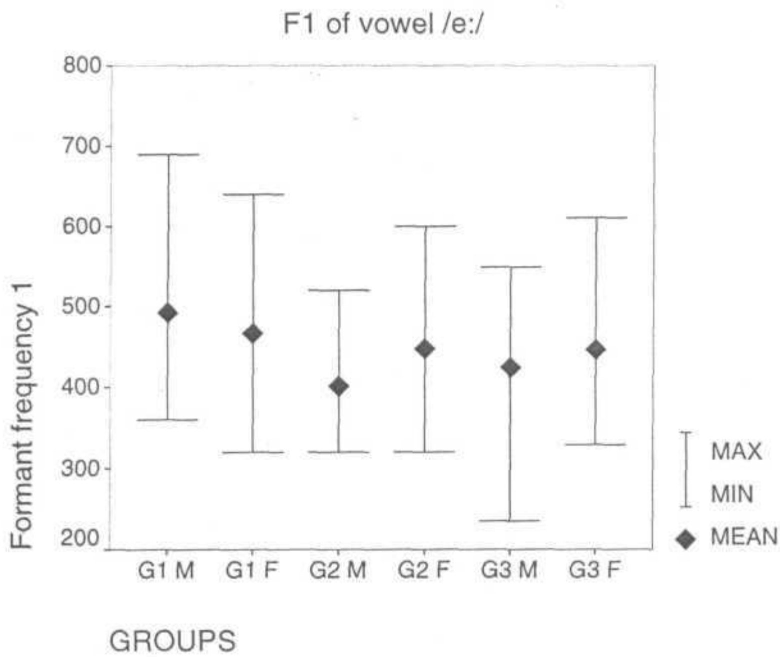
The results of one way ANOVA across the **three** groups on males showed that there was no significant difference for Fl of vowel /e/ between males of group 1 and group 3. Therefore the hypothesis stating that "there is no significant difference between males of groups 1 and 3 in terms of the Fl of vowel /e/ in Kannada" was accepted. When males of group 1 were compared with males of group 2 and also between males of group 2 with group 3, there were significant differences in Fl of the vowel /e/ with group 2 showing lower Fl. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 2 and 3 for Fl of the vowel /e/ in Kannada" was rejected.

Similar comparison across the female groups showed that there was significant difference between females of group 1 and group 3 for Fl of vowel *Id.* Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of Fl of the vowel /e/ in Kannada" was rejected. There were no significant differences between groups 1 and 2 and groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 in terms of Fl of the vowel /e/ in Kannada" was accepted.

On comparison across the sex in each group it was found that there was no significant difference between males and females of group 1 and group 3 for Fl of vowel /e/. Thus the hypothesis stating that "there were no significant differences between males and females for Fl of /e/ in group 1 and group 3 in Kannada" were accepted. When the males and females of group 2 were compared, females had significantly higher Fl for vowel /e/ Hence the hypothesis stating that "there is no



Graph 23



Graph 24

significant difference between males and females for Fl of /e/ in group 2 in Kannada" was rejected.

Vowel /e:/: It was observed from Table 4.23 that the mean Fl of vowel /e:/ in males of group 1 was 492 Hz and the SD and range were 64.5 and 330 Hz respectively. Females of group 1 showed a mean of 466 Hz, SD of 50 and range of 320 Hz respectively. The mean, SD and range for males of group 2 were 401 Hz, 45.6 and 200Hz respectively and for females they were 447 Hz, 48.2 and 280 Hz respectively. The mean, SD and range in case of males of group 3 were 424 Hz, 49.7 and 314 Hz respectively. In case of females of group 3 the mean, SD and range were 447 Hz, 69.9 and 282 respectively.

Examination of Table 4.23 and Graph 24 showed that both in case of males and females the mean values of Fl for /e:/ decreased from group 1 to group 3. But group 2 males had a lower Fl than group 3 males. With respect to females Fl was same in group 2 and group 3. It was found that the SD also increased with age in males. But group 2 males had a lower SD than group 3 males. In females, SD was highest in group 3 then in group 1 and in group 2. The range of Fl for the vowel /e:/ also decreased with increase in age in both males and females. In both males and females group 2 showed a lower range than group 3.

Administration of one way ANOVA to the scores revealed that in males there was significant difference for Fl of vowel /e:/ between males of groups 1 and 3 and groups 1 and 2 with group 1 showing a higher Fl than the other groups. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /e:/ in Kannada" was rejected. And there was significant difference between groups 2 and 3 also, with group 3 showing a high Fl. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 for Fl of the vowel /e:/ in Kannada" was rejected.

Statistical analysis across the female groups showed that there was significant difference between females of groups 1 and 3 and females of groups 1 and 2 for Fl of vowel /e:/ with group 1 showed higher Fl than groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 1 and 2 in terms of Fl of the vowel /e:/ in Kannada" was rejected. No significant difference between females of groups 2 and 3 was found on comparison. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of Fl of the vowel /e:/ in Kannada" was accepted.

Statistically there was significant difference between males and females of group 1 with females having a lower Fl. In groups 2 and 3 , females displayed higher Fl than their male counterparts for Fl of the vowel /e:/. Hence the hypothesis stating that "there are no significant differences between males and females for Fl of /e:/ in group 1 , group 2 and group 3 in Kannada" was rejected.

Vowel /a/: On scrutiny of Table 4.24, it can be found that the mean Fl of vowel /a/ in males of group 1 was 788 Hz and the SD and range were 152 and 760 Hz respectively. The mean, SD and range for females of group 1 were 766 Hz, 154.5 and 680 Hz respectively. In case of males of group 2, the mean, SD and range were 698Hz, 95.8 and 460Hz respectively and for females of group 2 they were 714 Hz, 100.2 and 460 Hz respectively. Males of group 3 had a mean of 616 Hz, SD of 98.4 and range of 534 Hz. Females of group 3 had the mean as 733 Hz, SD as 119.6 and range as 627 respectively.

It was evident from Table 4.24 and Graph 25 that in both males and females values of Fl for /a/ which decreased from group 1 to group 3 and then to group 2 . SD and range of Fl for /a/ also decreased with increase in age in males and females. But group 2 had a lower SD than group 3 in both males and females.

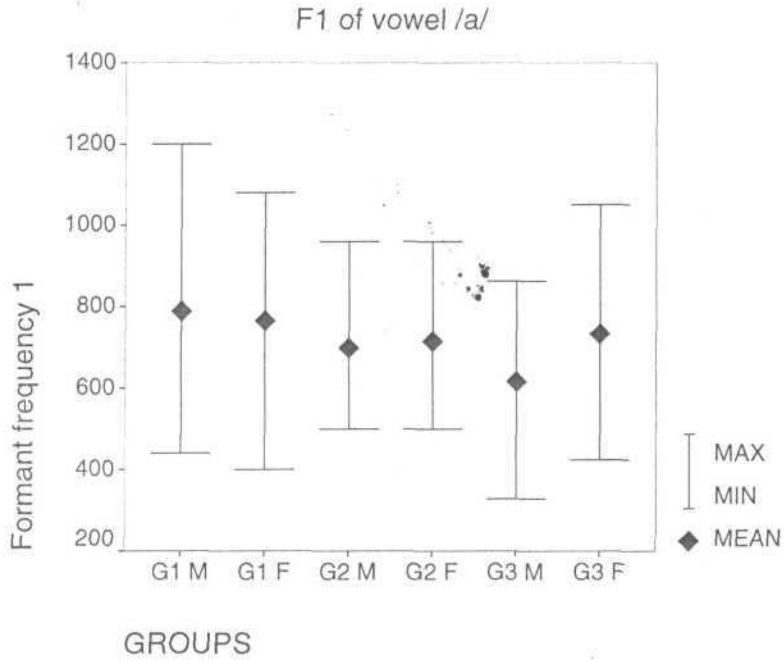
		/a/		/a:/	
		M	F	M	F
Group 1	Mean	788	766	1030	999
	SD	152	154.5	115.3	125.6
	Range	760	680	560	760
Group 2	Mean	698	714	806	895
	SD	95.8	100.2	88.1	88.9
	Range	460	460	480	600
Group 3	Mean	616	733	732	875
	SD	98.4	119.6	74.1	121.9
	Range	534	627	542	674

Table 4.24 : Mean , SD and Range of Fl for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

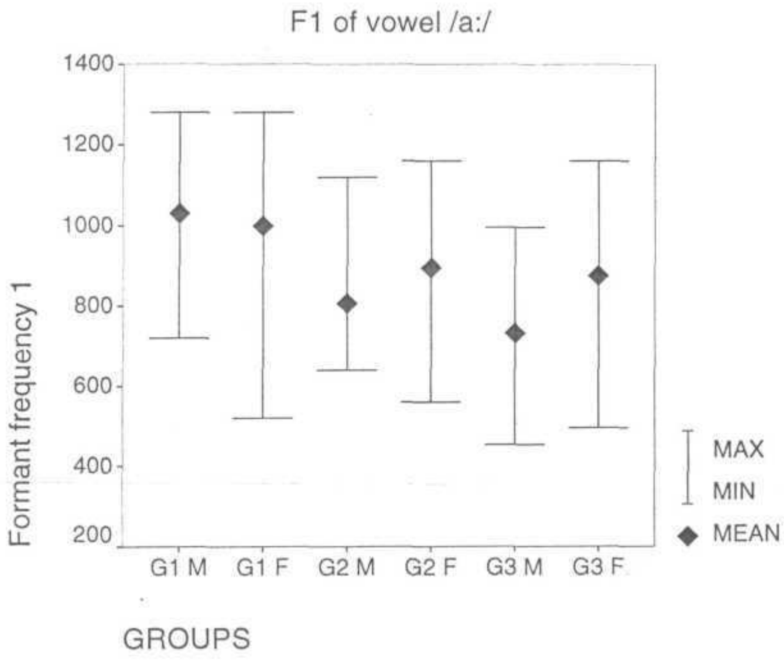
The results of comparison across males of different groups showed that there was significant difference for Fl of vowel /a/ between males of groups 1 and 3 and groups 1 and 2 with group 1 showed higher Fl than the other two groups. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /a/ in Kannada" was rejected. Similarly there was significant difference between males of groups 2 and 3 with group 3 having a lower Fl value. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 for Fl of the vowel /a/ in Kannada" was rejected.

On comparison of different female groups indicated that there was no statistically significant difference between females of group 1 and group 3 for Fl of vowel /a/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of Fl of the vowel /a/ in Kannada" was accepted. Statistically significant differences were found between females of groups 1 and 2 and groups 2 and 3. Females of group 2 showed lower Fl in both comparisons. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 for Fl of the vowel /a/ in Kannada" were rejected.

No statistically significant difference between males and females of group 1 and group 2 for Fl of vowel /a/ were observed. Hence the hypothesis stating that "there are no significant differences between males and females for Fl of /a/ in group 1 and group 2 in Kannada" were accepted. When the males and females of group 3 were compared, females had significantly higher Fl for vowel /a/. Hence the hypothesis stating that



Graph 25



Graph 26

"there is no significant difference between males and females for Fl of /a/ in group 3 in Kannada" was rejected.

Vowel /a:/: On examination of Table 4.24 , it was observed that the mean Fl of vowel /a:/ in males of group 1 was 1030 Hz and the SD and range were 115.3 and 560 Hz respectively. The mean, SD and range for females of group 1 were 999 Hz, 125.6 and 760 Hz respectively. The males of group 2 had 806Hz, 88.1 and 480Hz as mean, SD and range respectively. In case of females of group 2 the mean, SD and range were 895 Hz, 88.9 and 600 Hz respectively. The males of group 3 had a mean Fl of 732 Hz, SD of 74.1 and range of 542 Hz where as in females of group 3 the mean, SD and range were 875 Hz, 121.9 and 674 Hz respectively.

It was evident from Table 4.24 and Graph 26 that both males and females had the values of Fl for /a:/ which decreased from group 1 to group 3 linearly. SD also decreased with increase in age in males and females. But in females, group 2 had a lower SD than group 3. The range of Fl for the vowel /a:/ also decreased with increase in age in males and females . But group 2 showed a lower range than group 3 in both males and females.

In case of males it was seen that there was significant difference for Fl of vowel /a:/ between males of groups 1 and 3 and groups 1 and 2. Group 1 had higher Fl than the other groups. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /a:/ in Kannada" was rejected. Statistically significant difference was present between groups

2 and 3 with group 2 showing a high Fl. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 for Fl of the vowel /a:/ in Kannada" was rejected.

With reference to female groups it was noticed that there was no significant difference between females of groups 1 and 3 , groups 1 and 2 and between groups 2 and 3 for Fl of vowel /a:/. Hence the hypothesis stating that "there are no significant difference between females of groups 1 and 3, groups 1 and 2 and between groups 2 and 3 in terms of Fl of the vowel /a: / in Kannada" was rejected.

Statistically significant difference was noticed between males and females of group 1 , group 2 and group 3 for Fl of vowel *fa:/.* In group 1, males had a higher Fl where as in groups 2 and 3 females showed a higher Fl for vowel /a:/. Hence the hypothesis stating that "there are no significant difference between males **and** females for Fl of/a:/ in group 1, group 2 and group 3 **in** Kannada" was rejected.

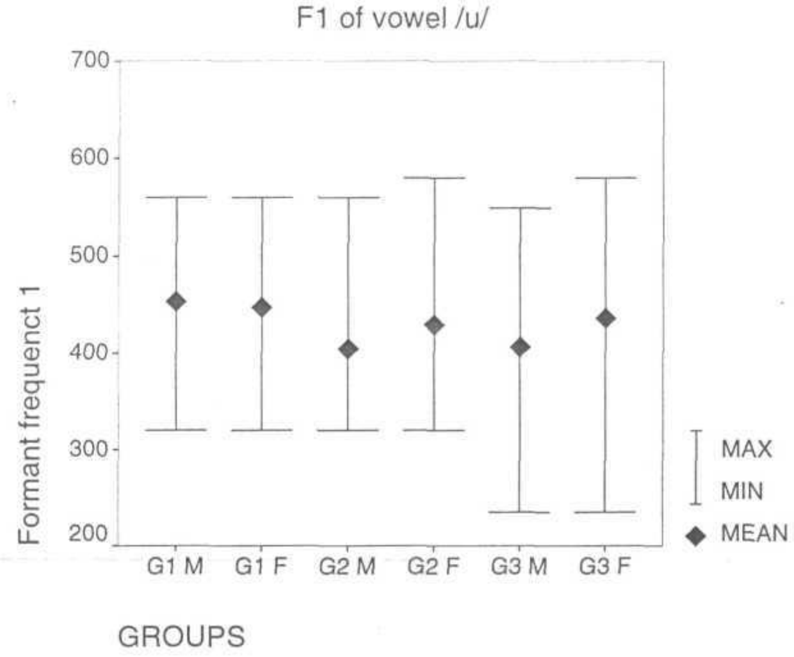
Vowel /u/*:* Table 4.25, revealed that the mean Fl of vowel /u/ in males of group 1 was 453 Hz and the SD and range were 48.3 and 240 Hz respectively and for range for females they were 477 Hz, 53.1 and 240 Hz respectively. Males of group 2 had the mean, SD and range as 404Hz, 47.7 and 240Hz respectively. The mean, SD and range for females of group 2 were 429 Hz, 55 and 260 Hz respectively. Males of group 3 had a mean of 406 Hz, SD of 59.2 and range of 314 Hz and for females of group 3 they were 436 Hz, 66.9 and 345 respectively.

From Table 4.25 and Graph 27, it was evident that both males and females had the values of Fl for /u/ decreasing from group 1 to group 3 and then to group 2. SD also decreased from group 1 to group 3 and then to group 2 in males. The range of Fl for the vowel *IvJ* in males was highest for group 3. Males of groups 1 and 2 had equal range. In females SD and range increased with increase in age.

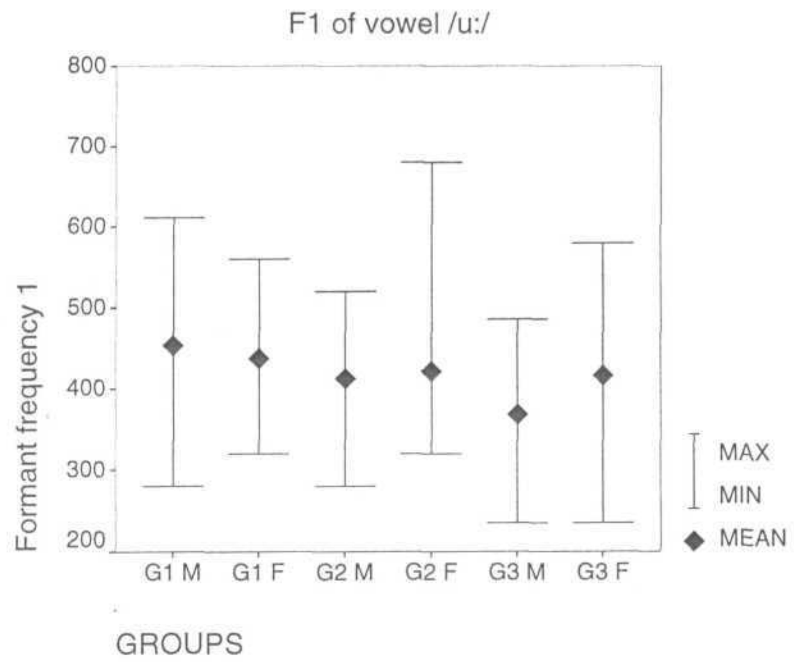
		/u/		/u:/		/o/		/o:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	453	477	453	473	501.1	496	499	476
	SD	48.3	53.1	59.2	52.5	78	57.7	57.8	51.5
	Range	240	240	331	240	360	280	320	320
Group 2	Mean	404	429	412	421	477	507	455	480
	SD	47.7	55	52	56.9	60.4	61.4	63.7	60.5
	Range	240	260	240	360	280	320	320	400
Group 3	Mean	406	436	368	416	495	561	445	463
	SD	59.2	66.9	63.4	65.5	48.3	59.3	54.2	78.1
	Range	314	345	251	345	251	235	294	439

Table 4.25: Mean, SD and Range of Fl for back vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

On comparison across males of different groups using one way ANOVA, it was seen that there was statistically significant difference for Fl of vowel *IvJ* between males of groups 1 and 3 and groups 1 and 2. Males of group 1 showed a higher Fl than groups 2 and 3. Therefore the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /u/ in Kannada" was rejected. There was no significant difference between groups 2 and 3. Hence the hypothesis stating that "there is no significant difference



Graph 27



Graph 28

between males of group 2 and group 3 for Fl of the vowel /u/ in Kannada" was accepted.

Among the different female groups, there was no significant difference between groups 1 and 3 and groups 2 and 3 for Fl of vowel /u/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 in terms of Fl of the vowel /u/ in Kannada" were accepted. However there was statistically significant difference between females of groups 1 and 2 with group 2 showing lower Fl than group 1. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 for Fl of the vowel /u/ in Kannada" was rejected.

Comparison between males and females disclosed that there was no significant difference in group 1 for Fl of vowel /u/. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of /u/ in group 1 in Kannada" was accepted. When the males and females of groups 2 and 3 were compared, it was revealed that females had significantly higher Fl for vowel /u/. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of/u/ in group 3 in Kannada" was rejected.

Vowel /u:/: It was observed from Table 4.25 that the mean Fl of long vowel /u:/ in males of group 1 was 453 Hz and the SD and range were 59.2 and 331 Hz respectively. The mean, SD and range for females of group 1 were 473 Hz, 52.5 and 240 Hz respectively. Males of group 2 had the mean, SD and range as 412Hz, 52 and 240Hz and for females they were 421 Hz, 56.9 and 360 Hz respectively. In group 3, males had the mean, SD and range as 368 Hz, 63.4 and 251 Hz respectively. The mean, SD and range for males of group 3 were 416 Hz, 65.5 and 345 respectively.

From Table 4.25 and Graph 28, it was evident **that in both** males and females **the** values of Fl for /u:/ decreased from group 1 to group 3 and then to group 2. SD also decreased from group 1 to group 3 and then to group 2 in males. In females SD increased as age increased. The range of Fl for the vowel /u:/ in males was highest for group 1 followed by group 3 and group 2. Groups 1 and 2 had equal ranges. In females, the range decreased from group 2 to group 3 and then to group 1.

The results of ANOVA, with reference to males, showed that there was significant difference for Fl of vowel /u:/ between males of groups 1 and 3 and groups 1 and 2. Males of group 1 had higher Fl than males of groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /u:/ in Kannada" was rejected. There was statistically significant difference between males of groups 2 and 3 with males of group 2 having high Fl. Hence the hypothesis stating that "there is no significant difference between males of group 2 and group 3 for Fl of the vowel /u:/ in Kannada" was rejected.

When the female groups were compared it was observed that there was no significant difference between females of group 1 and group 3 for Fl of vowel /u:/. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 3 in terms of Fl of the vowel /u:/ in Kannada" was accepted. Statistically significant difference was observed between females of groups 1 and 2 with group 2 showing a lower Fl and between females of groups 2 and 3 with group 3 showing a lower Fl. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 2 and 3 for Fl of the vowel /u:/ in Kannada" was rejected.

There was no significant difference between males and females in group 1 and group 2 for Fl of vowel /u:/. Thus the hypothesis stating that "there are no significant differences between males and females for Fl of /u:/ in group 1 and group 2 in Kannada" were accepted. When the males and females of group 3 were compared, females had significantly higher Fl for vowel /u:/. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of/u:/ in group 3 in Kannada" was rejected.

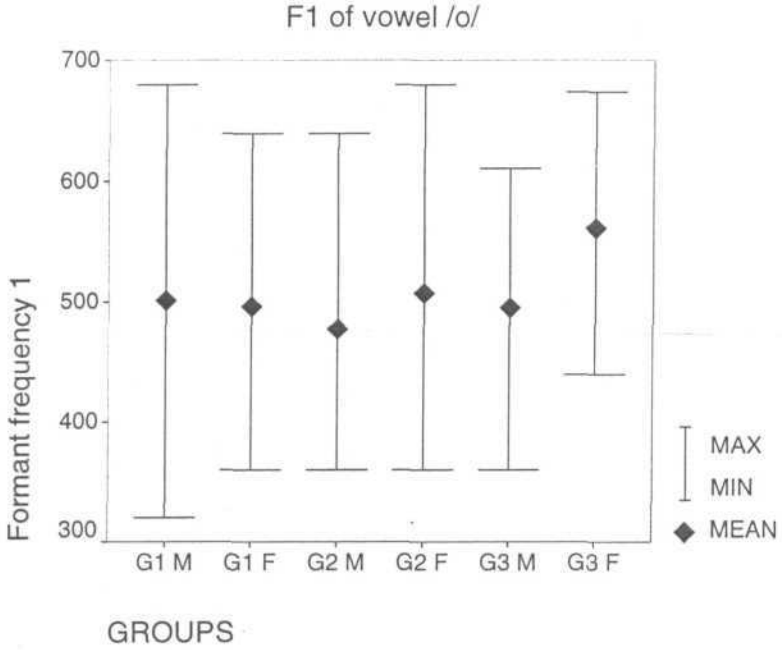
Vowel /o/: As in Table 4.25, the mean value of Fl of long vowel /o/ in males of group 1 was 501 Hz and the SD and range were 78 and 360Hz and for females they were 496 Hz, 57.7 and 280 Hz respectively. In group 2 the mean, SD and range for males were 477Hz, 60.4 and 280Hz respectively and for females they were 507 Hz, 61.4 and 320Hz respectively. Group 3 males had the mean, SD and range as 495 Hz, 48.3 and

251 Hz respectively. The mean, SD and range for females of group 3 were 561 Hz, 59.3 and 235 respectively.

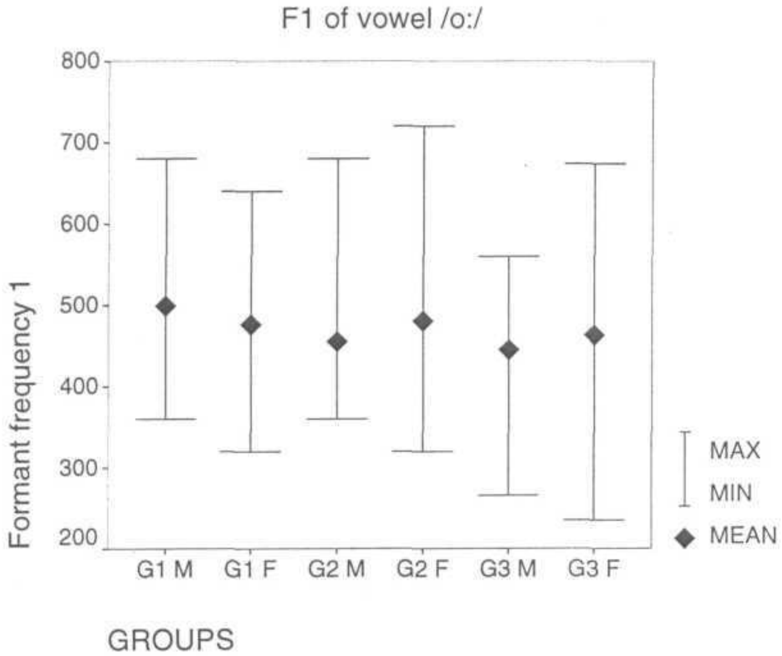
From Table 4.25 and Graph 29, it was evident that males had the values of Fl for *lol* which decreased from group 1 to group 3 and further to group 2 . In females the mean increased as age increased. SD decreased with increase in age in males. In females SD was highest in group 2 followed by group 3 and group 2 respectively. The range of Fl for the vowel /u:/ in males decreased with increase in age. In females, the range decreased from group 2 to group land then to group 3.

In case of males using one way ANOVA, it was seen that there was no significant difference for Fl of vowel *lol* between groups 1 and 3. Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 3 in terms of the Fl of vowel *lol* in Kannada" was accepted. Statistically significant differences were present between groups 1 and 2 and groups 2 and 3. Males of group 2 had lower Fl in both comparisons. Hence the hypothesis stating that "there are no significant difference between males of groups 1 and 2 and groups 2 and 3 for Fl of the vowel *lol* in Kannada" was rejected.

On comparison between the different female groups it wasfound that there was no significant difference between groups 1 and 3 and groups 1 and 2 for Fl of vowel *lol*. Hence the hypothesis stating that "there are no significant difference between females of groups 1 and 3 and groups 1 and 2 in terms of Fl of the vowel *lol* in



Graph 29



Graph 30

Kannada" were accepted. But there was significant difference between groups 2 and 3 with group 2 showing a lower Fl. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 for Fl of the vowel *lol* in Kannada" was rejected.

On comparison between males and females, there was no significant difference between males and females of group 1 for Fl of vowel *lol*. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of *lol* in group 1 in Kannada" was accepted. But in groups 3 and 2 , females had significantly higher Fl for vowel *lol*. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of /*ol* in groups 2 and 3 in Kannada" was rejected.

Vowel /o:/: Table 4.25 depicted that the mean Fl of long vowel /o:/ in males of group 1 was 499 Hz and the SD and range were 57.8 and 320Hz and for females they were 476 Hz, 51.5 and 320 Hz respectively. The mean, SD and range for males of group 2 were 455Hz, 63.7 and 320Hz and in case of females of group 2, the mean, SD and range were 480 Hz, 60.5 and 400Hz respectively. Males of group 3 had the mean, SD and range as 445 Hz, 54.2 and 294 Hz and for females of group 3 they were 463 Hz, 78.1 and 439 respectively.

From Table 4.25 and Graph 30, it was evident that in males the values of Fl for /o:/ decreased from group 1 to group 3. In females the mean was highest in group 2 decreasing to group 1 and then to group 2. In males SD was highest for group 2 followed by groups 1 and 3. In females SD increased with increase in age. The range of

Fl for the vowel /o:/ in males was least in group 3. Groups 1 and 2 had equal ranges in males. In females, the range increased with increase in age.

In different groups of males using one way ANOVA, it was found that there was significant difference for Fl of vowel /o:/ between males of groups 1 and 3 and groups 1 and 2. Males of group 1 had higher Fl than the other two groups. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the Fl of vowel /o:/ in Kannada" was rejected. There was no significant difference between males of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between males of group 2 and group 3 forFl of the vowel/o:/ in Kannada" was accepted.

Similarly in case of the female groups it was observed that there was no significant difference between females of groups 1 and 3 and groups 1 and 2 for Fl of vowel /o:/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups land 2 in terms of Fl of the vowel /o:/ in Kannada" were accepted. Also there was no significant difference between females of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 for Fl of the vowel /o:/ in Kannada" was accepted.

There was no statistically significant difference between males and females of group 1 for Fl of vowel /o:/. Hence the hypothesis stating that "there is no significant difference between males and females for Fl of /o:/ in group 1 in Kannada" was accepted. However in groups 3 and 2 , females had significantly higher Fl for vowel /o:/. Hence the hypothesis stating that "there are no significant differences between males and females for Fl of/o:/in groups 2 and 3 in Kannada" was rejected.

Tables 4.26 and 4.27 showed the presence or absence of significant difference in Fl between the different age groups.

Males	**/i/**	/I:/	***/e/***	/e:/	**/a/**	**/a:/**	*/u/*	**/u:/**	***/o/***	**/o:/**	**Total**
Gl vs G2	**p**	**P**	**A**	**P**	**P**	P	**P**	**P**	A	P	8/10
Gl vs G3	**p**	**P**	**P**	**P**	**P**	P	**P**	**P**	P	P	10/10
G2 vs G3	**A**	**P**	**P**	**P**	**P**	P	**P**	**P**	P	A	8/10

Table 4.26 : The results of test for significance of difference between the three age groups in males for Fl at 0.05 level

Females	*/i/*	**/I:/**	***/e/***	*/e:l*	/a/	**/a:/**	*/u/*	**/u:/**	/o/	***/o:/***	**Total**
Gl vs G2	**A**	**A**	P	**P**	A	**P**	A	**P**	**A**	***A***	4/10
Gl vs G3	**P**	**P**	A	**P**	**P**	**P**	**P**	A	**A**	A	6/10
G2 vs G3	**P**	**A**	A	A	**P**	**P**	A	A	**P**	A	4/10

Table 4.27 : The results of test for significance of difference between the three age groups in males for Fl at 0.05 level

Tables 4.26 and 4.27 depicted that Fl was significantly higher in group 1 compared to group 3 in both males and females. But in females number of vowels having statistically significant difference was comparatively less than in males. In males, group 2 also had significantly higher Fl than group 3. On scaling similar to Peterson and Barney's (1952) study, it was found that in males, Fl in group 1 was higher than in group 2 and group 3 by 14% and 16% respectively. And Fl in group 2 was higher than group 3 by only 3%. Similarly in females, Fl in group 1 was higher than in groups 2 and 3 by 5% each. Females of group 2 had higher Fl than females group 3 by only 2% (Table 4.40). Hence it can be stated that there is a linear decrease in Fl from child to adolescents and further to adults in both males and females.

Mvs F	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:l	**Total**
Gl	p	**P**	A	P	A	P	A	*A*	*A*	P	5/10
G2	p	P	P	P	A	P	P	*A*	P	P	8/10
G3	p	P	A	P	P	P	P	P	P	A	8/10

Table 4.28 : The results of test for significance of difference between males and females for Fl at 0.05 level in different groups

It is clear from Table 4.28 that there was significant difference in Fl across gender for all the three groups. Further, formant frequencies of vowels produced by males and females were compared by means of scale factors based on the method proposed by Fant (1966).

Scale factor for First formant frequency

$$Kl = \frac{\text{Fl of female}}{\text{Fl of male}} - 1 \times 100$$

In children (Group 1), males had significantly higher Fl where as females had higher Fl in adolescents (Group 2) and adults (Group 3). Fl was higher in males of groupl than in females by 3%. In groups 2 and 3, females had higher Fl than males by 7% and 11 % respectively (Table 4.42).

2.b Formant frequency 2

Vowel /i/*:* On the examination of Table 4.29, the mean F2 of vowel /i/ in males of group 1 was 2831 Hz and the SD and range were 296.6 and 1320 Hz respectively. In case of females of group 1, the mean, SD and range were 3040 Hz, 314 and 1600 Hz respectively. Males of group 2 had the mean, SD and range as 2316 Hz, 203.3 and 1200Hz respectively. The mean, SD and range for females of group 2 were 2467Hz, 225.6 and 1040 Hz respectively. In males of group 3 the mean F2 was 2162 Hz, SD was 146.7 and range was 847 Hz . Females of group 3 showed the mean, SD and range as 2468 Hz, 277.8 and 1224 Hz respectively.

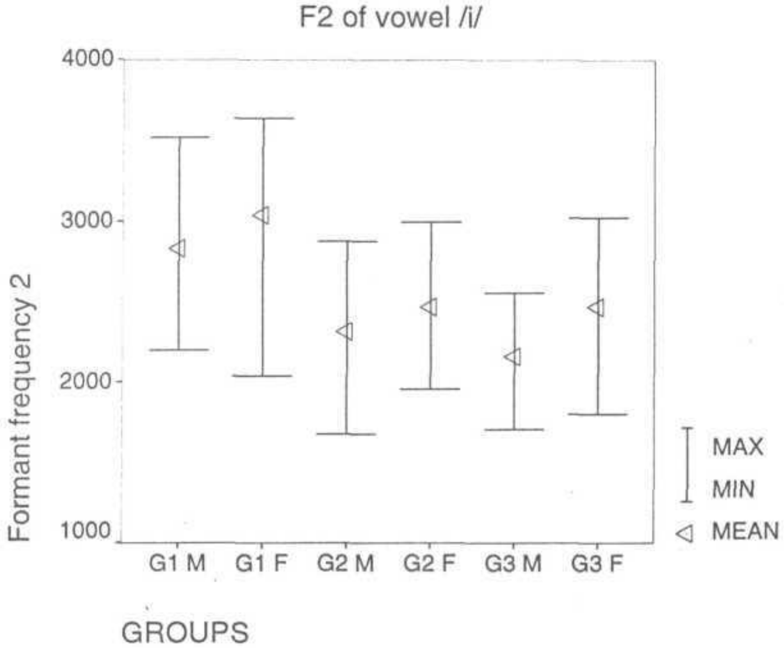
From Table 4.29 and Graph 31, it was found that both males and females had values of F2 which decreased with increase in age. It was found that the SD also decreased as the age increased in both males and females. But in females, group 3 had higher SD than group 2. The range of F2 also decreased with increase in age in both males and females. But in females, group 3 had a higher range than group 2.

		/i/		/i:/		/e/		/e:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	2831	3040	2974	3301	2537	2709	2819	3023
	SD	296.6	314	373.3	239.3	270	321	222.6	276.9
	Range	1320	1600	1840	1320	1299	1560	1220	1760
Group 2	Mean	2316	2467	2487	2692	2099	2272	2279	2434
	SD	203.3	225.6	196.8	182.5	181.8	206.8	153.1	182.4
	Range	1200	1040	920	740	800	880	840	800
Group 3	Mean	2162	2468	2316	2656	1888	2258	2157	2518
	SD	146.7	277.8	167.6	282.8	175.4	283.7	148.7	293.5
	Range	847	1224	831	1318	957	1192	737	1412

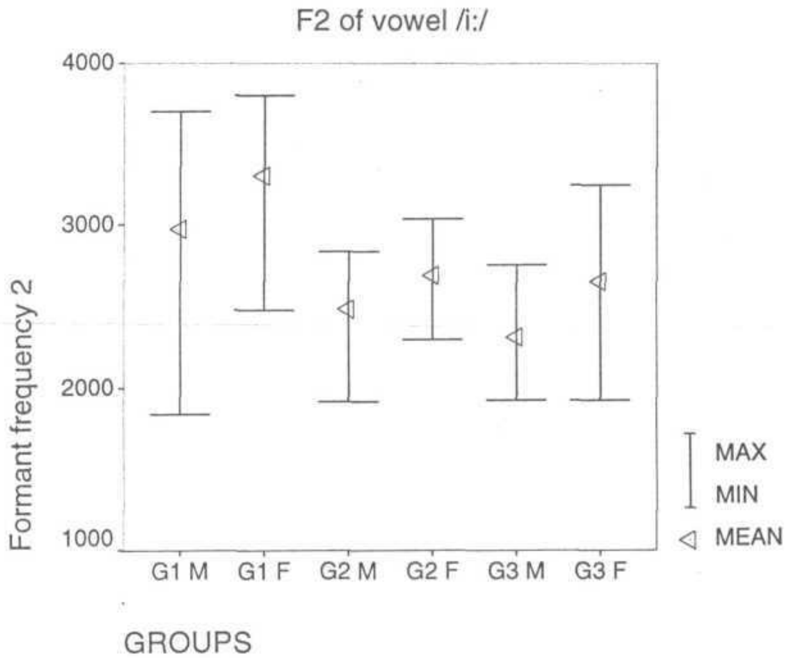
Table 4.29: Mean, SD and Range of F2 for front vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

The results of ANOVA showed that in case of males, group 1 had significantly higher F2 than group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of F2 of the vowel /i/ in Kannada" were rejected. When males of group 2 were compared with males of group 3 there was a significant difference in F2 of the vowel *HI* with group 2 showing a higher F2. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of F2 of the vowel *HI* in Kannada" was rejected.

The statistical analysis of scores of females of different groups using ANOVA showed that there were significant differences between groups 1 and 3 and groups 1 and 2. Group 1 had higher F2 in both cases. Hence the hypothesis stating that "there are no significant difference between females of groups 1 and 3 and groups 1 and 2 in terms of F2 of the vowel /i/ in Kannada" was rejected. But there was no significant difference between females of groups 2 and 3. Hence the hypothesis stating that "there



Graph 31



Graph 32

is no significant difference between females of groups 2 and 3 in terms of F2 of the vowel /i/ in Kannada" was rejected.

When the males and females of groups 1, 2 and 3 were compared in terms of F2 of vowel /i/ it was found that F2 was significantly higher in females. Hence the hypothesis stating that "there are no significant differences between males and females for F2 of /i/ in groups 1, 2 and 3 in Kannada" was rejected.

Vowel /I:/: On scrutiny of Table 4.29 it was found that the mean values of F2 of vowel /I:/ in males of group 1 was 2974 Hz and the SD and range were 373.3 and 1840 Hz respectively and for females they were 3301 Hz, 239.3 and 1320 Hz respectively. The mean, SD and range for males of group 2 were 2487 Hz, 196.8, and 920 Hz respectively and in females the mean, SD and range were 2692 Hz, 182.5 and 740 Hz respectively. In group 3 the mean, SD and range for males were 2316 Hz, 167.6 and 831 Hz and for females they were 2656 Hz, 282.8 and 1318 respectively.

It was clear from Table 4.29 and Graph 32 that in both males and females the values of F2 for /I:/ decreased from group 1 to group 3. It was found that the SD also decreased with increase in age in males. But in females SD was highest in group 3 followed by group 1 and then in group 2. The range of F2 for the vowel /i:/ also decreased with increase in age in both males and females, except that the females of group 3 had a higher range than females of group 2.

Among the three groups of males, males of group 1 had significantly higher F2 for /I:/ than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of F2 for the vowel /I:/ in Kannada" was rejected. When males of group 2 were compared with males of group 3, group 2 had significantly higher F2. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of F2 of the vowel /I:/ in Kannada" was rejected.

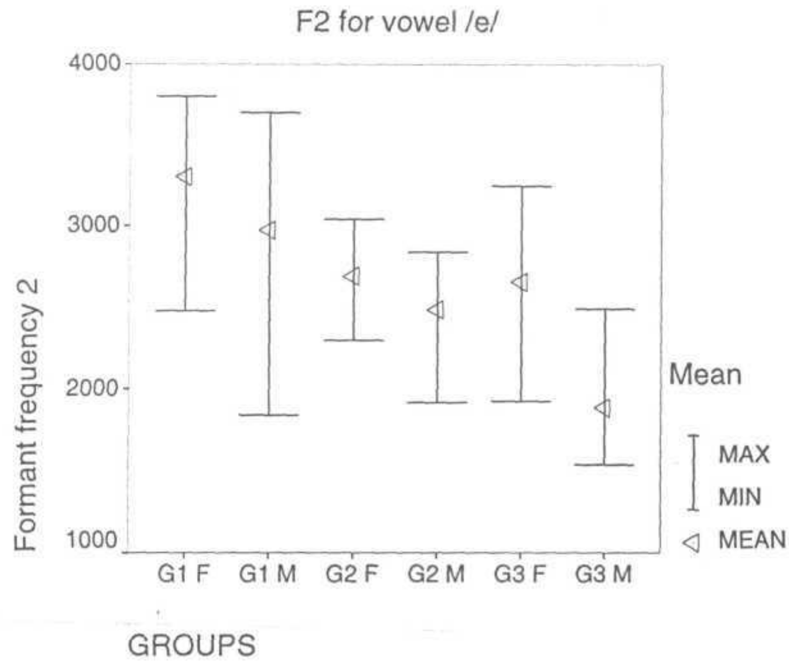
With reference to different groups of females, it was found that the females of group 1 had significantly higher F2 when compared with females of groups 2 and 3 for F2 of vowel /I:/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 1 and 2 in terms of the F2 of vowel /i:/ in Kannada" was rejected. There was no significant difference between females of groups 2 and 3 for F2 of vowel /i:/. Therefore the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of Fl of the vowel /I:/ in Kannada" was accepted.

When comparison was made across gender for group 1, group 2 and group 3, F2 for /I:/was significantly higher in females for all the three groups. Hence the hypothesis stating that "there are no significant difference between males and females for F2 of /I:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

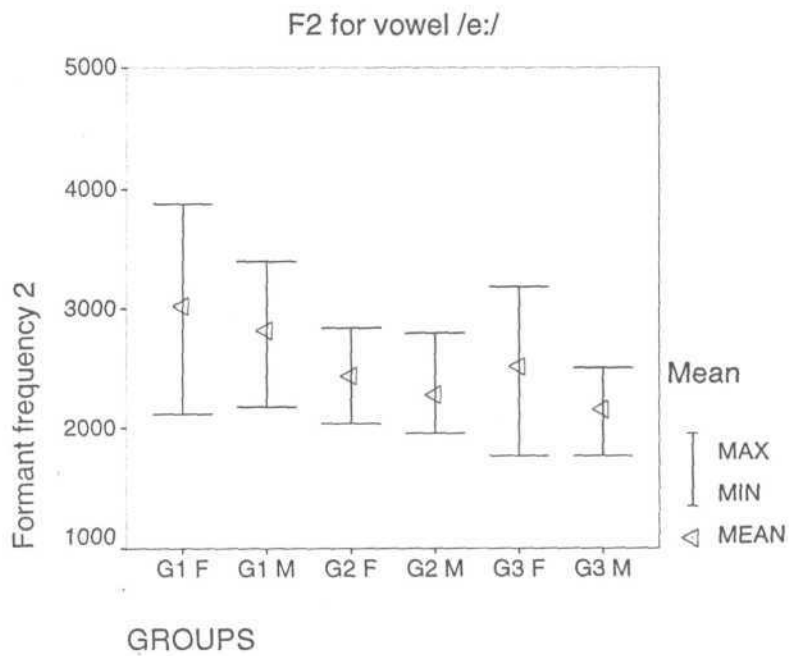
Vowel /e/*:* It was observed from Table 4.29 that the mean F2 of vowel /e/ in males of group 1 was 2537 Hz and the SD and range were 270 and 1299 Hz and for females they were 2709 Hz, 321 and 1560 Hz respectively. In group 2, the mean, SD and range for males were 2099 Hz, 181.8 and 800Hz respectively. The mean, SD and range for females of group 2 were 2272 Hz, 206.8 and 880 Hz . Group 3 males had a mean of 1888 Hz, SD of 175.4 and range of 957 Hz and for females of group 3 they were 2258 Hz, 283.7 and 1192 Hz respectively.

From Table 4.29 and Graph 33, it was inferred that both males and females had the values of F2 for /e/ which decreased from group 1 to group 3. It was found that SD also decreased with increase in age in males and females except that in females it was higher in group 3 than in group 2. The range of F2 for the vowel /e/ also decreased from group 1 to group 3 and then to group 2 in both males and females.

The results of ANOVA revealed that in males, group 1 had significantly higher F2 than groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of **the** F2 of vowel /e/ in Kannada" was rejected. On comparison between males of groups 2 and 3, it was found that group 2 **had** significantly higher F2 for /e/. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 for F2 of the vowel /e/ in Kannada" was rejected.



Graph 33



Graph 34

From the statistical analysis regarding the three female groups, there was significant difference between groups 1 and 2 and groups 1 and 3 for F2 of vowel /e/. Group 1 had higher F2 than the other two groups. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of F2 of the vowel /e/ in Kannada" was rejected. There was no. significant difference between groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of F2 of the vowel /e/ in Kannada" was accepted.

When males and females of each group were compared, females of all the three groups had significantly higher F2 than their male counterparts. Hence the hypothesis stating that "there are no significant difference between males and females for F2 of /e/ in groups 1, 2 and 3 in Kannada" were rejected.

Vowel /e:/: On perusal of Table 4.29 it was found that the mean Fl of vowel /e:/ in males of group 1 was 2819 Hz and the SD and range were 222.6 and 1220 Hz and for females they were 3023 Hz, 276.9 and 1760 Hz respectively. In group 2, males had a mean of 2279Hz, SD of 153.1 and range of 840Hz . The mean, SD and range for females of group 2 were 2434 Hz, 182.4 and 800 Hz . Group 3 males had the mean, SD and range as 2157 Hz, 148.7 and 737Hz and for females they were 2518 Hz, 293.5 and 1412 respectively.

From the study of Table 4.29 and Graph 34, it was observed that in both males and females values of F2 for /e:/ decreased from group 1 to group 3 except that in females of group 2 had a lower F2 than group 3 females. It was found that the SD also decreased with increase in age in males. In females, group 3 had the highest SD and next in order were group 1 and 3. The range of F2 for the vowel /e:/ also decreased with increase in age in both males and females . But in females, group 2 showed a narrower range than group 3.

Among the male groups it was found that group 1 had significantly higher F2 than groups 2 and 3 and group 2 had significantly higher F2 than group 3. Thus the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F2 of vowel /e:/ in Kannada" was rejected.

Similarly across the three female groups, there was significant difference between groups 1 and 3 and groups 1 and 2 for F2 of vowel /e:/. Group 1 had higher F2 than groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 1 and 2 in terms of F2 of the vowel /e:/ in Kannada" was rejected. But there was no significant difference between groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of F2 of the vowel /e:/ in Kannada" was accepted.

The results of comparison between males and females of each group revealed that there was significant difference between males and females of group 1, group 2 and group 3 for F2 of vowel /e:/ with females having a higher F2 in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for F2 of/e:/ in group 1 , group 2 and group 3 in Kannada" was rejected.

Vowel /a/: Observation of Table 4.30 revealed that the mean F2 of vowel /a/ in males of group 1 was 2043 Hz , SD was 345.3 and range was 1680 Hz and the mean, SD and range for females of group 1 were 2149 Hz, 423.9 and 2200 Hz respectively. In group 2 the mean, SD and range for males were 1625 Hz, 231.5 and 1320Hz and for females they were 1825 Hz, 221.7 and 1320 Hz . The mean, SD and range for males of group 3 were 1507 Hz, 194.6 and 941 Hz respectively. In females of group 3 the mean F2 was 1766 Hz, SD was 243.3 and range was 1721 Hz.

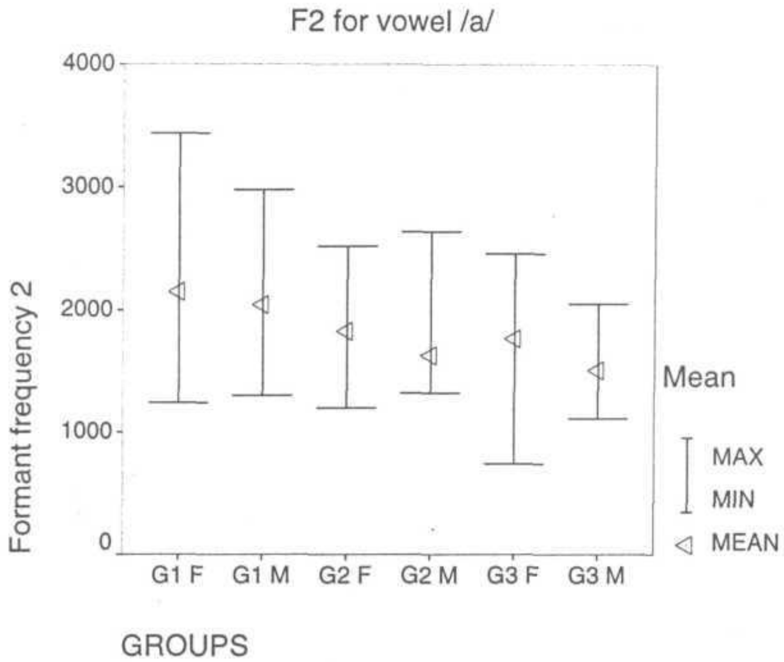
From the Table 4.30 and Graph 35, it is evident that in both males and females values of F2 for /a/ decreased with increase in age. SD and range of F2 decreased with increase in age in males and females. However, females of group 2 had a lower SD and range than females of group 3.

		/a/		/a:/	
		M	F	M	F
Group 1	Mean	2043	2149	1792	1778
	SD	345.3	423.9	148.8	229.5
	Range	1680	2200	860	1720
Group 2	Mean	1625	1825	1457	1594
	SD	231.5	221.7	113.1	112.1
	Range	1320	1320	600	520
Group 3	Mean	1507	1766	1296	1490
	SD	194.6	243.3	117.4	174.3
	Range	941	1721	811	1298

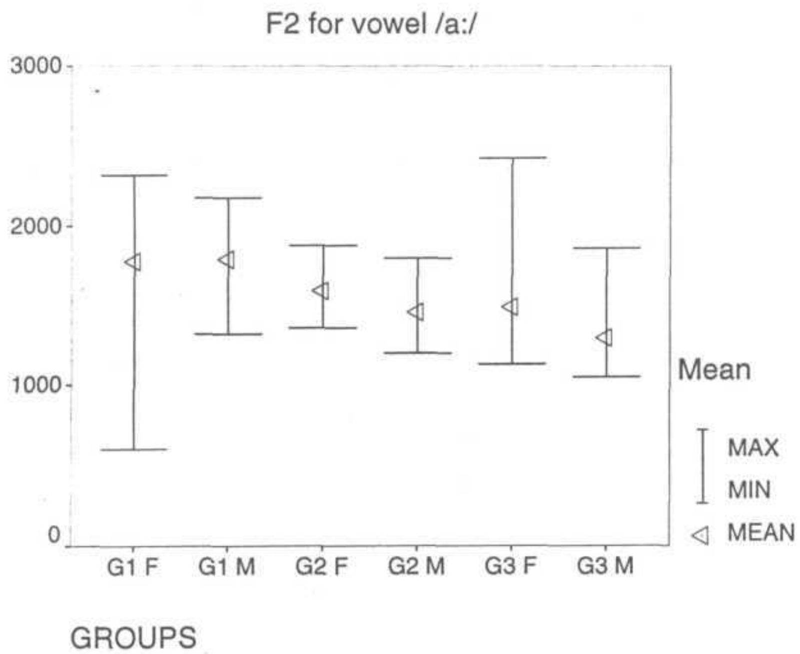
Table 4.30: Mean, SD and Range of F2 for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

Across the different groups of males using one way ANOVA, it was observed that there was significant difference for F2 of vowel /a/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F2 for /a/ than groups 2 and 3 and males of group 2 had significantly higher F2 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F2 of vowel /a/ in Kannada" was rejected.

Similarly in case of female groups also it was observed that group 1 had significantly higher F2 than groups 2 and 3 and group 2 had significantly higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F2 of vowel /a in Kannada" was rejected.



Graph 35



Graph 36

When males and females of each group were compared, females exhibited higher F2 in all the three groups. Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /a/ in groups 1, 2 and 3 in Kannada" were rejected.

Vowel /a:/: On scrutiny of Table 4.30, the mean F2 of vowel /a:/ in males of group 1 was 1792 Hz and the SD and range were 148.8 and 860 Hz and for females of group 1 they were 1778 Hz, 229.5 and 1720 Hz respectively. In group 2, males had the mean, SD and range as 1457 Hz, 113.1 and 600 Hz and for females they were 1594 Hz, 112.1 and 520 Hz respectively. Group 3 males had a mean F2 of 1296 Hz, SD of 117.4 and range of 811 Hz respectively. The mean, SD and range for males of group 3 were 1490 Hz, 174.3 and 1298 Hz respectively.

From Table 4.30and Graph 36 it is evident that in both males and females the values of F2 for /a:/ decreased from group 1 to group 3 linearly. SD also decreased with increase in age in males and females. The range of F2 for the vowel /a:/ also decreased with increase in age in males and females .

The results of comparison in different groups of males showed that there was significant difference for F2 of vowel /a:/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had higher F2 than the other two groups and males of group 2 had higher F2 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F2 of vowel /a:/ in Kannada" was rejected.

On comparison across the three female groups it was observed that there were significant differences between females of groups 1 and 3, groups 1 and 2 and between groups 2 and 3 for F2 of vowel /a:/. Females of group 1 had higher F2 than groups 2 and 3 and group 2 had higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and between groups 2 and 3 in terms of F2 of the vowel /a: / in Kannada" was rejected.

When comparison was made across gender it was noticed that females of groups 1 and 3 had significantly higher F2 than their male counterparts. Hence the hypothesis stating that "there are no significant differences between males and females for F2 of/a:/ in group 1 and group 3 in Kannada" was rejected. But there was no significant difference across sex in group 2 for F2. Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /a:/ in group 2 in Kannada" was accepted.

Vowel /u/: It is evident from Table 4.31 that the mean F2 of vowel /u/ in males of group 1 was 1276 Hz and the SD and range were 158.2 and 915 Hz and for females they were 1383 Hz, 190.9 and 960 Hz . In group 2 males had a mean of 1213 Hz, SD of 107.8 and range of 480 Hz . The mean, SD and range for females of group 2 were 1218 Hz, 129.9 and 720 Hz respectively. Group 3 males had the mean, SD and range as 1063 Hz, 134.8 and 690 Hz and for females of group 3 were 1130 Hz, 179.6 and 1003 respectively.

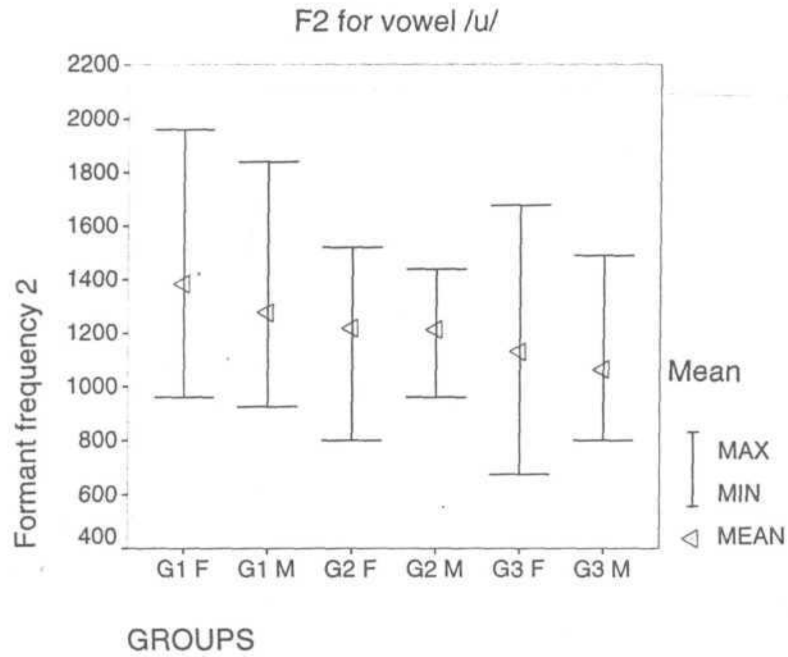
From Table 4.31 and Graph 37, it is evident that in both males and females values of F2 for /u/ decreased from group 1 to group 3. SD decreased from group 1 to group 3 and then to group 2 in males and females. The range decreased from group 1 to group 3 and then to group 2 in males . In females, range was highest for group 3 decreasing to group 1 and then to group 2 .

		/u/		/u:/		/o/		/o:/	
		M	F	M	F	M	F	M	F
Group 1.	Mean	1276	1383	1204	1184	1168	1386	1272	1229
	SD	158.2	190.9	142.6	134.4	107.1	116.9	148.9	147.3
	Range	915	960	760	760	404	540	795	720
Group 2	Mean	1213	1218	1107	1115	1187	1167	1156	1151
	SD	107.8	129.9	128.1	175.7	118.6	139.6	112.8	111
	Range	480	720	640	640	380	620	560	600
Group 3	Mean	1063	1130	892	935	1171	1177	938	971
	SD	134.8	179.6	127	153.2	112.6	103.4	109.2	130.3
	Range	690	1003	565	847	534	440	581	628

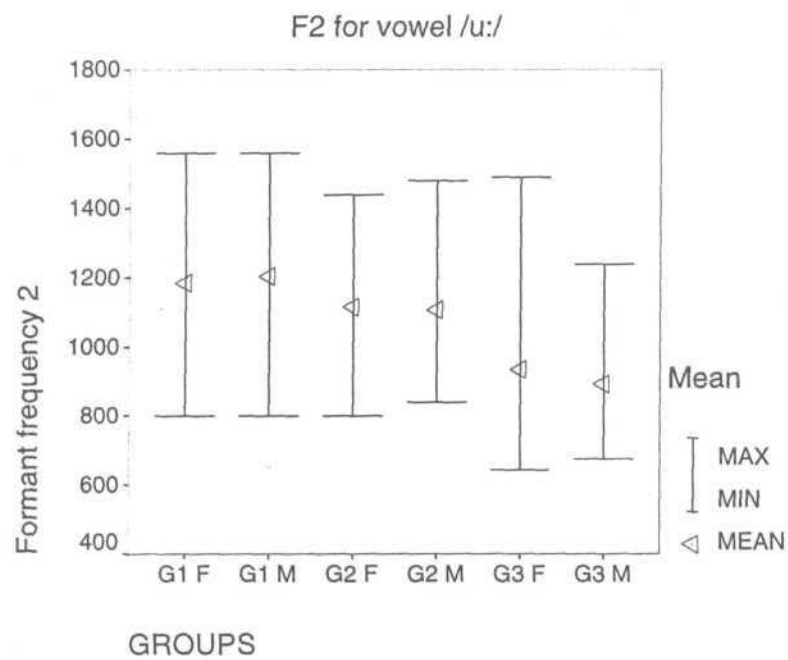
Table 4.31: Mean, SD and Range of F2 for back vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

The statistical analysis of scores of males showed that there was significant difference for F2 of vowel /u/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F2 than groups 2 and 3 and group 2 had significantly higher F2 than group 3. Thus the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3.in terms of F2 of vowel *IvJ* in Kannada" was rejected.

Similarly in case of the female groups, it was observed that there was significant difference for F2 of vowel /u/ between females of groups 1 and 3, groups 1 and 2 and



Graph 37



Graph 38

groups 2 and 3. Females of group 1 had significantly higher F2 than females of groups 2 and 3 and group 2 had significantly higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F2 of vowel /u/ in Kannada" was rejected.

When males and females of each group were compared, females showed significantly higher F2 for /u/ in all the three groups, Hence the hypothesis stating that "there are no significant difference between males and females for F2 of/u/ in group 1 group 2 and group 3 in Kannada" was rejected.

Vowel /u:/: It was inferred from Table 4.31 that the mean F2 of long vowel /u:/ in males of group 1 was 1204 Hz and the SD and range were 142.6 and 760 Hz and for females they were 1184 Hz, 134.4 and 760 Hz respectively. Males of group 2 had the mean, SD and range as 1107 Hz, 128.1 and 640 Hz and in females they were 1115 Hz, 175.7 and 640 Hz respectively. In group 3 males the mean was 892 Hz, SD was 127 and range was 565 Hz and e for females of group 3 they were 935 Hz, 153.2 and 847 respectively.

From Table 4.31 and Graph 38, it is evident that both males and females had the values of F2 for /u:/ which decreased from group 1 to group 3. SD also decreased with increase in age in males. In females, SD was highest for group 2 followed by group 3 and 1 respectively. In males the range decreased with increase in age. In females, the range decreased from group 3 to group 1 and then to group 2.

Using one way ANOVA, in males it was found that there was significant difference for F2 of vowel /u:/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F2 than groups 2 and 3. Males of group 2 had significantly higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F2 of vowel /u:/ in Kannada" was rejected.

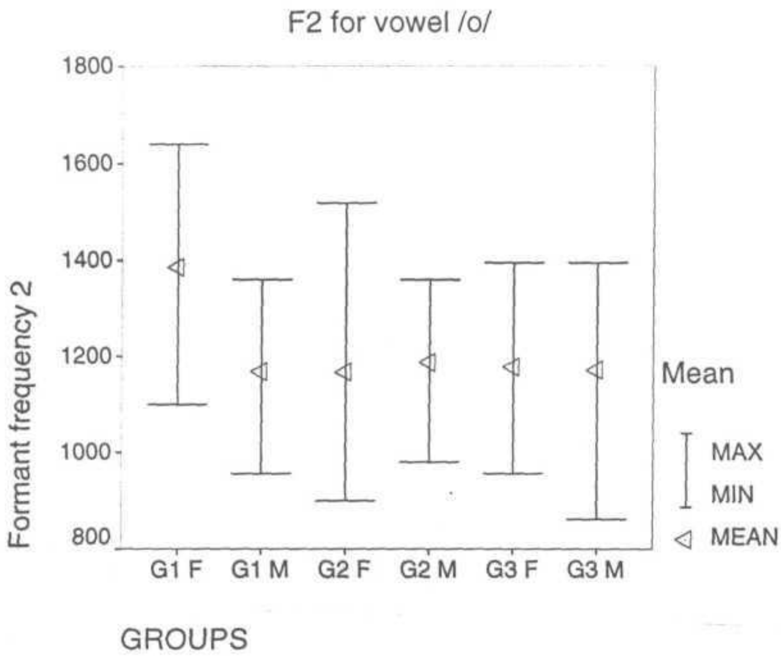
Similarly in case of female groups statistical comparison showed that there was significant difference for F2 of vowel /u:/ between groups 1 and 3, groups 1 and 2 and groups 2 and 3. Group 1 had significantly higher F2 than groups 2 and 3 and group 2 had significantly higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F2 of vowel /u:/ in Kannada" was rejected.

On comparison between males and females in each group it was known that there was no significant difference between males and females of group 1. and group 2 for F2 of vowel /u:/. Hence the hypothesis stating that "there are no significant differences between males and females for F2 of /u:/ in group 1 and group 2 in Kannada" were accepted. But when the males and females of group 3 were compared, females had significantly higher F2 for vowel /u:/. Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /u:/ in group 3 in Kannada" was rejected.

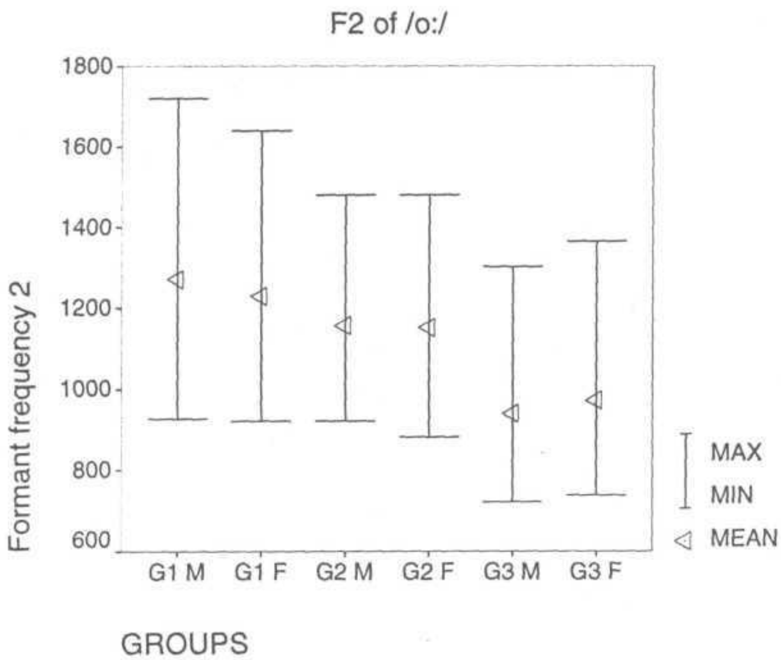
Vowel *lol:* Table 4.31 displays that the mean F2 of vowel *lol* in males of group 1 was 1168 Hz and the SD and range were 107.1 and 404Hz and for females they were 1386 Hz, 116.9 and 540 Hz respectively. Males of group 2 had the mean, SD and range as 1187 Hz, 118.6 and 38OHz . The mean, SD and range for females of group 2 were 1167 Hz, 139.6 and 620 Hz respectively. In males of group 3, the mean was 1171 Hz, SD was 112.6 and range was 534 Hz and for females of group 3 they were 1177 Hz, 103.4 and 440 Hz respectively.

From the Table 4.31 and Graph 39, it was observed that in males, the mean F2 of vowel *lol* was highest in group 2 followed by group 3 and group 1 respectively. In females, the mean F2 of vowel *lol* was highest in group 1 followed by group 3 and group 2 respectively. In males, SD decreased from group 2 to group 3 and then to group 1. In females, SD was highest in group 2 followed by group land group 3 respectively. The range of F2 for the vowel *Iw.l* in males decreased from group 3 to group 1 and then to group 2. In females, the range decreased from group 2 to group 1 and then to group 3.

Results of comparison across the three groups of males showed that F2 was significantly higher in males of group 1 than in males of groups 2 and 3. Also F2 was significantly higher in males of group 2 than in males of group 3. Hence the hypothesis



Graph 39



Graph 40

stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F2 of vowel */of* in Kannada" was rejected.

Similarly in the female groups, F2 was significantly higher in females of group 1 than in females of groups 2 and 3 and it was significantly higher in females of group 2 than in group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F2 of the vowel /o/ in Kannada" was rejected.

Results of comparison across gender in the three groups revealed that females of group 1 had significantly higher F2 than their male counter parts . Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /o/ in group 1 in Kannada" was rejected. There was no significant difference between males and females of groups 2 and 3 for F2 of vowel /o/. Hence the hypothesis stating that "there are no significant differences between males and females for F2 of *lol* in groups 2 and 3 in Kannada" was accepted.

Vowel /o:/: On examination of Table 4.31, the mean F2 of **long** vowel /o/*l* in males of group 1 was 1272 Hz , SD was 148.9 and range was 795 Hz . The mean, SD and range for females of group 1 were 1229 Hz, 147.3 and 720 Hz respectively. In group 2 the mean, SD and range for males were 1156 Hz, 112.8 and 560 Hz and for females they were 1151 Hz, 111 and 600Hz . The mean, SD **and** range for males of group 3 were

938 Hz, 109.2 and 581 Hz and for females they were 971 Hz, 130.3 and 628 respectively.

From Table 4.31 and Graph 40, it was evident that in both males and females values of F2 for /o:/ decreased from group 1 to group 3. In males SD decreased with increase in age. In females SD decreased from group 1 to group 3 and then to group 2. The range of F2 for the vowel /o:/ in both males and females decreased from group 1 to group 3 and then to group 2.

On comparison across males it was found that F2 of vowel /o:/ was significantly higher in males of group 1 than in males of groups 2 and 3. Also F2 was significantly higher in males of group 2 than in males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F2 of vowel /o:/ in Kannada" was rejected.

Similarly in female groups, there was significant difference between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F2 of vowel /o:/. Females of group 1 had significantly higher F2 than groups 2 and 3 and females of group 2 had significantly higher F2 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F2 of the vowel /o:/ in Kannada" was rejected.

On comparison between males and females, males in group 1 had significantly higher F2 than females . Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /o:/ in group 1 in Kannada" was rejected. In group 2, there was no significant difference between males and females for F2 of vowel /o:/ Thus the hypothesis stating that "there is no significant difference between males and females for F2 of /o:/ in group 2 in Kannada" was accepted. In group 3, females had significantly higher F2. Hence the hypothesis stating that "there is no significant difference between males and females for F2 of /o:/ in group 3 in Kannada" was rejected.

Tables 4.32 and 4.33 show the presence or absence of significant difference in F2 between different age groups.

Males	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	**Total**
Gl vs G2	P	P	P	P	P	P	P	P	P	P	10/10
Gl vs G3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vs G3	P	P	P	P	P	P	P	P	P	P	10/10

Table 4.32 : The results of tests for significance of difference between the three age groups in males for F2 at 0.05 level

Females	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl vs G2	P	P	P	P	P	P	P	P	p	P	10/10
Gl vs G3	P	P	P	P	P	P	P	P	p	P	10/10
G2 vs G3	A	A	A	A	P	P	P	P	p	P	6/10

Table 4.33 : The results of tests for significance of difference between the three age groups in males for F2 at 0.05 level

Tables 4.32 and 4.33 depicted that F2 was significantly higher in group 1 compared to groups 2 and 3 and in both males and females. Also group 2 had significantly higher F2 than group 3 in both males and females. On scaling it was observed that in males, group 1 had higher F2 than groups 2 and 3 by 16% and 23% respectively. Males of group 2 had higher F2 than males of group 3 by 10%. On the same lines, in females of group 1 had higher F2 than group 2 and 3 by 16% and 18% respectively. F2 in group 2 females was higher than in group 3 females by 3% only (Table 4.40). Hence it can be said with authenticity that there is a decrease in F2 from children to adolescents and further marked decrease to adults for vowels in Kannada in both males and females.

Mvs F	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl	P	P	P	P	P	P	P	A	P	P	9/10
G2	P	P	P	P	P	A	P	A	A	A	6/10
G3	P	P	P	P	P	P	P	P	A	P	9/10

Table 4.34: The results of tests for significance of difference between males and females for F2 at 0.05 level

It was clear from Table 4.34 that there was significant difference in F2 between males and females for the three groups for vowels in Kannada. In all the three groups females had significantly higher F2 than their male counterparts. When scaling was done for F2 on the method proposed by Fant (1966), females showed higher F2 in group 1 and 2 by 6% and in group 3 by 12% (Table 4.42).

Scale factor for Second formant frequency

$$K2 = \frac{\text{F2 of female}}{\text{F2 of male}} - 1 \times 100$$

2.c Formant frequency 3

Vowel /i/: On examination of Table 4.35, it was observed that the mean F3 of vowel /i/ in males of group 1 was 3174 Hz and the SD and range were 315.5 and 1860 Hz and for females of group 1 they were 3683 Hz, 287.7 and 2160 Hz respectively. The males of group 2 had a mean F3 , SD and range as 3071 Hz, 290 and 1560Hz respectively. The mean, SD and range for females of group 2 were 3173 Hz, 298.4 and 1520 Hz respectively. In group 3 the mean, SD and range for males were 2821 Hz, 290.6 and 2196 Hz respectively and for females of group 3 were 3055 Hz, 332.2 and 1800 respectively.

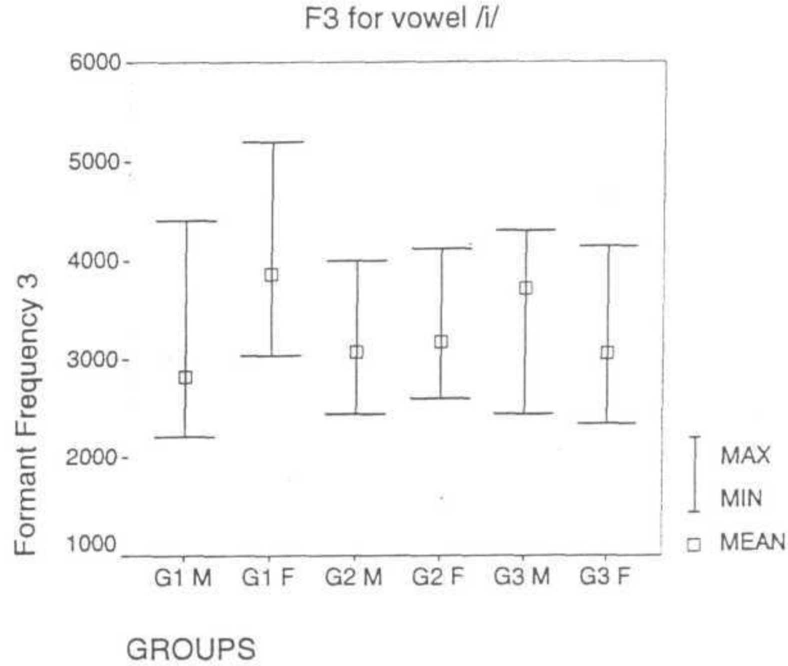
From the Table 4.35 and Graph 41, it was inferred that in both males and females had the values of F3 for vowel /i/ which decreased linearly from group 1 to group 3. It was found that the SD also decreased with increase in age in males. Males of group 3 and group 2 had equal SD. In females, SD decreased from group 3 to group 1. The range of F3 for the vowel /i/ in males was highest in group 3 and then in group 1 and group 2. In females the range was highest in group 1 followed by group 3 and group 2 respectively.

On comparison using one way ANOVA, group 1 males had significantly higher F3 than males of group 2 and group 3 males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of F3 of the vowel /i/ in Kannada" was rejected. When males of group 2 were compared with males of group 3, group 2 had significantly higher F3 for the vowel /i/l. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of F3 of the vowel /i/ in Kannada" was rejected.

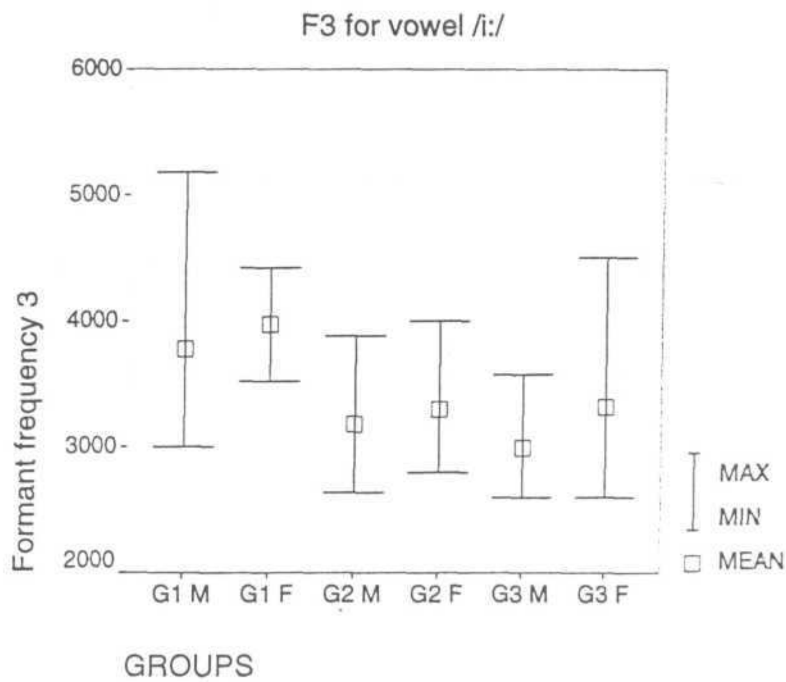
		/i/		/i:/		/e/		/e:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	3714	3683	3778	3970	3634	3792	3672	3836
	SD	315.5	287.7	344.6	189.8	412.9	244	253.4	206
	Range	1860	2160	2180	900	2040	1240	1180	1360
Group 2	Mean	3071	3173	3176	3296	2983	3106	2996	3071
	SD	290	298.4	234.2	199.6	202.6	176.4	255.9	203.9
	Range	1560	1520	1240	1200	880	1000	1200	1480
Group 3	Mean	2821	3055	2991	3314	2655	3015	2767	3186
	SD	290.6	332.2	210.4	419.6	213.3	308.2	183.7	368.6
	Range	2196	1800	976	1899	1412	1490	1066	2071

Table 4.35: Mean, SD and Range of F3 for front vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

Statistical analysis using ANOVA in females revealed that that there were significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Females of group 1 had significantly higher F3 than groups 2 and 3 and group 2 had significantly higher F3 than group 3. Hence the hypothesis stating that "there are no



Graph 41



Graph 42

significant difference between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of F3 of the vowel /i/ in Kannada" were rejected.

When the males and females of group 1 were compared F3 was significantly higher in males. Hence the hypothesis stating that "there is no significant difference between males and females for F3 of /i/ in group lin Kannada" was rejected. In group 2 and group 3, F3 of vowel */i/* was significantly higher in females. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of /i/ in group 2 and group 3 in Kannada" was rejected.

Vowel /I:/: On examination of Table 4.35, it was made out that the mean F3 of vowel /I:/ in males of group 1 was 3778 Hz, SD was 344.6 and range was 2180 Hz. The mean, SD and range for females of group 1 were 3970 Hz, 189.8 and 900 Hz respectively. For males in group 2 the mean, SD and range were 3176 Hz, 234.2 and 1240 Hz and for females of group 2 were 3296 Hz, 199.6 and 1200 Hz respectively. The mean, SD and range for males of group 3 were 2991 Hz, 210.4 and 976 Hz respectively. The mean, SD and range for females of group 3 were 3314 Hz, 419.6 and 1899 Hz.

It was clear from Table 4.35 and Graph 42 that in both males and females the values of F3 for /I:/ decreased from group 1 to group 3. However in females, group 3 had a higher F3 than group 2. It was found that the SD also decreased with increase in age in males. SD decreased from group 3 to group 2 and then to group 1 in females.

The range of F3 for the vowel /I:/ in males was highest in group 1 and then in group 2 and group 3 respectively. In females the range increased with increase in age.

By comparing the three groups of males using one way ANOVA, males of group 1 had significantly higher F3 for /I:/ than males of group 2 and group 3 . Hence the hypothesis stating that "there is no significant difference between males of groups 1 and 2 and groups 1 and 3 in terms of F3 of the vowel /I:/ in Kannada" was rejected. When group 2. males were compared with group 3 males there was significant difference in the F3 of vowel /I:/ with group 2 having a higher F3. Therefore the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of F3 of the vowel /I:/ in Kannada" was rejected.

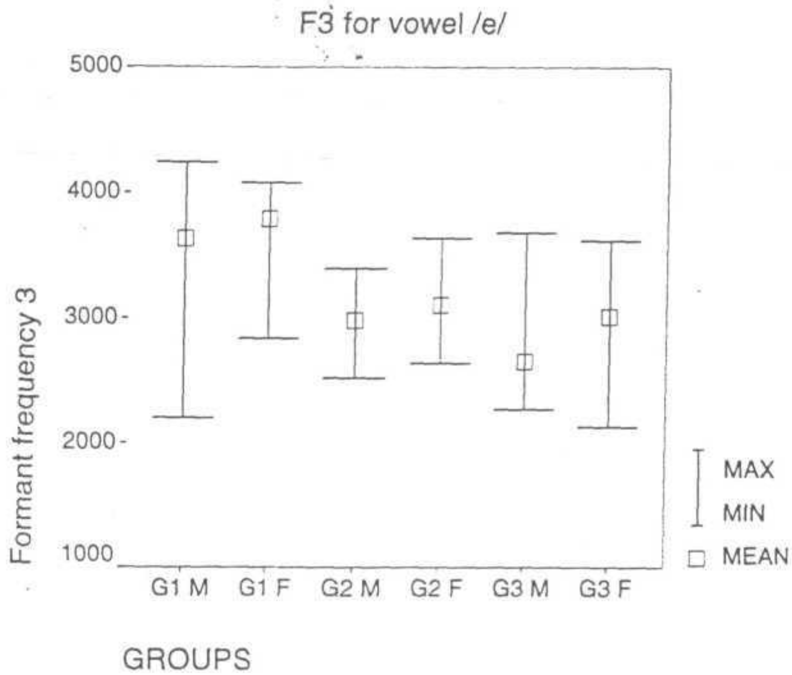
When the female groups were compared it was found that there was significant difference between females of groups 1 and 3 and groups 1 and 2 for F3 of vowel /I:/ with group 1 showing higher F3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and 1 and 2 in terms of F3 of vowel /I:/ in Kannada" was rejected. But there was no significant difference between females of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 in terms of F3 of the vowel /I:/ in Kannada" was accepted.

Comparison between males and females showed that in group 1, group 2 and group 3, F3 of vowel /I:/ was significantly higher in females. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of /I:/ in groups 1, group 2 and group 3 in Kannada" was rejected.

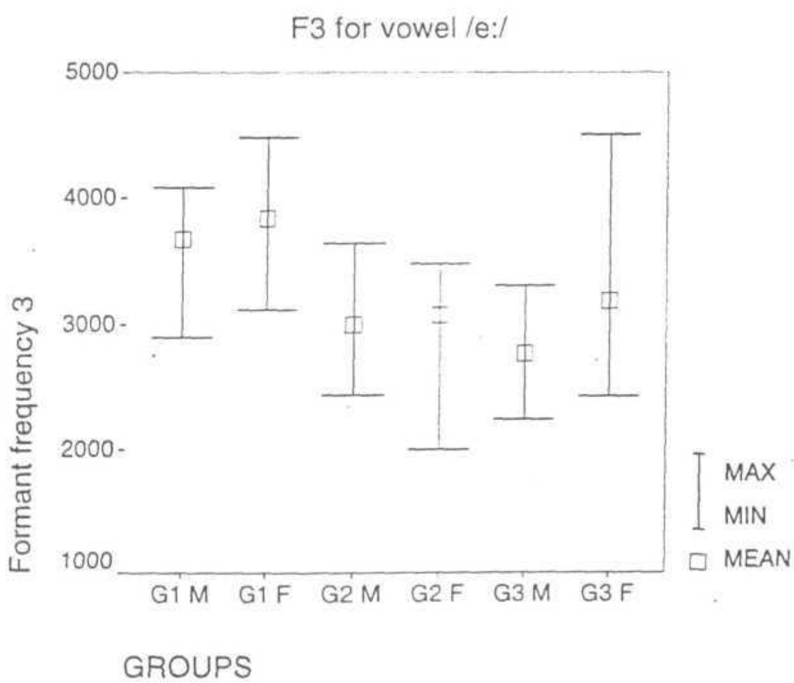
Vowel /e/*:* On scrutiny of Table 4.35, it was found that the mean F3 of vowel /e/ in males of group 1 was 3634 Hz and the SD and range were 412.9 and 2040 Hz respectively. The mean, SD and range for females of group 1 were 3792 Hz, 244 and 1240 Hz respectively. In group 2 males the mean, SD and range were 2983 Hz, 202.6 and 880Hz and for females they were 3106 Hz, 176.4 and 1000 Hz respectively. Males of group 3 had the mean, SD and range as 2655 Hz, 213.3 and 1412 Hz and in case of females they were 3015 Hz, 308.2 and 1490 respectively.

From the Table 4.35 and Graph 43, it was observed that both males and females showed the values of F3 for /e/ which decreased from group 1 to group 3. In males SD decreased from group 1 to group 3 and then to group 2. In females, SD was highest in group 3 followed by group 1 and group 2 respectively. The range of F3 for the vowel /e/ was highest in group 1 followed by group 3 and 2 respectively in males. In females the range was highest in group 3 and next in the order was group 1 and 2 respectively.

In case of males comparisons using one way ANOVA, it was found that there was significant difference for F3 of vowel /e/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in males. Males of group 1 had significantly higher F3 than males of groups 2 and 3 . Males of group 2 had significantly higher F3 than males of group 3. Hence the. hypothesis stating that "there are no significant differences



Graph 43



Graph 44

between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of the F3 of vowel /e/ in Kannada" was rejected.

Similar statistical analysis across all the female groups showed that females of group 1 had significantly higher F3 than females of groups 2 and 3. Females of group 2 had significantly higher F3 than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of the F3 of vowel /e/ in Kannada" was rejected.

On comparison across gender for the three groups it was disclosed that there was significant difference between males and females of group 1, group 2 and group 3 for F3 of vowel /e/ with females showing higher F3. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of *Id* in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /e:/: On perusal of Table 4.35, males of group 1 had the mean F3 of vowel /e:/ as 3672 Hz , SD as 253.4 and range as 1180 Hz and for females of group 1 they were 3836 Hz, 206 and 1360 Hz respectively. In males of group 2 the mean was 2996 Hz, SD was 255.9 and range was 1200Hz and for females they were 3071 Hz, 203.9 and 1480 Hz respectively. The mean, SD and range for males of group 3 were 2767 Hz, 183.7 and 1066 Hz and for females of group 3 they were 3186 Hz, 368.6 and 2071 respectively.

From the Table 4.35 and Graph 44, it was deduced that in both males and females F3 for /e:/ decreased from group 1 to group 3 and then to group 2. It was found that the SD was highest in group 2 followed by group 1 and group 3. In females, SD was highest in group 3 followed by group 1 and group 2 . The range of F3 for the vowel /e:/ was highest in group 2 then decreasing to groupl and group 3. In females the range for F3 of /e:/ increased with increase in age.

Statistical comparison across the male groups showed that there was significant difference for F3 of vowel /e:/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F3 than groups 2 and 3. Males of group 2 had significantly higher F3 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /e:/ in Kannada" was rejected.

Similarly in case of females, there was significant difference for F3 of vowel /e:/ between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Females of group 1 had significantly higher F3 than groups 2 and 3 and group 2 had significantly higher F3 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /e:/ in Kannada" was rejected.

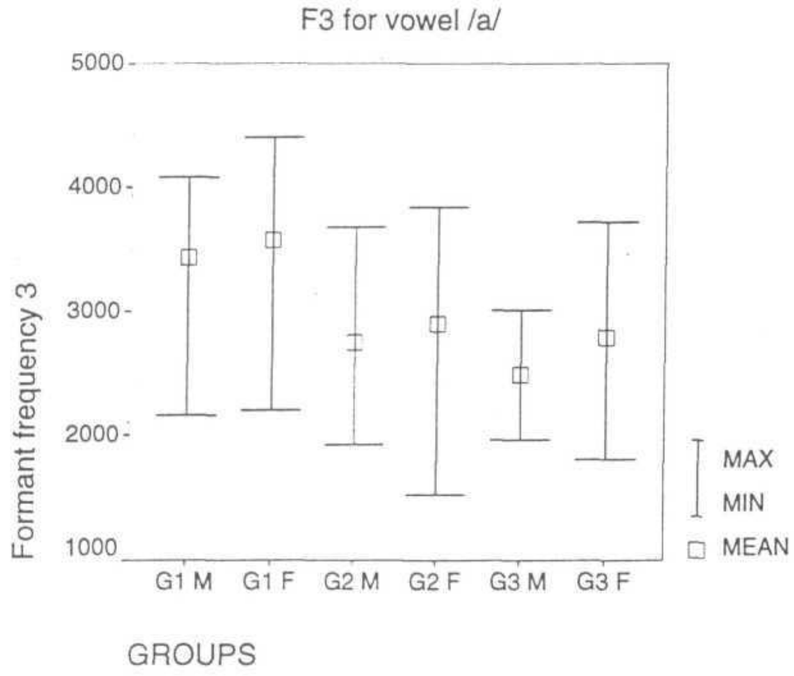
The results of comparison across gender revealed that females had significantly higher F3 than males in group 1, group 2 and group 3 for vowel /e:/. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of/e:/ in group 1, group 2 and group 3 in Kannda" was rejected.

Vowel /a/: The study of Table 4.36 showed that the mean F3 of vowel /a/ in males of group 1 was 3433 Hz and the SD and range were 401.7 and 1920 Hz and for females they were 3573 Hz, 446.3 and 2200 Hz respectively. Males of group 2 had the mean as 2747 Hz, SD as 328.8 and range as 1760 Hz. The mean, SD and range for females of group 2 were 2897 Hz, 316.1 and 2320 Hz. It was found that the mean, SD and range for males of group 3 were 2488 Hz, 230.6 and 1050 Hz and for females of group 3 they were 2784 Hz, 303.6 and 1918 Hz respectively.

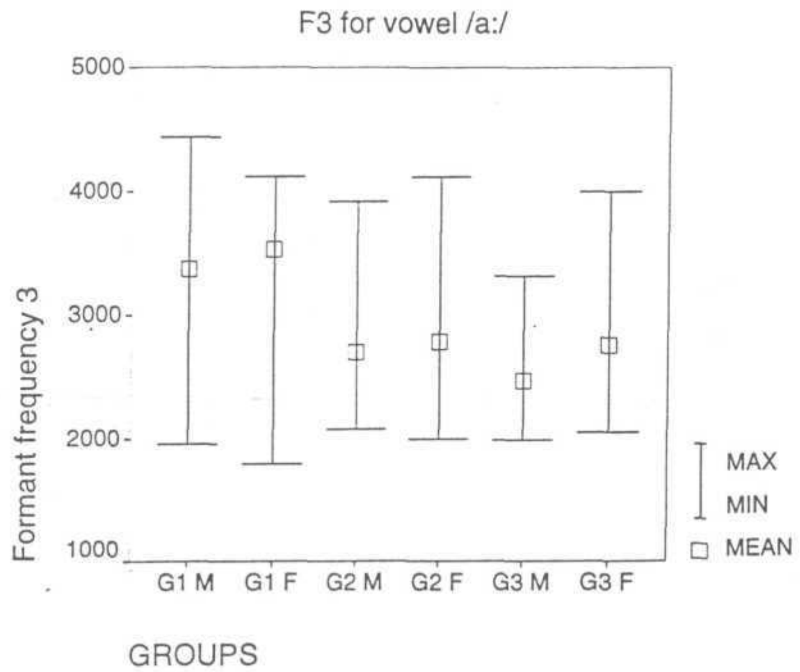
From Table 4.36 and Graph 45, it was evident that both males and females had the values of F3 for/a/ which decreased from group 1 to group 3. SD and range also decreased with increase in age in males and females.

		/a/		/a:/	
		M	F	M	F
Group 1	Mean	3433	3573	3375	3534
	SD	401.7	446.3	378.7	366.9
	Range	1920	2200	2480	2320
Group 2	Mean	2747	2897	2703	2790
	SD	323.8	316.1	348.9	339
	Range	1760	2320	1840	2120
Group 3	Mean	2488	2784	2470	2759
	SD	230.6	303.6	230.4	368.8
	Range	1050	1918	1328	1946

Table 4.36 : Mean , SD and Range of F3 for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults . (Group 3)



Graph 45



Graph 46

Statistical comparison between males of different groups showed that males of group 1 had significantly higher F3 for vowel /a/ than males of groups 2 and 3. Similarly it was observed that males of group 2 had significantly higher F3 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 in terms of the F3 of vowel /a/ in Kannada" was rejected.

Similarly comparisons between the female groups showed that females of group 1 had significantly higher F3 than females of groups 2 and 3 and group 2 showed significantly higher F3 than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 in terms of the F3 of vowel /a/ in Kannada" was rejected.

When males and females were compared, females had higher F3 in all the three groups for vowel /a/ than males. Thus the hypothesis stating that "there are no significant differences between males and females for F3 of /a/ in group 1 , group 2 and group 3 in Kannada" was rejected.

Vowel /a:/: Table 4.36 revealed that the mean F3 of vowel /a:/ in males of group 1 was 3375 Hz and the SD and range were 378.7 and 2480 Hz and for females they were 3534 Hz, 366.9 and 2320 Hz respectively. Males of group 2 had the mean, SD and range as 2703 Hz, 348.9 and 1840 Hz . The mean, SD and range for females of group 2 were 2790 Hz, 339 and 2120 Hz respectively. In males of group 3 the mean was

2470 Hz, SD was 230.4 and range was 1328 Hz and for females they were 2759 Hz, 368.8 and 1946 Hz respectively.

On inspection of Table 4.36 and Graph 46, it was evident that in both males and females F3 for /a:/ decreased from group 1 to group 3 linearly. SD also decreased with increase in age in males. But in females, group 3 had the highest SD followed by group 1 and group 2. The range of F3 for the vowel /a:/ decreased with increase in age in both males and females .

In different groups of males using one way ANOVA, it was observed that there was significant difference for F3 for vowel /a:/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F3 than males of groups 2 and 3 . Males of group 2 had significantly higher F3 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F3 of vowel /a:/ in Kannada" was rejected.

Similarly when different female groups were compared there was significant difference for F3 for vowel /a:/ between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3. Females of group 1 had significantly higher F3 than females of groups 2 and 3 and females of group 2 had significantly higher F3 than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /a:/ in Kannada" was rejected.

On gender comparison in each group it was noticed that there were significant differences between males and females of group 1, group 2 and group 3 for F3 for vowel /a:/. In all the three groups females had a higher F3 than males. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of/a:/ in group 1, group 2 and group 3 in Kannda" was rejected.

Vowel /u/: Scrutiny of Table 4.37 showed that the mean F3 of vowel /u/ in males of group 1 was 3079 Hz and the SD and range were 551.4 and 2000 Hz and for females they were 3334 Hz, 594.5 and 2400 Hz respectively. In males of group 2 , the mean, SD and range were 2532 Hz, 264.8 and 1280Hz and for females they were 2695 Hz, 346.5 and 1880 Hz respectively. Group 3 males had the mean as 2403 Hz, SD as 277.6 and range as 1632 Hz and for females of group 3 they were 2624 Hz, 358.7 and 1961 Hz respectively.

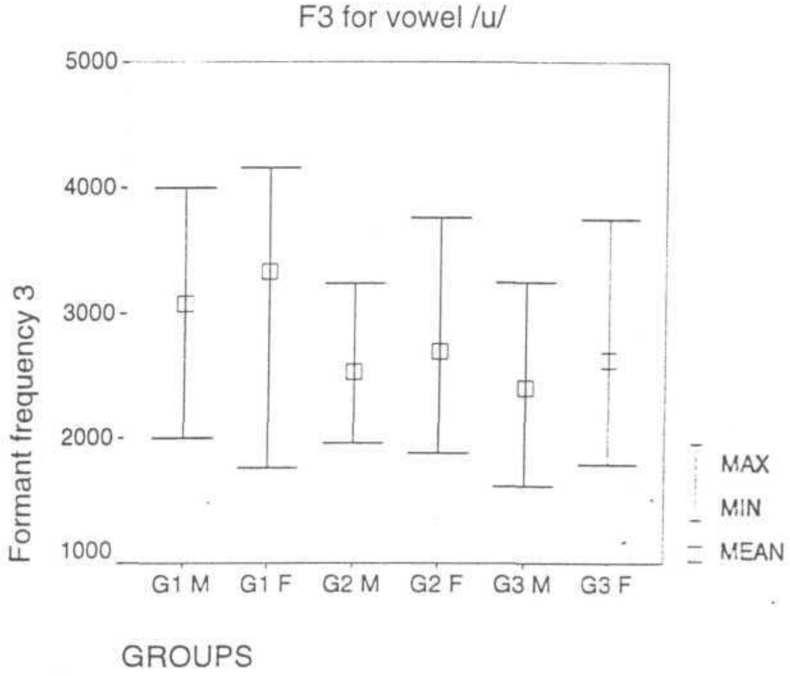
Table 4.37 and Graph 47 depicted that in both males and females values of F3 for /u/ decreased from group 1 to group 3. SD and range decreased from group 1 to group 3 and then to group 2 in both males and females.

		/u/		/u:/		/o/		/o:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	3079	3334	3013	3603	3217	3521	3436	3624
	SD	551.4	594.5	592.4	405.2	612.9	477.1	419.6	337.8
	Range	2000	2400	1923	1960	2300	2000	2280	1960
Group 2	Mean	2532	2695	2483	2736	2557	2749	2566	2769
	SD	264.8	346.5	308.6	326.5	272.7	300.6	281.3	313.2
	Range	1280	1880	1320	1640	1120	1360	1960	1920
Group 3	Mean	2403	2624	2468	2649	2452	2727	2506	2709
	SD	277.6	358.7	313.1	382.8	248	298.3	245	327.2
	Range	1632	1961	2193	1851	1318	1449	1687	1569

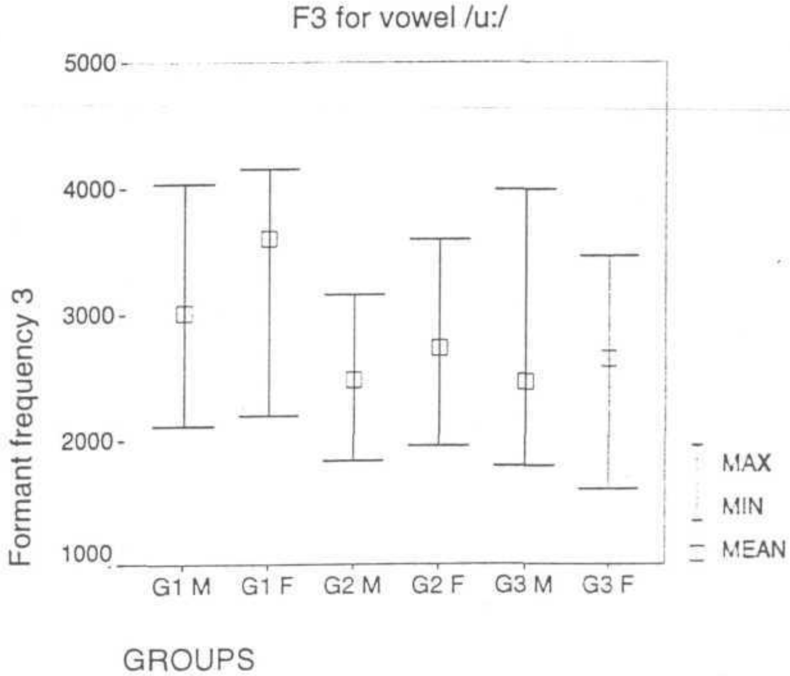
Table 4.37: Mean, SD and Range of F3 for back vowels in males and females of 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

On statistical analysis of scores of different groups of males, it was found that there was significant difference for F3 of vowel /u/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F3 than groups 2 and 3. Males of group 2 had significantly higher F3 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /u/ in Kannada" was rejected.

Similarly on comparison across the three female groups it was observed that females of group 1 had significantly higher F3 than females of groups 2 and 3 and females of group 2 had significantly higher F3 than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /u/ in Kannada" was rejected.



Graph 47



Graph 48

When comparing across males and females, females had significantly higher F3 in all the three groups. Thus the hypothesis stating that "there are no significant differences between males and females for F3 of /u/ in group 1, group 2 and group 3 in Kannada" was rejected.

Vowel /u/: On perusal of Table 4.15, the mean F3 of long vowel /u:/ in males of group 1 was 3013 Hz , SD was 592.4 and range was 1923 Hz . The mean, SD and range for females of group 1 were 3603 Hz, 405.2 and 1960 Hz respectively. Males of group 2 had the mean, SD and range as 2483 Hz, 308.6 and 1320 Hz and for females they were 2736 Hz, 326.5 and 1640 Hz respectively. In group 3 males had a mean of 2468 Hz, SD of 313.1 and range of 2193 Hz and for females they were 2649 Hz, 382.8 and 1851 respectively.

From the Table 4.37 and Graph 48, it was observed that both males and females had the values of F3 for /u:/ which decreased from group 1 to group 3. SD also decreased with increase in age in males and females. However in females, group 2 had a lower SD than group 3. The range of F3 for the vowel /u:/ in males was highest for group 3 followed by group land by group 2 respectively. In females, the range decreased from group 1 to group 3 and then to group 2.

Using one way ANOVA across different groups of males, it was noticed that there was significant difference for F3 of vowel /u:/ between males of groups 1 and 3 and groups 1 and 2. Males of group 1 had significantly higher F3 than groups 2 and 3.

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Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of the F3 of vowel /u:/ in Kannada" was rejected. But there was no significant difference between groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between males of group 2 and group 3 for F3 of the vowel /u:/ in Kannada" was accepted.

Comparison across the female groups revealed that females of group 1 had significantly higher F3 than females of groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 2 and groups 1 and 3 in terms of Fl of the vowel /u:/ in Kannada" were accepted. But there was no significant difference between groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 for F3 of the vowel /u:/ in Kannada" was rejected.

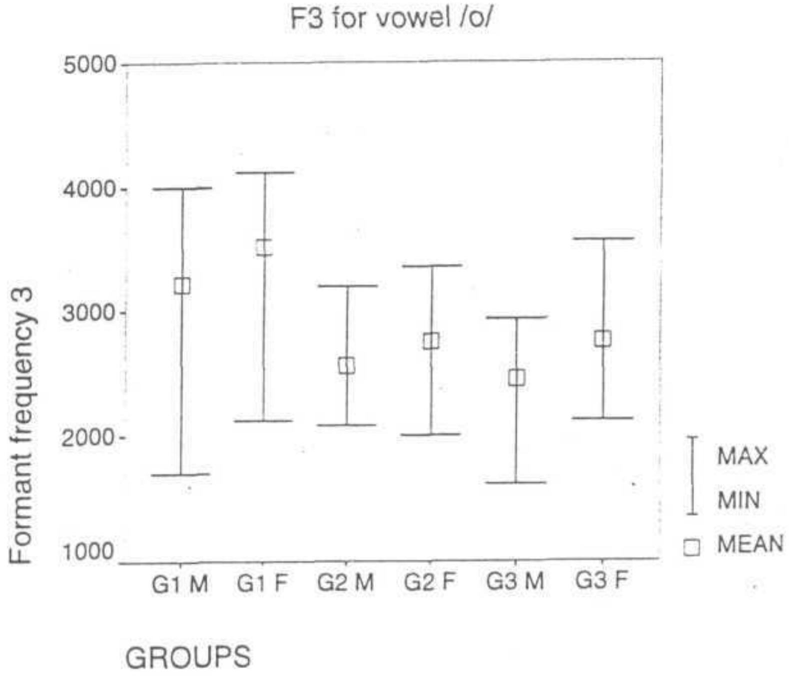
When males and females of each group was compared, females showed higher F3 for vowel /u:/ in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of/u:/ in group 1, group 2 and group 3 in Kannda" was rejected.

Vowel /o/: Study of Table 4.37 showed that the mean F3 of long vowel *lot* in males of group 1 was 3217 Hz and the SD and range were 612.9 and 2300 Hz and for females they were 3521 Hz, 477.1 and 2000 Hz respectively. Males of group 2 had the mean, SD and range as 2557Hz, 272.7 and 1120 Hz and for females they were 2749 Hz, 300.6 and 1360 Hz respectively. Group 3 males had the mean as 2452 Hz, SD as 248 and range as 1318 Hz and for females they were 2727 Hz, 298.3 and 1449 respectively.

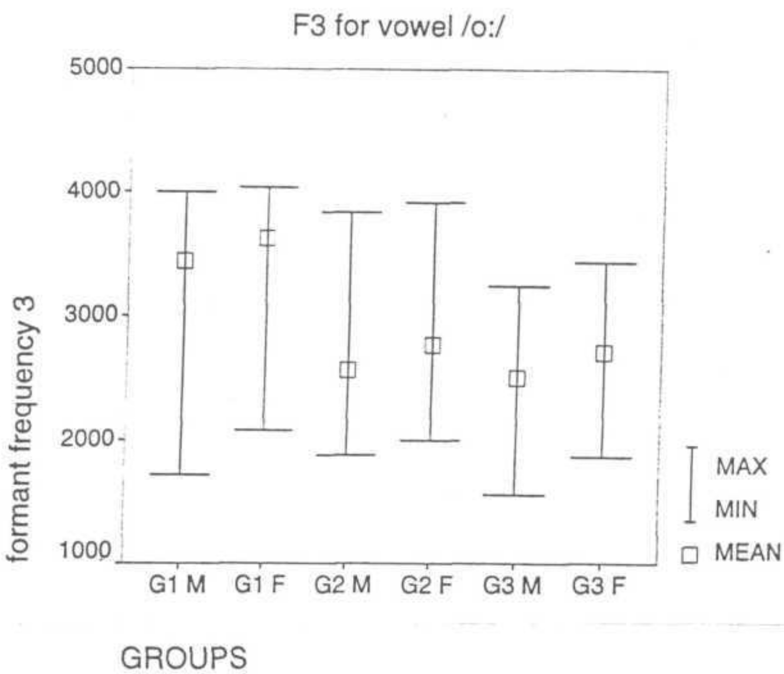
From Table 4.37 and Graph 49, it was inferred that both males and females had the values of F3 for *lol* which decreased from group 1 to group 3. SD decreased with increase in age in males and females. The range of F3 for the vowel /u:/ in males and females the range decreased from group 1 to group 3 and then to group 2.

Using one way ANOVA, comparison across the males showed that group 1 had significantly higher F3 than groups 2 and 3 and group 3 had significantly higher F3 than group 2. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F3 of vowel /o/ in Kannada" was rejected.

Similarly across the female groups, there was significant difference between groups 1 and 3 and groups 1 and 2 for F3 of vowel /o/. Females of group 1 had significantly higher F3 than females of groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups land 2 in terms of F3 of the vowel /*o/* in Kannada" was rejected. But there was no significant difference between females of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 for F3 of the vowel /*o/* in Kannada" was accepted.



Graph 49



Graph 50

On comparison across gender, females of all the three groups had higher F3 than males. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of /o/ in groups 1, 2 and 3 in Kannada" was rejected.

Vowel /o:/: Table 4.37 showed that the mean F3 for vowel /o:/ in males of group 1 was 3436 Hz and the SD and range were 419.6 and 2280 Hz and for females they were 3624 Hz, 337.8 and 1960 Hz respectively. The mean, SD and range for males of group 2 were 2566Hz, 281.3 and 1960 Hz and for females they were 2769 Hz, 313.2 and 1920 Hz respectively. Males of group 3 had a mean of 2506 Hz, SD of 245 and range of 1687 Hz . The mean, SD and range for females of group 3 were 2709 Hz, 327.2 and 1569 Hz respectively.

From the Table 4.37 and Graph 40, it was evident that in both males and females F3 for /o:/ decreased from group 1 to group 3. In males, SD decreased with increase in age. In females SD decreased from group 1 to group 3 and then to group 2. The range of F3 for the vowel /o:/ in males and females decreased with increase in age.

The results of comparison across males using one way ANOVA, it was noticed that there were significant differences for F3 of vowel /o:/ between males of groups 1 and 3 and males of groups 1 and 2. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 and groups 1 and 2 in terms of F3 for vowel /o:/ in Kannada" was rejected. There was no significant difference found between males of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between males of group 2 and group 3 for F3 of the vowel /o:/ in Kannada" was rejected.

On comparison across the female groups, there was significant difference between females of groups 1 and 3 and groups 1 and 2 for F3 of vowel /o:/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups land 2 for F3 for the vowel /o:/ in Kannada" was rejected. But there was no significant difference between females of groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups 2 and 3 for F3 of the vowel /o:/ in Kannada" was accepted.

On comparison across males and females it was observed that in all the groups females had higher F3 values. Hence the hypothesis stating that "there are no significant differences between males and females for F3 of/o:/ in groups 1, 2 and 3 in Kannada" was rejected.

Tables 4.38 and 4.39 show the presence or absence of significant difference in F3 between the different age groups.

Males	/i/	**/I:/**	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl vs G2	P	P	P	P	P	P	P	P	P	P	10/10
Gl vs G3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vs G3	P	P	P	P	P	P	P	A	P	A	8/10

Table 4.38: The results of test for significance of difference between the three age groups in males for F3 at 0.05 level

Females	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl vs G2	P	P	P	P	P	P	P	P	P	P	10/10
Gl vs G3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vs G3	P	A	P	P	p	P	A	A	A	A	5/10

Table 4.39: The results of test for significance of difference between the three age groups in males for F3 at 0.05 level

The study of Tables 4.38 and 4.39 showed that F3 was significantly higher in group 1 compared to groups 2 and 3 in both males and females. Also group 2 had significantly higher F3 than group 3 in both males and females. However in females the difference was not observed mainly for the back vowels.

When scaling of F3 was done applying the procedure used by Peterson and Barney (1952), it was found that in males, group 1 had higher F3 than groups 2 and 3 by 20% and 25% respectively. This finding is in consonance with Peterson and Barney's (1952) reports that formant frequencies of eight year old children are about 25% higher than that of adult males and 20% higher than that of adult females. Group 2 had higher F3 than group 3 by 7% in males. In females, group 1 had higher F3 than groups 2 and 3 by 20% and 21% respectively. Females of group 2 had higher F3 than group 3 females by 2% (Table 4.40). Hence it was found that there was a linear decrease in F3 from children to adolescents and further marked decrease in adults in both sexes.

Formants	Group 1 / Group 3		Group 1 / Group 2		Group 2 / Group 3	
	M	F	M	F	M	F
Fl	16%	5%	14%	5%	3%	2%
F2	23%	18%	16%	16%	10%	3%
F3	25%	21 %	20%	20%	7%	2%

Table 4. 40 : Shows the percentage by which group 1 is greater than groups 2 & 3 and by which group 2 is greater than group 3 for formant frequencies.

From the results obtained on the formant frequencies it seemed that the developmental trend appeared more strongly when children versus adult male comparisons were made. In females the developmental trend was less obvious as they had higher formants similar to children. This is in accordance with Eguchi and Hirsh (1969) who reported that children aged six years had formant values equal to those for the woman subjects. In general the formant frequency values of vowels produced by children decrease with increase in age. Borden and Harris (1980) reported that relative formant positions for a particular vowel are similar for men, women and children, but the actual resonant frequencies are higher for small vocal tracts. The differences in the frequencies of formants is not simply related to change in length, however because the larger vocal tracts of men have a relatively larger ratio of pharyngeal area to oral cavity area compared to women or children.

Mvs F	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl	♀	P	P	P	P	P	P	♀	♀	P	10/10
G2	P	P	P	P	P	P	P	P	P	P	10/10
G3	P		P	P	P	P	P	P	P	P	10/10

Table 4.41: The results of test for significance of difference between males and females for F3 at 0.05 level

It was clear from Table 4.41 that there was significant difference in F3 across gender in all the three groups. Generally females had significantly higher F3 than their male counterparts. Further, F3 of vowels produced by males and females were compared by means of scale factors based on the method proposed by Fant (1966). The scaling results are presented in Table 4.42.

Scale factor for Third formant frequency

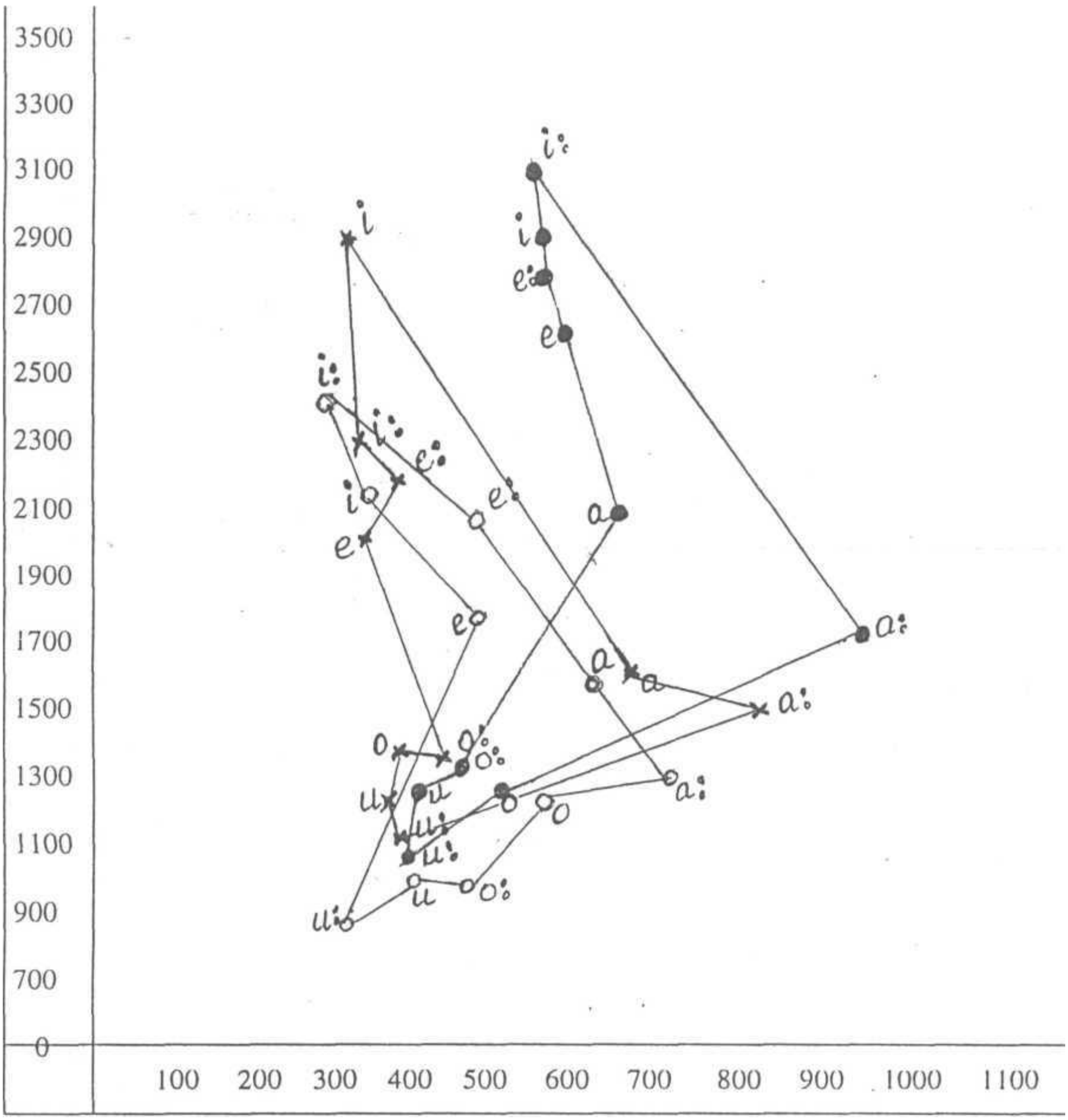
$$K3 = \frac{\text{F3 of female}}{\text{F3 of male}} - 1 \times 100$$

Using the above formula it was found that females had higher F3 in groups 1 and 2 by 6% and in group 3 by 10%. Venkatesh(1995) reported that adult females had higher F3 than adult males by 14 %. Fant (1966) found the scale factor to be around 18% in case of Swedish speakers. According to Chiba & Kajiyama (1941), the total length of an average female vocal tract is about 15% shorter than an average male vocal tract. The higher formant frequencies found in females may be because of the shorter vocal tract in them when compared to males.

Formants	**Group 1**	**Group 2**	**Group 3**
Fl	**-3 %**	**7%**	11 %
F2	**6%**	**6%**	12%
F3	**6%**	**6%**	10%

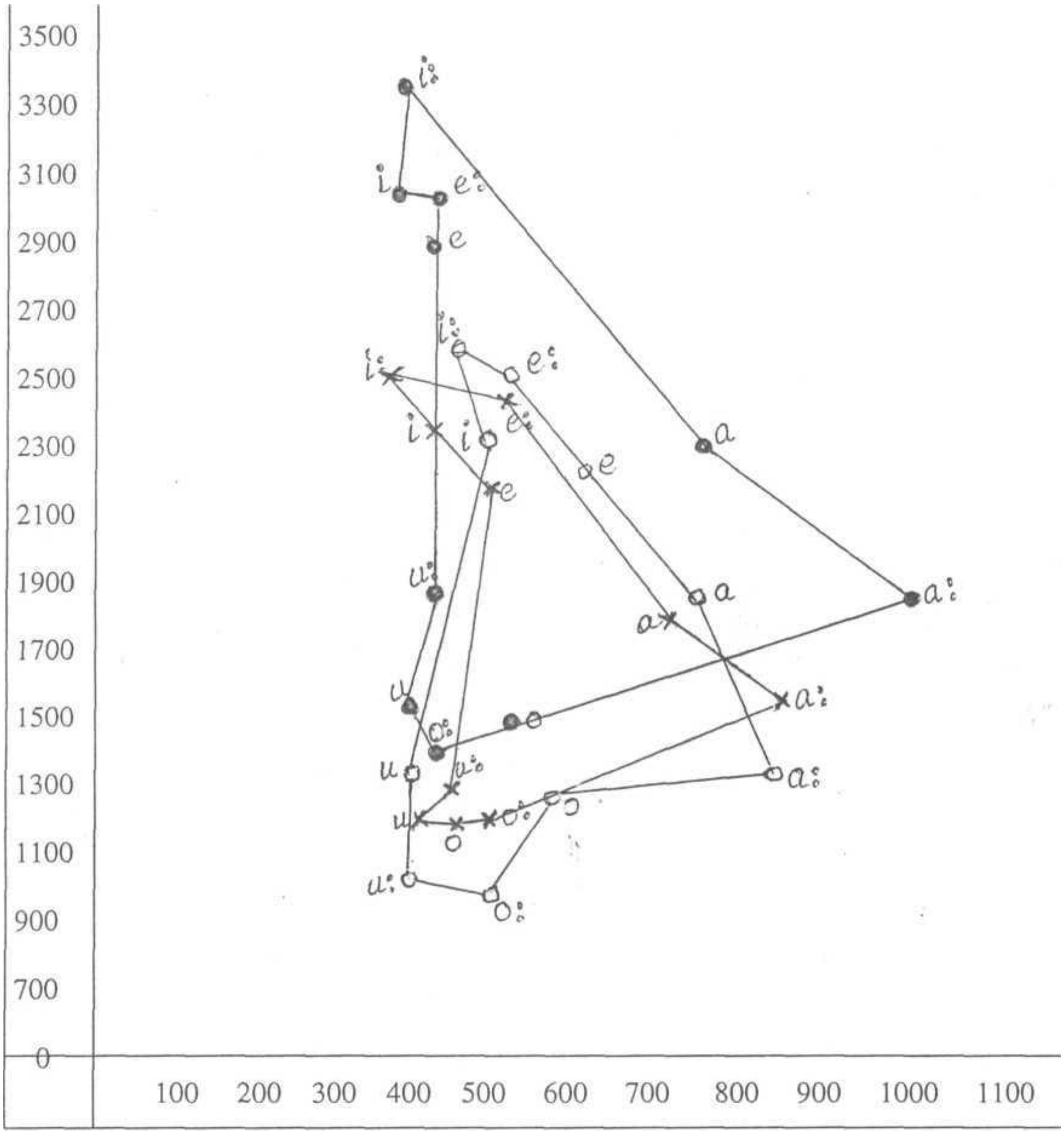
Table 4.42 : Shows the Female / male formant frequency percentage in different groups

Table 4.43 presents the values of F1,F2 and F3 in males and females of different age groups obtained in the present study for Kannada vowels. Graph 51 and Graph 52 show Fl v/s F2 scatter plots for mean values of all the three formants in males and females



Graph 51: Scatter plot of formant frequencies of vowels in Kannada for the three groups of males.

O - Adults X - Adolescents ● - Children



Graph 52: Scatter plot of formant frequencies of vowels in Kannada for the three groups of females.

O - Adults X - Adolescents ● - Children

respectively. Table 4. 44 shows the formant frequencies of the vowels obtained in the present study and other studies in Kannada for adults.

Vowels	Formants	Group 1		Group 2		Group 3	
		M	F	M	F	M	F
A	Fl F2 F3	788 2043 3433	766 2149 3573	698 1625 2747	714 1825 2897	616 1507 2488	733 1766 2784
A:	Fl F2 F3	**1030** 1792 3375	999 1778 3534	806 1457 2703	895 1594 . 2790	732 1296 2470	875 1490 2759
I	Fl F2 F3	428 2831 3714	424 3040 3683	387 2316 3071	401 2467 3173	375 2162 2821	423 2468 3055
I:	Fl F2 F3	447 **2974** 3778	412 3301 3970	369 2487 3176	383 2692 3296	344 2316 2991	393 2656 3314
U	F1 F2 F3	453 1276 **3079**	477 1323 3334	404 1213 2532	429 1218 2695	406 1063 2403	436 1130 2624
U:	Fl F2 F3	453 **1204** **3013**	473 1184 3603	412 1107 2483	421 1115 2736	368 892 2468	416 935 2649
e	Fl F2 F3	510 **2537** 3634	509 2709 3792	463 2099 2983	523 2272 3106	509 1888 2655	531 2258 3015
E:	Fl F2 F3	492 2819 3672	466 3023 3836	401 2279 2996	447 2434 3071	424 2157 2767	447 2518 3186
0	Fl F2 F3	501 **1168** **3217**	496 1386 3521	477 1187 2557	507 1167 2749	495 1171 2452	561 1177 2727
0:	Fl F2 F3	499 1272 3436	476 1229 3624	455 1156 2566	480 1151 2769	445 938 2506	463 971 2709

Table 4. 43: Fl, F2 and F3 for vowels in Kannada in males and females of different age groups obtained in the present study

From the examination of Table 4.43 , the following observations have been made on Fl,F2andF3 :

a) Among the four **front vowels** considered in the study, vowel *Id* had the highest and vowel /I:/ had the lowest Fl in both males and females of groups 1 and 2 and 3.

b) Vowel /I:/ had the highest and vowel /e/ had the lowest F2 in both males and females of groups 1 and 2 and 3. Venkatesh (1995) also reported that vowel /I:/ had the highest F2 in adult males and females.

c) Vowel /I:/ had the highest and vowel /e/ had the lowest F3 in males of groups 1, 2 and 3. In females of all the three groups /I;/ had the highest F3 and vowel /i/ had the lowest F3 in groups 1 and 3 . Vowel /e/ had the lowest F3 in females of group 2.

d) Vowels /a:/ had the highest and /a/ had the lowest Fl in all the groups among the **central vowels.**

e) Vowel /a/ had the highest and vowel /a:/ had the lowest F2 in all the groups for both males and females.

f) Vowel /a/ was higher than vowel /a:/ for F3 in all the groups for both males and females.

g) Among the **back vowels,/o/** had the highest Fl in males for all the three groups. Fl was lowest for vowel /u:/ in groups 1 and 3 and /u/ in group 2 in males. In females vowel /o:/ had the highest Fl in group 1 and /o/ was highest in groups 2 and 3. Fl was lowest for /u:/ in the three groups of females.

h) Vowel /u/ had the highest F2 in males of groups 1 and 2 and vowel /o/ in group 3. Vowel /o/ had the lowest F2 in group 1 and vowel /u:/ had the lowest F2 in groups 2 and 3 in males. In females, /o/ had highest F2 in groups 1 and 3 and /u/ in group 2. F2 was lowest for vowel /u:/ for all the three groups of females. Venkatesh (1995) also reported that vowel /u:/ had the lowest F2 in adult males and females.

i) Vowel /o:/ had the highest F3 in all groups of males and females except in females of group 3 which showed highest F3 for vowel *lol*. Vowel /u:/ had the lowest F3 for males of groups 1 and 2. Vowel /u/ had the lowest F3 in group 3 males and females of groups 1, 2 and 3.

Vowels	Formants	Rajapurohit (1982) Males	Savithri 1989	Venkatesh (1995)		Present study	
				M	F	M	F
A	Fl F2 F3	750 1500 2500	670 1535 2690	556 1419 2628	674 1685 2845	616 1507 2488	733 1766 2784
a:	Fl F2 F3	800 1400 2600	-	696 1222 2581	855 1482 2955	732 1296 2470	875 1490 2759
I	Fl F2 F3	280 2200 2800	380 2105 2855	379 2158 2799	456 2585 3199	375 2162 2821	423 2468 3055
I:	Fl F2 F3	305 2300 3100	-	348 2337 3024	415 2841 3531	344 .2316 2991	393 2656 3314
U	Fl F2 F3	260 460 1000	450 725 2445	414 1240 2596	499 1344 2977	406 1063 2403	436 1130 2624
U:	Fl F2 F3	300 500 1000	-	385 918 2671	463 948 2924	368 892 2468	416 935 2649
e	Fl F2 F3	400 2000 3500	490 1670 2300	457 2031 2686	505 2393 3125	509 1888 2655	531 2258 3015
E:	Fl F2 F3	500 2200 3500	-	435 2225 2795	522 631 3278	424 2157 2767	447 2518 3186
0	Fl F2 F3	500 1000 2200	515 1170 2155	530 1174 2573	571 1324 2837	495 1171 2452	561 1177 2727
0:	Fl F2 F3	600 1000 2500	-	446 1065 2634	513 1154 2929	445 938 2506	463 971 2709

Table 4.44: Fl, F2 and F3 of vowels obtained in the present study and other studies in Kannada

The formant data of the present study was compared with the formant data of Kannada vowels obtained by Rajapurohit (1982), Savithri (1989) and Venkatesh (1995). Rajapurohit (1982) has measured the formant data based on the utterances of one male subject and Savithri (1989) has measured the formant data only for short vowels using three male subjects. Venkatesh (1995) has measured the formant data for all the ten vowels for both adult males and females in the context of a single consonant /k/. The formant data obtained in the present study agreed more with data obtained by Savithri (1989) and Venkatesh (1995) than with Rajapurohit (1982). This may be due to the dialectical variations and the individual differences in the vocal tract structure.

The results of the present study are in consonance with several earlier studies. Potter and Peterson (1948) and Kent (1976) reported that formant frequencies of vowels in children are higher than that of adult females and higher yet than the values for adult males. Eguchi and Hirsh (1969) noted a systematic lowering in average Fl and F2 as a function of increasing age, which was attributed to a generalized lengthening of the vocal tract. Study by Dalston (1975) revealed that Fl, F2 and F3 were larger and more overlapping for children than for adults. Lieberman's (1990) study also showed that the most obvious acoustic distinction between the vowels of younger children, older children and adults was the higher values of formant frequencies in younger children. Elizabeth (1998) has also reported that formants reduced in frequency as age progressed from 7-8 years to adults. Another salient observation made in the present study was that the drop in formant frequencies were more in F2 and F3 than in Fl from children to adults. Similar observation was made by Eguchi and Hirsh (1969). Hence Fl was more stable and appears to be fairly independent of age.

In the present study of vowels of Kannada, the variability in formant frequencies also decreased with increasing age from children to adolescents. Further reduction in variability to adults was not very significant. Eguchi and Hirsh (1969) has also noticed that at about the age of 11 or 12 years the variability in children was same as the variability in adults. They viewed their data on Fl and F2 as evidence that the young children were more inaccurate in articulatory positioning than the older subjects. They remarked that younger children do not move their tongues to exactly the same position for a particular vowel as it occurs in repetitions of the same sentence, at least not so exactly the same as older children and adults. In the present study of vowels of Kannada, on overall observation the variability of Fl and F2 was higher for central vowels whereas for F3 the variability was higher for the back vowels in all the groups. However for all the vowels variability in formants decreased with increase in age. Eguchi and Hirsh (1969) noted in their data that variability of Fl was higher for middle vowels than high front or high back vowels.

The present study on vowels of Kannada also showed that there were systematic differences between the average formant frequencies of male and female speakers, that is the formants were higher in the female subjects. The obtained results are in agreement with the studies carried out by Peterson and Barney (1952), Eguchi and Hirsh (1969), Fant (1973) and Venkatesh (1995). In adult females, vocal tract tend to be shorter than those of adult males and accordingly female formants tend to be higher in frequency. Pols et al (1973) and Van Nierop et al (1973) found a significant difference between male and female formant frequencies in Dutch vowels. Yang (1996) made a comparative study of American English and Korean vowels produced by male and female speakers and the data revealed considerable variation in vocal tract length between male and female speakers. However in the present study, it was found that the difference across sex in children was overlapping, that is, for some of the vowels males had higher formants than females and vice versa. Benett (1980) also reported that there were areas where mean formant values for males and females overlapped and even some children's formant frequencies fell in the regions typical of the opposite sex in the seven and eight year old groups. In the present study a larger degree of overlap occurred for Fl. With respect to F2, there was substantial separation between males and females for most of the vowels and with respect to F3 it was present for all the ten vowels.

Based on the results obtained on formant frequencies in the present study, the following conclusions have been drawn:

a) Formant frequencies (Fl, F2 and F3) decreased from children to adolescents markedly and there was further gradual decrease to adults.
b) The drop in formant frequencies were more in F2 and F3 than in Fl from childhood to adulthood. Fl was more stable and appears to be fairly independent of age.
c) For all the vowels variability in formants decreased with increase in age.
d) In children Fl was higher in males and in adolescents and adults it was higher in females. F2 and F3 were higher in females than their male counterparts in all the three groups.

2.d Fundamental frequency (FO)

The F0 of the vowel was defined as the fundamental frequency at the mid point of the first vowel in the test word /C_1 $V_1C_2V_2$/.

Vowel /i/: It was evident from the study of Table 4.45 that the mean F0 of vowel /i/ in males of group 1 was 266 Hz and the SD and range were 20.5 and 98 Hz and for females of group 1 they were 254 Hz, 26.8 and 122 Hz respectively. Males of group 2 had a mean of 183 Hz, SD of 35.9 and range of 140 Hz and for females they were 251 Hz, 18.6 and 145 Hz respectively. The mean, SD and range for males of group 3 were 126 Hz, 10.7 and 74 Hz and for females of group 3 they were 197 Hz, 20.1 and 122 Hz respectively.

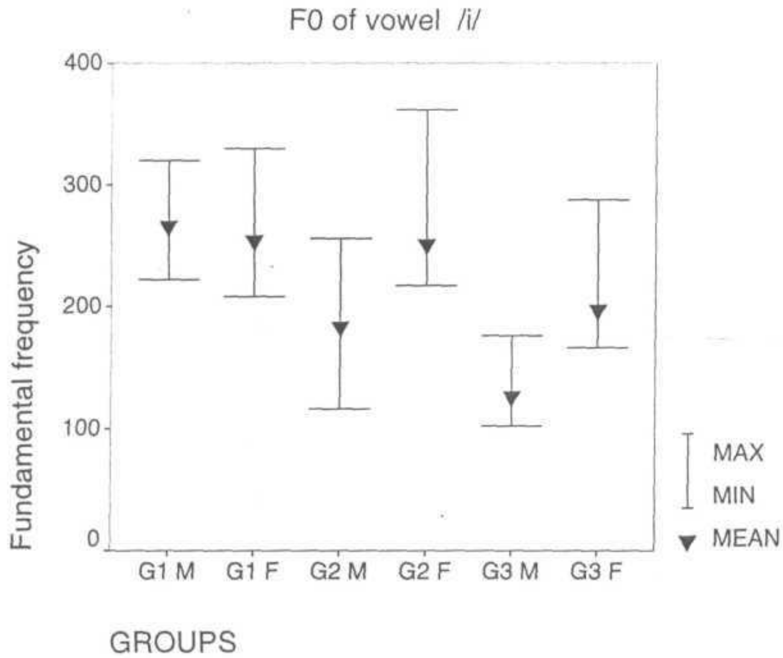
From the examination of Table 4.45 and Graph 53, it was observed that in both males and females FO of/i/decreased from group 1 to group 3. It was found that the SD in males was highest in group 2 followed by group 1 and 3 respectively. SD in females was highest in group 1 and then decreased to group 3 and 2 respectively. The range of FO for the vowel /i/ in males was highest in group 2 followed by group I and 3 respectively. In females the range was highest in group 2 and groups 1 and 3 had equal range.

On comparison using one way ANOVA among the males of three groups, it was observed that males of group 1 had significantly higher FO than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of FO of the vowel /i/ in Kannada" was rejected. When males of group 2 were compared with males of group 3 there was significant difference in FO of the vowel /i/ with group 2 having a higher FO. Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of FO of the vowel /i/ in Kannada" was rejected.

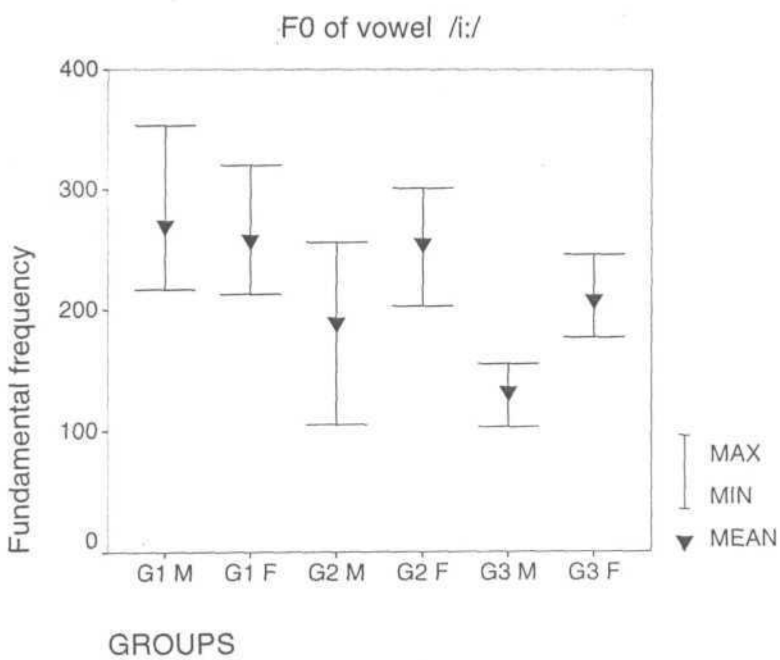
	/i/		/i:/		/e/		/e:/	
	M	F	M	F	M	F	M	F
Group 1 -Mean	266	254	270	258	261	245	264	249
SD	20.5	26.8	23.5	26.3	23.7	20.6	20.1	22.4
Range	98	122	136	107	169	79	93	110
Group 2- Mean	183	251	189	255	185	242	189	242
SD	35.9	18.6	36.2	20.5	36.4	17.4	33.9	16.1
Range	140	145	151	200	132	80	119	72
Group 1-Mean	126	197	131.9	208	124.7	189	126.7	193
SD	10.7	20.1	11.5	18.1	10.8	19.2	11.3	18.2
Range	74	122	52	69	78	124	73	69

Table 4.45: Mean, SD and Range of F0 for front vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

Similarly in females using ANOVA, it was found that there was significant difference between females of groups 1 and 3 and groups 2 and 3. Females of group 3 had lower F0 in both cases. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, and groups 2 and 3 in terms of F0 of the vowel /i/ in Kannada" were rejected. On comparing females of groups 1 and 2, no significant difference in F0 was found. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of F0 of the vowel *I'll* in Kannada" was accepted.



Graph 53



Graph 54

When the males and females of group 1 were compared, F0 was significantly higher in males. Hence the hypothesis stating that "there is no significant difference between males and females for FO of /i/ in group 1 in Kannada" was rejected. In group 2 and group 3, FO of vowel /i/ was significantly higheT in females. Hence the hypothesis stating that "there are no significant differences between males and females for FO of /i/ in group 2 and group 3 in Kannada" was rejected.

Vowel /I:/: On examination of Table 4.45, it was found that the mean FO of vowel /I:/ in males of group 1 was 270 Hz and the SD and range were 23.5 and 136 Hz and for females of group 1 they were 258 Hz, 26.3 and 107 Hz respectively. Males of group 2 had a mean of 189 Hz, SD of 36.2 and range of 151 Hz and for females they were 255 Hz, 20.5 and 200 Hz respectively. In group 3, males had the mean as 131.9 Hz, SD as 11.5 and range as 52 Hz and for females of group 3 they were 208 Hz, 18.1 and 69 respectively.

It was clear from Table 4.45 and Graph 54 that both males and females showed the values of F0 for /I:/ which decreased from group 1 to group 3. It was found that the SD in males decreased from group 2 to group 1 and then to group 3. In females SD decreased with increase in age. The range of F0 for the vowel /I:/ in males and females decreased from group 2 to group 1 and then to group 3.

On comparison across male of different groups using one way ANOVA, it wns disclosed that males of group 1 had significantly higher F0 for /I:/ than males of group 2 and group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of F0 of the vowel /I:/ in Kannada" was rejected. When males of group 2 were compared with males of group 3, FO of vowel /I:/ was significantly higher in group 2 . Hence the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of FO of the vowel /I:/ in Kannada" was rejected.

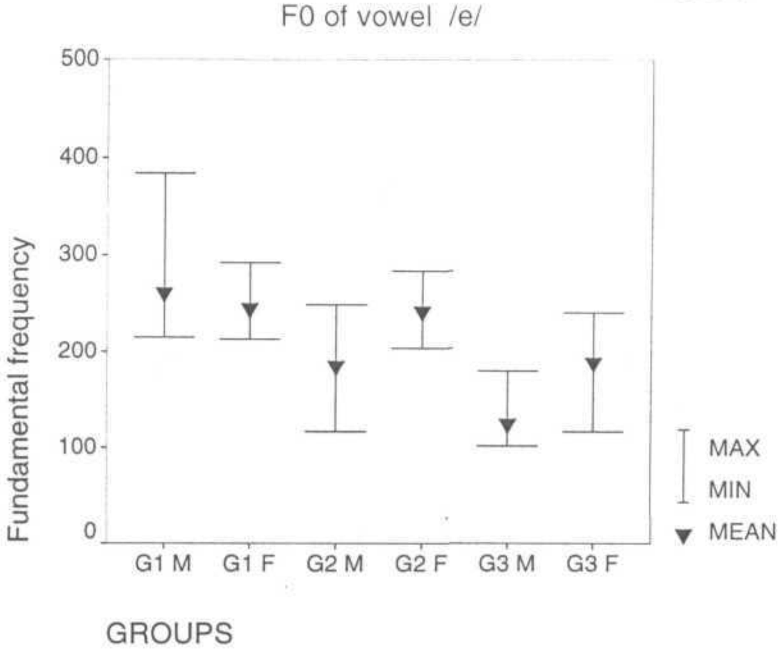
Similarly when the females of the three groups were compared, it was found that there was significant difference between females of groups 1 and 3 and females of groups 2 and 3 for FO of vowel /I:/. In both cases females of group 3 had lower FO. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and 2 and 3 in terms of F0 of vowel */I:/* in Kannada" was rejected. And there was no significant difference between females of groups 1 and 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of FO of the vowel /I:/ in Kannada" was accepted.

When males and females of group 1 were compared, F0 of vowel /I:/ was significantly higher in males. Therefore the hypothesis stating that "there is no significant difference between males and females for F0 of /I:/ for group 1 in Kannada" was rejected. On comparison across gender in groups 2 and 3, females had significantly higher F0. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /I:/ in groups 2 and 3 in Kannada" was rejected.

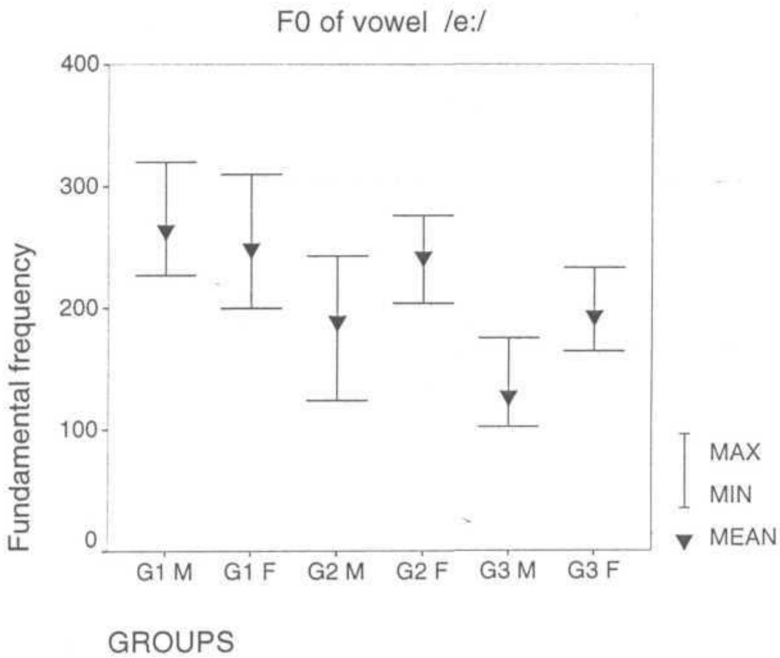
Vowel /e/*:* it was evident from Table 4.45 that the mean FO of vowel /e/ in males of group 1 was 261 Hz and the SD and range were 23.7 and 169 Hz and for females they were 245 Hz, 20.6 and 79 Hz respectively. In males of group 2, the mean was 185 Hz, SD was 36.4 and range was 132Hz and for females they were 242 Hz, 17.4 and 80 Hz respectively. The mean, SD and range for males of group 3 were 125 Hz, 10.8 and 78 Hz and for females they were 189 Hz, 19.2 and 124 respectively.

From Table 4.45 and Graph 55, it was evident that in both males and females FO for vowel /e/ decreased with increase in age. It was found that the SD was highest in group 2 followed by groups 1 and 3 respectively in males. In females, SD was highest in group 1 followed by group 3 and group 2 respectively. The range of FO for the vowel /e/ decreased with increase in age in males where as in females range seemed to increase with increase in age.

The results of comparison across different groups of males using one way ANOVA, it was observed that there was significant difference for F0 of vowel /e/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in males. Males of group 1 had significantly higher F0 than groups 2 and 3 and group 2 had significantly higher F0 than group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of the F0 of vowel /e/ in Kannada" was rejected.



Graph 55



Graph 56

On comparison across the different female groups it was found that there was significant difference for F0 of vowel *Id* between groups 1 and 3, and groups 2 and 3. Females of group 3 had lower F0 in both cases. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 in terms of the F0 of vowel /e/ in Kannada" was rejected. But there was no significant difference for F0 of vowel /e/ between females of groups 1 and 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 in terms of the F0 of vowel /e/ in Kannada" was accepted.

When males and females of each group were compared, F0 of vowel /e/ was significantly higher in males of groupl. Hence the hypothesis stating that "there is no significant difference between males and females for F0 of /e/ for group 1 in Kannada" was rejected. On comparison across gender in groups 2 and 3, it was noticed that females had significantly higher F0 than males. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /e/ for groups 2 and 3 in Kannada" was rejected.

Vowel /e:/: On perusal of Table 4.45 it was observed that the mean F0 of vowel /e:/ in males of group 1 was 264 Hz and the SD and range were 20.1 and 93 Hz and for females they were 249 Hz, 22.4 and 110 Hz respectively. Males of group 2 had the mean as 189 Hz, SD as 33.9 and range as 119 Hz and for females they were 242 Hz, 16.1 and 72 Hz respectively. In males of group 3 the mean was 127 Hz, SD was 11.3 and range was 73 Hz and for females they were 193 Hz, 18.2 and 69 Hz respectively.

From the scrutiny of Table 4.45 and Graph 56, it was made out that both males and females had the values of FO for /e:/ which decreased with increase in age. It was found that the SD was highest in group 2 followed by groupl and group 3 respectively. In females, SD was highest in group 1 and then decreased to group 3 and group 2 respectively. The range of F0 for the vowel /e:/ was highest in group 2 followed by groupl and group 3 respectively in males. In females the range for FO of /e:/ was highest in group 3 and then decreasing to group l and group 2 respectively.

Among the three groups of males using one way ANOVA, it was seen that males of group 1 had significantly higher F0 than males of groups 2 and 3. And males of group 2 had significantly higher F0 than males of group 3. Hence the hypothesis stating **that** "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F0 of vowel /e:/ in Kannada" was rejected.

In case of female groups statistical comparison showed that there was significant difference for FO of vowel /e:/ between groups 1 and 3, groups 1 and 2 and groups 2 and 3. Hence the hypothesis stating that "there is no significant difference between females of groups I and 3, groups 1 and 2 and groups 2 and 3 for F0 of vowel /e:/ in Kannada" was rejected.

The results of comparison between males and females showed that males had significantly higher F0 in group 1. Hence the hypothesis stating that "there is no significant difference between males and females for F0 of /e:/ for group 1 in Kannada" was rejected. Females had significantly higher F0 than males in group 2 and group 3 for vowel /e:/. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /e:/ for group 2 and group 3 in Kannada" was rejected.

Vowel /a/: On examination of Table 4.36 it was found that the mean F0 of vowel /a/ in males of group 1 was 259 Hz and the SD was 20.5 and the range was 93 Hz and for females they were 245 Hz, 22.1 and 102 Hz respectively. In males of group 2 the mean was 180 Hz, SD was 37 and range was 146 Hz and for females they were 240 Hz, 17.5 and 101 Hz respectively. Group 3 males had a mean F0 of 121 Hz, SD of 9.8 and range of 54 . The mean, SD and range for females of group 3 were 186 Hz, 19.2 and 130 Hz respectively.

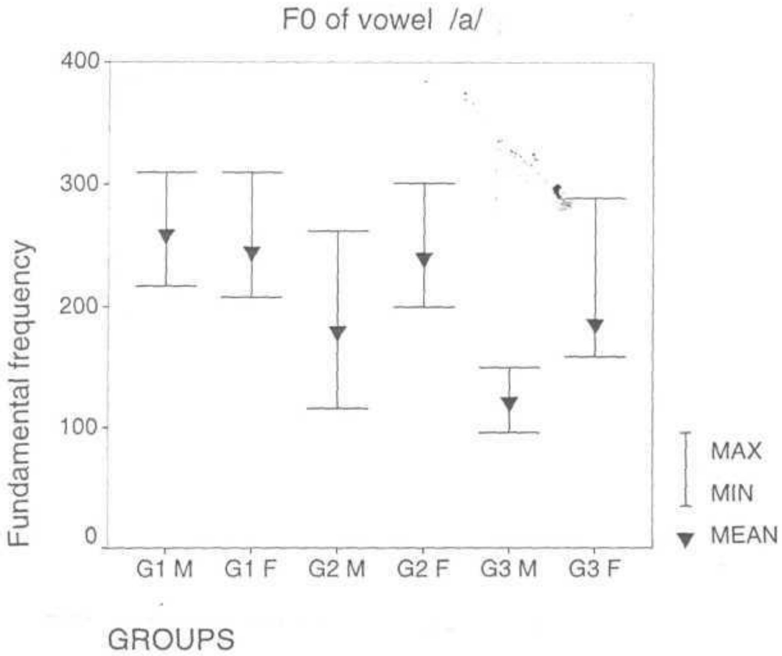
From the examination of Table 4.46 and Graph 57, it was evident that both males and females had the values of F0 for /a/ which decreased from group 1 to group 3. SD was highest in group 2 followed by groups 1 and 3 respectively in males. In females SD was highest in group 1 followed by groups 3 and 2 respectively. The range of F0 was highest in group 2 followed by groups 1 and 3 in males. In females it decreased from group 3 to group 1 and then to group 2.

	/a/		/a:/	
	M	F	M	F
Group 1 -Mean	259	245	256	252
SD	20.5	22.1	20.5	25.5
Range	93	102	104	118
Group 2- Mean	180	240	185	239
SD	37	17.5	34.2	16.8
Range	146	101	154	88
Group 1 - Mean	121	186	121	187
SD	9.8	19.2	11	25.3
Range	54	130	67	132

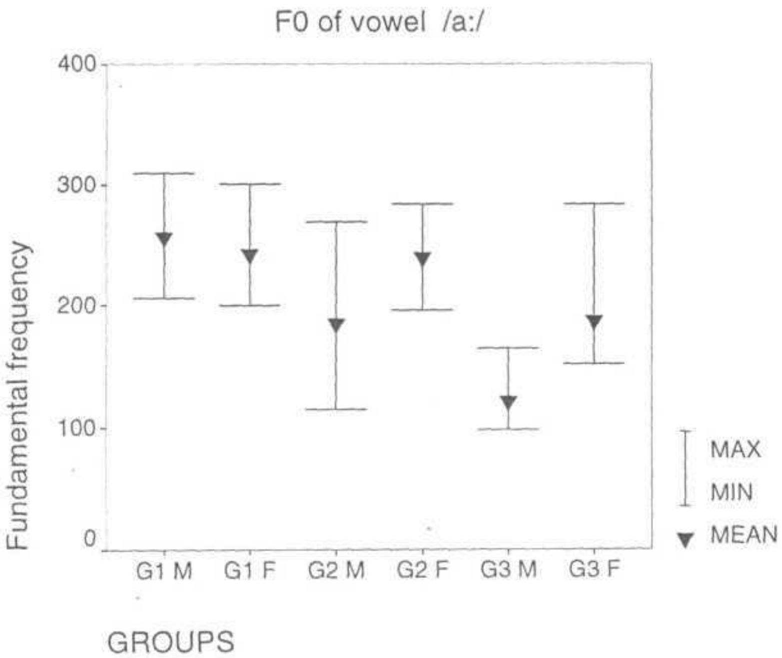
Table 4.46 : Mean, SD and Range of FO for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

When the males of the three groups were compared, it was noticed that there were significant differences for F0 of vowel /a/ between groups 1 and 3 , groups 1 and 2 and groups 2 and 3. Males of group 1 had significantly higher F0 than males of groups 2 and 3. And males of group 2 had significantly higher F0 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups **1** and 3, groups 1 and 2 and groups 2 and 3 in terms of the F0 of vowel /a/ in Kannada" was rejected.

Similarly across the three female groups, there was significant difference for F0 of vowel /a/ between groups 1 and 3 , groups 1 and 2 and groups 2 and 3. Females of group 1 had significantly higher F0 than females of groups 2 and 3. And females of group 2 had significantly higher F0 than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3,



Graph 57



Graph 58

groups 1 and 2 and groups 2 and 3 in terms of the F0 of vowel /a/ in Kannada" was rejected.

When comparisons across males and females were carried out, it was observed that males of group 1 had significantly higher F0 than females of group 1. Thus the hypothesis stating that "there is no significant difference between males and females for F0 of /a/ for group 1 in Kannada" was rejected. Females had higher F0 in groups 2 and 3 for vowel /a/ than their male counterparts. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /a/ for group 2 and group 3 in Kannada" was rejected.

Vowel /a:/: On observation of Table 4.46 it was found that the mean F0 of vowel /a:/ in males of group 1 was 256 Hz and the SD and range were 20.5 and 104 Hz and for females were 252 Hz, 25.5 and 118 Hz respectively. Males of group 2 had the mean as 185 Hz, SD as 34.2 and range as 154 Hz and for females they were 239 Hz, 16.8 and 88 Hz respectively. The mean, SD and range for males of group 3 were 121 Hz, 11 and 67 Hz and for females of group 3 they were 187 Hz, 25.3 and 132 Hz respectively.

It was evident from Table 4.46 and Graph 58 that both males and females had linearly decreasing values of F0 for /a/ from group 1 to group 3. SD was highest in group 2 followed by groups 1 and 3 respectively in males. In females SD was highest in group 1 followed by groups 3 and 2 respectively. The range of FO was highest in group 2 followed by groups 1 and 3 in males. In females it decreased from group 3 to group 1 and then to group 2

On comparison across males of different age groups studied using one way ANOVA, it was observed that males of group 1 had significantly higher F0 than males of groups 2 and 3. And males of group 2 had significantly higher F0 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F0 of vowel /a:/ in Kannada" was rejected.

Using ANOVA when the female groups were compared, there' was significant difference for F0 for vowel /a:/ between groups 1 and 3 , groups 1 and 2 and groups 2 and 3. Females of group 1 had significantly higher F0 than females of groups 2 and 3. And females of group 2 had significantly higher F0 than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for F0 of vowel /a:/ in Kannada" was rejected.

On comparison across sex, males of group 1 had significantly higher F0. Hence the hypothesis stating that "there is no significant difference between males and females for F0 of /a:/ for group 1 in Kannada" was rejected. Females had higher F0 in groups 2 and 3 for vowel /a:/. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /a:/ for group 2 and group 3 in Kannada" was rejected.

Vowel /u/: It was found from Table 4.47 that the mean F0 of vowel /u/ in males of group 1 was 268 Hz and the SD and range were 20.5 and 112 Hz and for females of group 1 they were 252 Hz, 25.5 and 118 Hz respectively. The mean, SD and range for males of group 2 were 185 Hz, 35.7 and 133 Hz and for females they were 250 Hz, 17.7 and 92 Hz. The mean, SD and range for males of group 3 were 129 Hz, 9.8 and 47 Hz and for females of group 3 they were 203 Hz, 21.7 and 119 Hz respectively.

On examining Table 4.47 and Graph 59, it was evident that both males and females showed the values of FO for /u/ which decreased from group 1 to group 3. In males SD was highest in group 2 and next in order were group 1 and 3. SD in females followed the decreasing order of group 1, group 3 and group 2. The range of FO was highest in group 2 followed by groups 1 and 3 in males. It was highest in group 3 and then decreased to groups 1 and 2 in females.

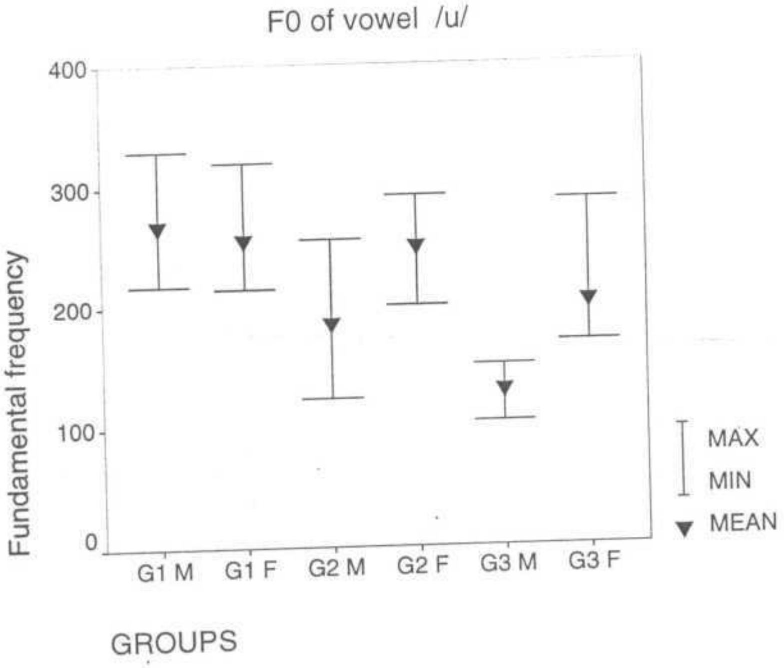
	/u/		/u:/		/o/		/o:/	
	M	F	M	F	M	F	M	F
Group 1 - Mean	268	252	273	256	255	245	267	251
SD	20.5	25.5	20.7	23.3	19.1	22.9	21.5	24.6
Range	112	118	113	105	78	110	97	106
Group 2- Mean	185	250	184	258	183	243	188	250
SD	35.7	17.7	34.5	16.9	39.3	17.9	35.9 •	17.4
Range	133	92	133	101	131	76	155	80
Group 1- Mean	129	203	131	205	122	189	128	195
SD	9.8	21.7	10.3	18.1	10.1	17.4	9.9	16.6
Range	47	119	46	96	44	66	41	69

Table 4.47 : Mean, SD and Range of F0 for back vowels in males and females of 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

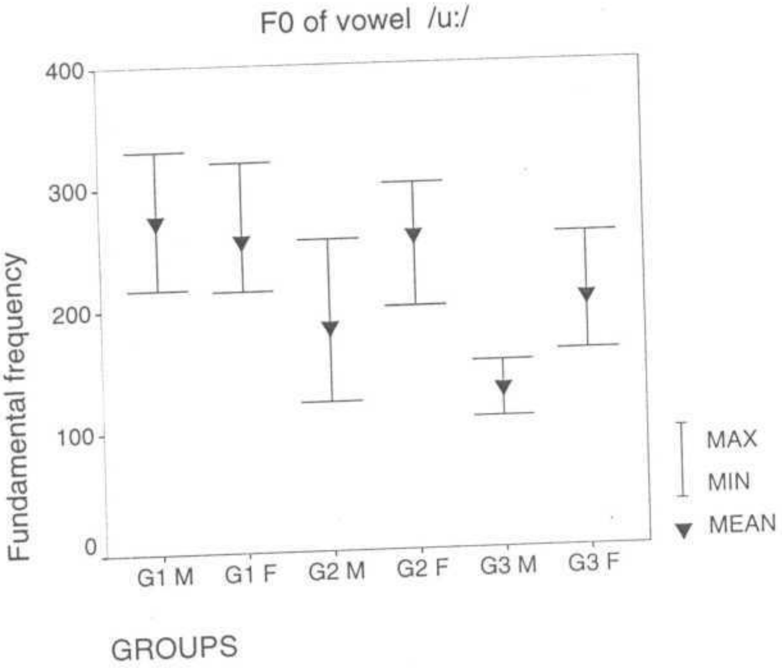
The results of comparison across males showed that males of group 1 had significantly higher F0 than males of groups 2 and 3. And males of group 2 had significantly higher F0 than males of group 3. Thus the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F0 of vowel /u/ in Kannada" was rejected.

Similarly the results of comparison across the female groups showed that there was significant difference for F0 of vowel /u/ between groups 1 and 3 , and groups 2 and 3. Females of group 3 had lower F0 in both instances. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 for F0 of vowel /u/ in Kannada" was rejected. But there was no significant difference between females of groups 1 and 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 for F0 of vowel /u/ in Kannada" was accepted.

On comparison between males and females it was observed that males of group 1 had significantly higher F0 than their female counterparts. Hence the hypothesis stating that "there is no significant difference between males and females for F0 of /u/ for group 1 in Kannada" was rejected. But females had higher F0 than males in groups 2 and 3 for vowel /u/. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /u/ for group 2 and group 3 in Kannada" was rejected.



Graph 59



Graph 60

Vowel /u:/: Scrutiny of Table 4.47 showed that the mean F0 of long vowel /u:/ in males of group 1 was 273 Hz and the SD and range were 20.7 and 113 Hz and for females of group 1 they were 256 Hz, 23.3 and 105 Hz respectively. Males of group 2 had the mean as 184 Hz, SD as 4.5 and range as 133 Hz . The mean, SD and range for females of group 2 were 258 Hz, 16.9 and 101 Hz . The mean, SD and range for males of group 3 were 131 Hz, 10.3 and 46 Hz and for females they were 205 Hz , 18.1 and 96 Hz respectively.

From the study of Table 4.47 and Graph 60, it was seen that males had the values of F0 for /u:/ which decreased with increasing age. But in females F0 decreased from group 2 to group 1 and then to group 3. SD in males was highest in group 2 followed by groups 1 and 3 respectively. In females SD decreased from group 1 to group 3 and then to group 2 . The range of F0 for the vowel /u:/ in males was highest for group 2 followed by group 1 and by group 3 respectively. In females, the range decreased from group 1 to group 3 and then to group 2 .

When the three male groups were compared using one way ANOVA, it was found that there was significant difference for F0 of vowel /u:/ between groups 1 and 3 , groups 1 and 2 and groups 2 and 3. Group 1 had significantly higher F0 than groups 2 and 3 and group 2 had significantly higher F0 than group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 in terms of F0 of vowel /u:/ in Kannada" was rejected.

When the three female groups were compared, there was significant difference between groups 1 and 3 and groups 2 and 3 for F0 of vowel /u:/. Females of group 3 had lower F0 than groups 1 and 2. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 in terms of F0 of the vowel /u:/ in Kannada" was rejected. But there was no significant difference between groups 1 and 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 for FO of the vowel /u:/ in Kannada" was accepted.

Males of group 1 had significantly higher F0 than females on comparison across gender. Hence the hypothesis stating that "there is no significant difference between males and females for FO of /u:/ for group 1 in Kannada" was rejected. But females had higher FO in groups 2 and 3 for vowel /u:/. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /u:/ for group 2 and group 3 in Kannada" was rejected.

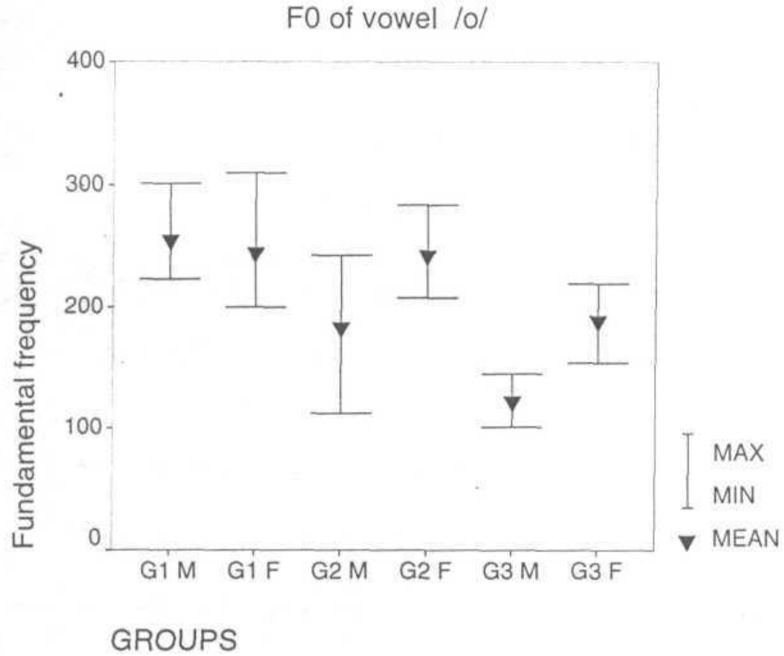
Vowel /o/: It was evident from the study of Table 4.47 that the mean F0 of vowel /o/ in males of group 1 was 255 Hz and the SD and range were 19.1 and 78 Hz and for females they were 245 Hz, 22.9 and 110 Hz respectively. Inmales of group 2, the mean was 183 Hz, SD was 39.3 and range was 131 Hz. The mean, SD and range for females of group 2 were 243 Hz, 17.9 and 76 Hz respectively. Group 3 males had the mean as 122 Hz, SD as 10.1 and range as 44 Hz and for females they were 189 Hz, 17.4 and 66 Hz respectively.

From the examination of Table 4.47 and Graph 61, it was evident that in both males and females F0 decreased with increased in age. In males SD was highest in group 2 and then decreased to groups 1 and 3 . In females SD decreased with increased in age. In males the range was highest in group 2 and next in order were groups 1 and 3 respectively. In females the range of F0 for vowel /o/ decreased with increase in age.

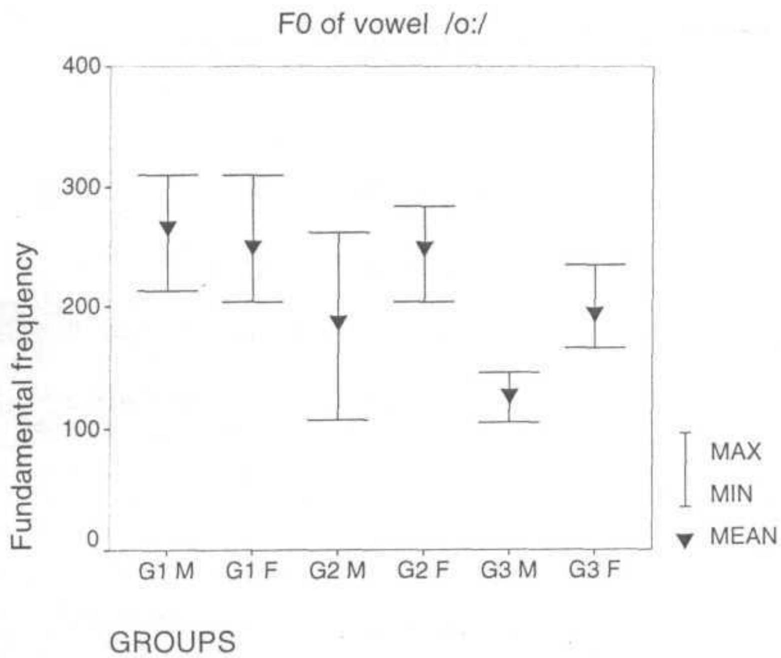
Statistical analysis revealed that males of group 1 had significantly higher F0 than males of groups 2 and 3. And males of group 2 had significantly higher F0 than group 3 for vowel /o/. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for F0 of vowel /o/ in Kannada" was rejected.

Similarly comparisons across the female groups showed that there was significant difference between groups 1 and 3 and groups 2 and 3 for F0 of vowel /o/. Females of group 3 had lower F0 than the other groups. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 in terms of F0 of the vowel /o/ in Kannada" was rejected. But there was no significant difference between females of groups 1 and 2. Therefore the hypothesis stating that "there is no significant difference between females of groups 1 and 2 for F0 of the vowel /o/ in Kannada" was accepted.

When males and females of each group were compared it was noticed that males of group 1 had significantly higher F0 than their female counterparts. Hence the



Graph 61



Graph 62

hypothesis stating that "there is no significant difference between males and females for F0 of /o/ for group 1 in Kannada" was rejected. In groups 2 and 3, females had higher F0 than males. Hence the hypothesis stating that "there are no significant differences between males and females for F0 of /o/ in groups 2 and 3 in Kannada" was rejected.

Vowel /o/*:* Table 4.47 depicted that the mean F0 for long vowel /o:/ in males of group 1 was 267 Hz and the SD and range were 21.5 and 97 Hz and for females they were 251 Hz, 24.6 and 106 Hz respectively. The mean, SD and range for males of group 2 were 188 Hz, 35.9 and 155 Hz and for females they were 250 Hz, 17.4 and 80 Hz respectively. Males of group 3 had the as 128 Hz, SD as 9.9 and range as 41 Hz. The mean, SD and range for females of group 3 were 195 Hz, 16.6 and 69 Hz respectively.

From the Table 4.47 and Graph 62, it was clear that in both males and females values of FO for /o:/ decreased from group 1 to group 3. In males SD was highest in group 2 followed by groups 1 and 3 respectively. In females SD decreased with age. In males the range was highest in group 2 followed by groups 1 and 3 . In females the range of F0 for vowel /o:/ decreased with increase in age.

The results of comparison across males revealed that males of group 1 had significantly higher F0 than males of groups 2 and 3. Also males of group 2 had significantly higher F0 than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 in terms of F0 for vowel /o:/ in Kannada" was rejected.

In case of the female groups, there was significant difference between groups 1 and 3 and groups 2 and 3 for F0 of vowel /o:/. In both cases F0 was lower in females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3 and groups 2 and 3 for F0 for the vowel /o:/ in Kannada" was rejected. But there was no significant difference between females of groups 1 and 2. Hence the hypothesis stating that "there is no significant difference between females of groups 1 and 2 for F0 of the vowel /o:/ in Kannada" was accepted.

Males of group 1 had significantly higher F0 than their female counterparts when males and females of group 1 were compared. Hence the hypothesis stating that 'there is no significant difference between males and females for F0 of /o:/ in group 1 in Kannada" was rejected. In groups 2 and 3,females had higher F0 than males. Thus the hypothesis stating that "there are no significant differences between males and females for FO *of /o:/* in groups 2 and 3 in Kannada" was rejected.

To have an overall glimpse of the presence or absence of significance of difference in terms of F0 between the three age groups, the summary of the results have been presented in Tables 4.48 and 4.49 .

Males	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:l	/o/	/o:/	Total
Gl vsG2	P	P	P	P	P	P	P	P	P	p	10/10
G] vsG3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vsG3	P	P	P	P	P	P	A		P	p	9/10

Table 4.48 : The results of test for significance of difference between the three age groups in case of males for F0 at 0.05 level

Females	/i/	/I:/	/e/	/e:/	/a/	/a:/	/ul	/u:/	/o/	/o:/	Total
Gl vs 2	P	P	P	P	P	P	P	A	A	A	7/10
Gl vs 3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vs 3	A	A	A	P	P	P	A	P	P	P	6/10

Table 4.49 : The results of test for significance of difference between the three age groups in case of females for F0 at 0.05 level

The study of Tables 4.48 and 4.49 showed that F0 was significantly higher in group 1 compared to groups 2 and 3 in both males and females. And group 2 had significantly higher F0 than group 3 in males and females. The developmental trend appeared more strongly when the comparison was made between children and adults. In females the difference in F0 between groups 2 and 3 was absent mainly for the front vowels. Hence it was concluded that there was a decrease in F0 from childhood to adolescence and further marked decrease to adulthood in both sexes. The variability and range of F0 also decreased with age. However they were higher in the adolescent male group than in the other groups.

Mvs F	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:l	Total
Gl	P	P	P	p	P	A	P	P	p	P	9/10
G2	P	P	P	P	P	P	P	P	p	P	10/10
G3	P	P	P	P	P	P	P	P	p	P	10/10

Table 4.50: Results of test for significance of difference across gender in the three groups for F0

It was clear from Table 4.50 that there were significant differences in F0 across gender for all the three groups. In group 1, males had higher F0 than females where as in groups 2 and 3, females had significantly higher F0 than their male counterparts. Table 4.51 gives the F0 values obtained in the present study for all the three groups for Kannada vowels. Table 4.52 presents the values of F0 of other Indian studies with the present study.

Vowels	Group 1		Group 2		Group 3	
	M	F	M	F	M	F
A	259	245	180	240	121	186
a:	256	252	185	239	121	187
I	266	254	183	251	126	197
I:	270	258	189	255	132	208
U	268	252	185	250	129	203
u:	273	256	184	258	131	205
E	261	245	185	242	125	_ 189
e:	264	249	189	242	127	193
O	255	245	183	243	122	189
o:	267	251	188	250	128	195

Table 4.51: F0 values of vowels obtained in the present study for all the three groups for vowels in Kannada

The results from this part of the study leads to the following conclusions:

a) Among the four front vowels considered in the study, vowel /I:/ had the highest F0 in both males and females of groups 1 and 2 and 3. This finding is in agreement with the F0 values obtained by Peterson & Barney (1952); Evan (1975); Peterson (1977); Fischer Joergensen (1990) & Venkatesh (1995).

b) Vowel /e/ showed the lowest F0 in all the groups except in group 2 males where it was for vowel /i/.

c) Among the central vowels /a/ and /a:/, short vowel /a/ had a higher F0 in males of groups 1 and 2 and females of group 2. In males of group 3 F0 of vowels /a/ and /a:/ were equal. In females of groups 1 and 3, vowel /a:/ had an edge over /a/.

d) Among the back vowels, /u:/ had the highest F0 in both males and females of all the groups except in group 2 males. Vowel /o/ had the lowest F0 commonly in all the groups.

Investigators	**Male**	**Female**
1. Sheela(1974)	126	217
2. Jayaram(1975)	123	225
3. Nataraja&Jagadish(1984)	141	237
4. Vanaja(1986)	127	234
5. Nataraja(1986)	119	223
6. Sridevi (1987)	119	218
7. Thermar (1991)	124	233
8. Suresh(1991)	123	219
9. Sanjay(1991)	131	220
10. Rajashekar (1991)	148	-
ll.Krishnan(1992)	122	231
12.Patak(1997)	126	231
13.Prabha(1997)	125	214
14. Pradeep(1997)	136	240
15. Venkatesh(1995)	146	253
16. Rajkumar(1998)	140	240
17. Present study	126	195

Table 4.52: The values of F0 in normal Indian population as reported by different investigators.

Table 4.53 presents the F0 values obtained in the present study for males and females in adults with those of Venkatesh (1995) and for children with those of Jayaprakash (1998). The F0 values obtained in the present study are slightly different from those obtained by the other two studies. This may be because of the differences in the age range considered and also because of differences in the number of words used as test material and methodology .

	Adults				Children			
Kannada Vowels	Venkatesh(1995) M	F	Present study M	F.	Jayaprakash(1998) M	F	Present study M	F
a	141	237	121	187	213	262	259	245
a:	134	239	121	187	212	249	256	252
i	149	259	126	197	248	271	266	254
I:	159	277	132	208	-	-	270	258
u	149	258	129	203	237	252	268	252
u:	159	283	131	205	201	253	273	256
e	140	240	.125	189	230	260	261	245
e:	146	250	127	193	-	-	264	249
o	138	241	122	189	-	-	255	245
o:	148	252	128	195	221	250	267	251

Table 4.53: F0 values for adults and children obtained in the present study and by others in Kannada

Physiological and anatomical data on the laryngeal and respiratory systems also support the nonlinear/functionally different view of children's speech. Polga & Werb (1979) in a review on respiratory physiology in children, provide evidence that children's airways were different from adults in ways other than size. For example the static recoil of the lungs did not change in a linear manner through out childhood. Anatomical data on the vocal folds also strongly supported the notion of a non isotopic relationship between the adult and child speech mechanism. Hirano, Kurita and Nakashima (1983) have noted not only the most obvious differences between children and adults, that was that the vocal folds were longer and more massive in adults, but also that the inner structure of the vocal folds was different. It was not until girls and boys reached adolescence that structure and size of the vocal folds were adult like. Hence one cannot expect the laryngeal and respiratory systems in children learning speech to function in the same manner as the adult systems. In the present study the variability and range of F0 decreased as a function of age except in the case of adolescent males as reported by Eguchi and Hirsh (1969), Kent

(1976), Horii (1983) and Rashmi (1985). This possibly reflects the increase in neuro muscular maturation.

It has long been established that major changes in vocal output were closely related to adolescence. Adolescence is the period of change associated with the shift from childhood to adult status. It involves growth spurts and marked physiological/psychological changes and the appearance of both primary and secondary sexual characteristics. It has also been suggested that down ward shifts in speaking fundamental frequency level (SFF) mark this process (Aronson 1990; Boone, 1988; Luchsinger & Arnold 1965; Wilson 1979). Curry (1940) provided an early test of this idea. He compared the data obtained from 6 year olds and 18 year olds with 14 year old boys who presumably represented an adolescent population. His data for 14 year olds (median=242Hz) suggested that as a group in his subjects probably the voice change process had not started. Data reported on physical changes suggested that adolescent growth spurts, while variable, could start for boys as early as 12 years of age and last for several years (Marshall & Tanner, 1986). The rapid development of the larynx occurs between 13-15 years (Naider,1965). In the present study of vowels in Kannada, the adolescent group considered were in the age group of 14-15 years and the results have shown that the pubertal voice change had already started in them and hence a marked lowering of FO was seen compared to the younger group. Standard deviation of FO was observed to be higher in the adolescent boys than in girls because of the frequent pitch breaks occurring in this period. This finding is in consonance with Eguchi and Hirsh (1969) and Rashmi (1985) where they have reported a higher SD in adolescent boys than in the other groups. The pitch and quality changes that occur at puberty are much more apparent in males than in females because of the greater magnitude of the pitch drop. In the present study, the pitch drop in females from adolescence to adulthood were significant only in six out of ten vowels studied. This finding supports the study by Michel et al (1966) who indicated that by age of 15 mutational change of voice is essentially completed in females. Kushal Raj (1983) has reported thatSFF decreases with age, males showing a sudden decrease around 11 years of age. And no significant difference was found between males and females until 11 years. Rashmi (1985) has reported marked lowering of SFF in males at 14 years and in females from 8 years onwards. In general females showed little change in FO and SFF as a function of increase in age.

It is commonly asserted in the literature that prior to adolescence there are no significant differences in the vocal mechanisms or vocal productions of boys and girls (Murphy, 1964; Luchsinger & Arnold, 1965; Kaplan 1971). Several studies in the past have reported that there is no significant difference of fundamental frequency of speech between boys and girls of 7 and 8 years (Potter and Steinberg, 1950; Peterson and Barney, 1952; Murphy, 1964; Sorenson,1989). Kent (1976) has reported that FO values were distinguished by sex only after the age of 11 years although smaller sex differences might occur before that age. Despite these assertions, there was some anatomical and perceptual evidence which supported the existence of sex related vocal differences, prior to puberty. Crelin (1973), suggested that sexual differences in laryngeal growth appeared by the third year. Perceptual differences between the voices of male and females children have also been demonstrated. Several studies have shown that listeners could judge the sex of the child speakers with some degree of accuracy from voice samples (Weinberg & Benette 1971; Benett and Weinberg, 1979). Bennett (1981) reports that a significant difference between the average F0 of preadolescent male and female children begin to emerge by the age of 7-8 years. In the present study also a sex difference in FO was apparent by the age of 7-8 years. Males of 7-8 year age group had significantly higher FO than females of the same group which marked the beginning of a drop for female voices . In males the adolescent voice change had not started by 8-9 years. The present finding of higher FO in males of 7-8 years is in support of another Indian study by Rashmi (1985) where she had found higher FO in males of 7-8 years than in females for vowels /a/, /i/ and /u/. Similarly Arun Biran (1995) studied FO in children and reported a higher FO in males than females in the age group of 8-9 years. Anusha (1999) also found a higher FO in boys than in girls of 7-10 years though not significant. Other studies on Indian population have indicated that in males the lowering of FO was gradual till the age of 10 years (Gopal 1980), 15 years (Samual,1973), 13 years (Usha, 1978) and 14 years (Rashmi, 1985). Hence the present data seemed to suggest that although the onset of voice change occured earlier in females, males and females completed the change at approximately the same age. In the present study, females used a greater range of FO in adults whereas in adolescents and children males had a greater range of FO. This observation is in consonance with reports of Gopal (1986.) that females used a greater frequency range than males in the age range of 16-25 years. Hudson (1981) also reported similar findings. Venkatesh (1995) has also reported higher range in females compared to males in adults.

The results obtained on fundamental frequency lead to the following conclusions:

a) It was observed that there is a decrease in F0 from children to adolescents and further marked decrease to adults in both sexes.

b) There was significant difference in F0 across males and females for the three age groups.

c) In children, males had higher F0 than females where as in adolescents and adults, females had significantly higher F0 than their male counterparts.

d) The range and variability of F0 decreased as a function of age. However because of the rapid development of the larynx between 13-15 years the range and variability of F0 were higher in the adolescent boys.

2.e Relative Intensity (Io)

Intensity of the vowel was defined as the RMS intensity at the mid point of the first vowel in the test word /$C_1V_1C_2V_2$/. The results of Io are presented in the following order of I, I:, e, e: (front vowels), a, a: (central vowels) and u, u:, o, o: (back vowels).

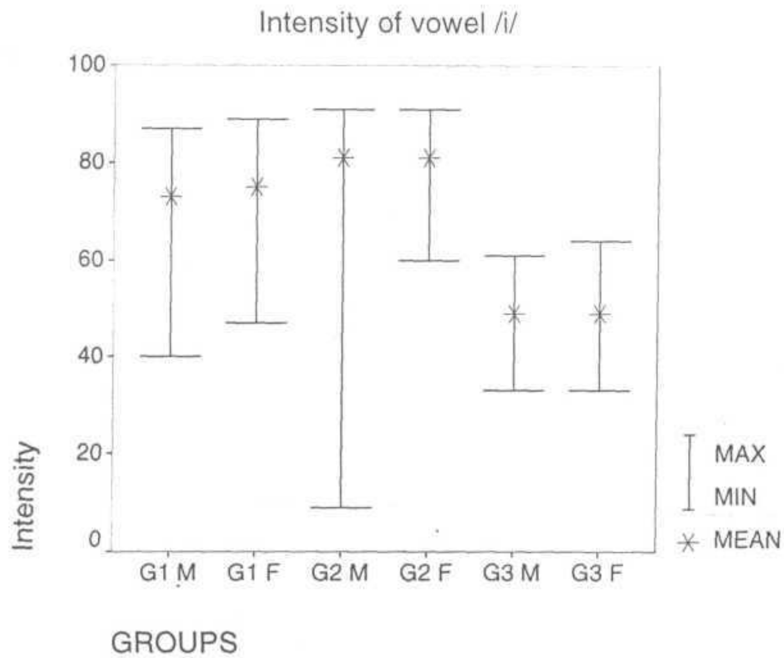
Vowel /i/: It was evident from Table 4.54, the mean Io of vowel /i/ in males of group 1 **was** 72.9 dBR and the SD and range were 10.7 and 47 dBR and for females of group 1 were 74.6 dB R, 7.3 and 43 dB R respectively. For males of group 2 the mean, SD and range were 81.8 dBR, 6.9 and 26 dBR and for females of group 2 they were 80.5 dBR, 7.5 and 31 dBR respectively. Males of group 3 had the mean, SD and range as 48.7 dBR, 4.9 and 28 dBR and mean, SD and range for females of group 3 were 48.6 dBR, 5.6 and 31 dBR respectively.

From Table 4.54 and Graph 63, it was seen that in both males and females Io decreased from group 2 to group 1 and then to group 3. SD and range for Io in both males and females decreased with increase in age.

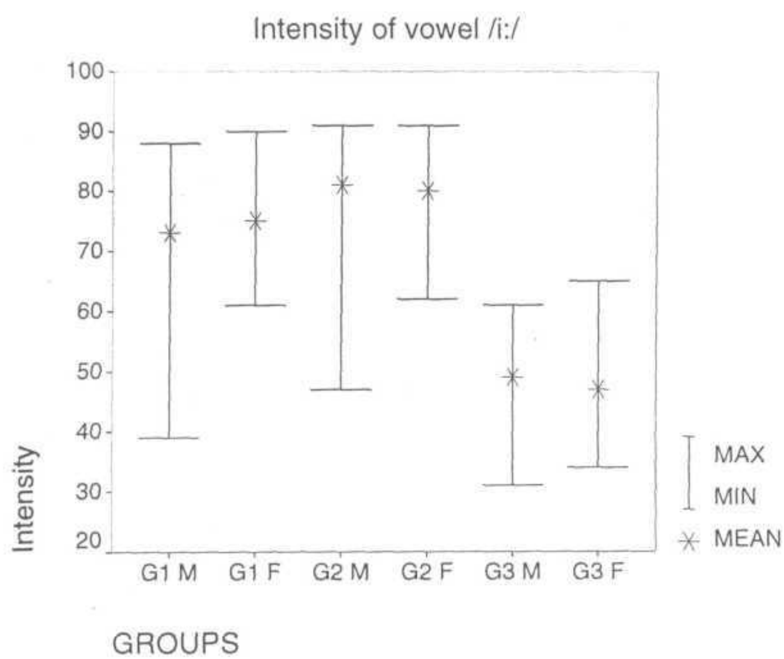
The results of comparisons of males of different groups, in terms of Io using one way ANOVA showed that males of group 1 had significantly higher Io than males of group 3 and significantly lower Io than group 2. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2 and groups 1 and 3 in terms of Io of the vowel /i/ in Kannada" was rejected. When males of group 2 were compared with males of group 3, there was significant difference in Io of the vowel /i/ with group 2 having higher Io. So the hypothesis stating that "there is no significant difference between males of groups 2 and 3 in terms of Io of the vowel /i/ in Kannada" was rejected.

		/i/		/i/		/e/		/e:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	72.9	74.6	72.8	75	74	75.7	74.1	76.6
	SD	10.7	7.3	9.7	6.7	9.8	6.5	9.9	6.9
	Range	47	42	49	29	42	26	46-	32
Group 2	Mean	81.8	80.5	81.2	80.3	81.5	81.4	83	81.2
	. SD	6.9	7.5	7.3	7.6	6.9	7.9	6.1	7.6
	Range	26	31	44	29	23	26	17	27
Group 3	Mean	48.7	48.6	48.8	47.3	48.8	48.5	50.5	50.5
	SD	4.9	5.6	4.9	5.7	4.9	5.8	4.5	5.9
	Range	28	31	30	31	28	31	28	32

Table 4.54: Mean, SD and Range of Io for front vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)



Graph 63



Graph 64

Similarly in case of females comparison of the three groups indicated that females of group 1 had significantly higher Io than group 3 and lower Io than group 2. Females of group 2 had significantly higher Io than group 3. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of the vowel /i/ in Kannada" was rejected.

When the males and females of the three groups were compared with each other, it was evident that there was no significant differences between the two in terms of Io in all the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for Io of /i/ in groups 1, 2 and group 3 in Kannada" was rejected.

Vowel /I:/: The study of Table 4.54 showed that the mean Io of vowel /I:/ in males of group 1 was 72.8 dBR and the SD and range were 9.7 and 49 dBR and for females of group 1 they were 75 dB R, 6.7 and 29 dBR respectively. Males of group 2 had the mean as 81.2 dBR, SD as 7.3 and range as 44 dBR and for females of group 2 they were 80.3 dBR, 7.6 and 29 dBR respectively. For males of group 3, the mean, SD and range were 48.8 dBR, 4.9 and 30 dBR and they were 47.3 dBR, 5.7 and 31 dBR respectively for females of group 3.

The inspection of Table 4.54 and Graph 64 depicted that in both males and females Io decreased from group 2 to group 1 and then to group 3. SD and range in males decreased with increase in age. SD in females was highest in group 2 followed by groups 1 and 3. In females, groups 1 and 2 had equal range while group 3 had a higher range.

When male of different age groups were compared across each other using ANOVA, the results depicted that there was significant difference for Io between groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 2 had significantly higher Io than males of groups 1 and 3. And males of group 1 had significantly higher Io than group 3. Therefore the hypothesis stating that "there are no significant differences between males of groups 1 and 2 ,groups 1 and 3 and groups 2 and 3 in terms of Io of the vowel /I:/ in Kannada" was rejected.

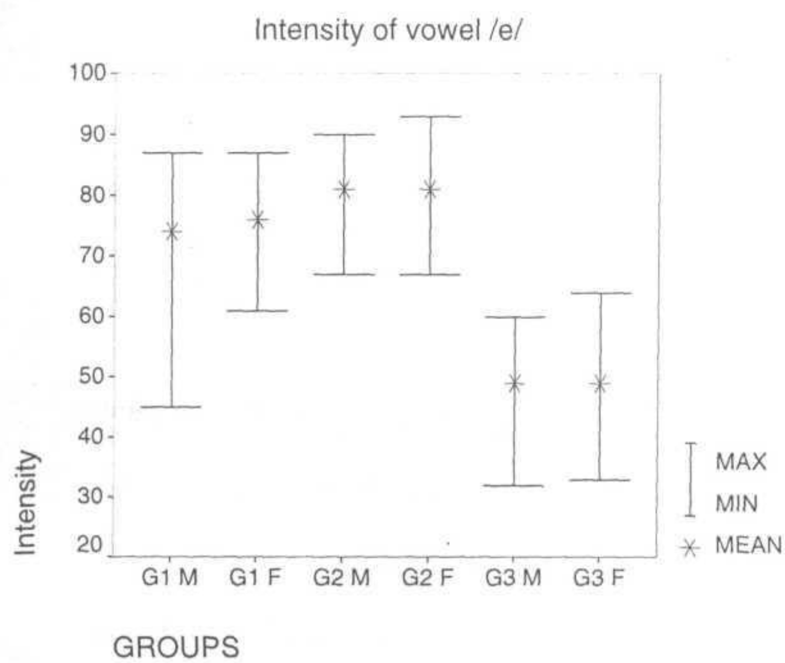
When females of the three groups were compared, it was evident that there were significant differences between groups 1 and 3, groups 1 and 2 and groups 2 and 3 for Io of vowel /I:/. Females of group 2 had significantly higher Io than females of groups 1 and 3. And females of group 1 had higher Io than group 3. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and 2 and 3 in terms of Io of vowel /I:/ in Kannada" were rejected.

On comparison of males and females in each group it was found that Io of vowel /I:/ was significantly higher in females of group 1. Hence the hypothesis stating that "there is no significant difference between males and females for Io of /I:/ in group 1 in Kannada" was rejected. Similar comparison between males and females of groups 2 and 3 showed that there were no significant differences in Io. Hence the hypothesis stating that "there are no significant differences between males and females for Io of/I:/ in groups 2 and 3 in Kannada" was accepted.

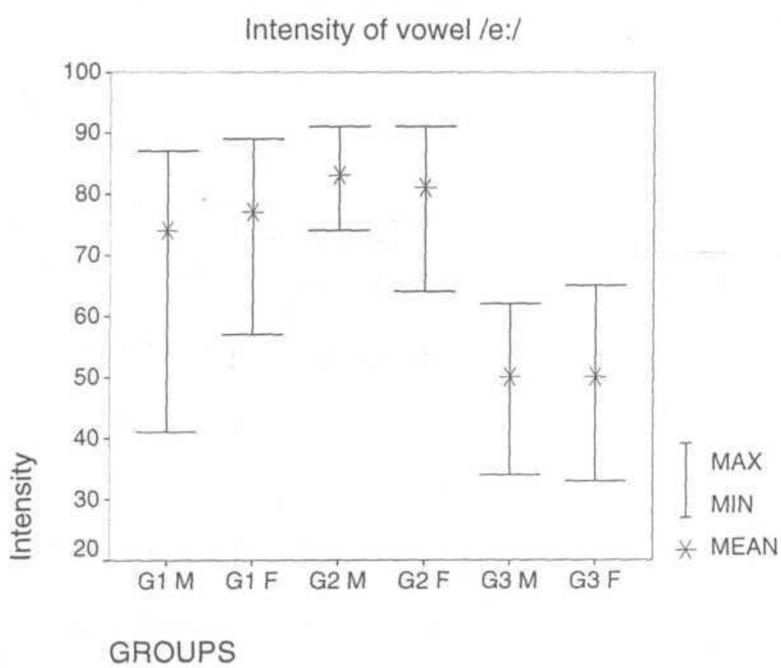
Vowel /e/: From Table 4.54 it can be noticed that the mean Io of vowel /e/ in males of group 1 was 74 dB R and the SD and range- were 9.8 and 42 dB R and for females of group 1 were 75.7 dB R, 6.5 and 26 dB R respectively. In males of group 2, the mean was 81.5 dB R, SD was 6.9 and range was 23 dB R and for females they were 81.4 dB R, 7.9 and 26 dB R respectively. The mean, SD and range for males of group 3 were 48.8 dB R, 4.9 and 28 dB R and for females of group 3 they were 48.5 dB R, 5.8 and 31 dB R respectively.

The inspection of Table 4.54 and Graph 65 showed that in both males and females Io decreased from group 2 to group 1 and then to group 3. SD in males decreased with increase in age. SD in females was highest in group 2 followed by groups 1 and 3. The range of Io for the vowel /i/ also decreased with age in males but group 2 had a lesser range than group 3. In females groups 1 and 2 had an equal range with group 3 having a higher range.

When comparison was made across males of three groups, it was disclosed that there was significant difference for Io of vowel /e/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 2 had significantly higher Io compared to males of groups 1 and 3. Males of group 1 had higher Io than group3. Hence the hypothesis stating that "there are no significant differences between males of



Graph 65



Graph 66

groups 1 and 2, groups 1 and 3 and groups 2 and 3 in terms of Io of the vowel *Id* in Kannada" was rejected.

In case of females, comparison across the groups yielded the results indicating that there was significant difference between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for Io of vowel *Id.* Females of group 2 had significantly higher Io compared to females of groups 1 and 3. Females of group 1 had higher Io than females of group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and 2 and 3 in terms of Io of vowel /e/ in Kannada" was rejected.

When males and females of different groups were compared, it was observed that in groups 1, 2 and 3, there were no significant differences in Io. Hence the hypothesis stating that "there are no significant differences between males and females for Io of *Id* in groups 1, 2 and 3 in Kannada" was accepted.

Vowel /e:/: Table 4.54 depicts that the mean Io of vowel /e:/ in males of group 1 was 74.1 dB R and the SD and range were 9.9 and 46 dB R respectively and for females of group 1 they were 76.6 dB R, 6.9 and 32 dB R respectively. The mean was 83 dB R, SD was 6.1 and range was 17 dB R for males of group 2. The mean, SD and range for females of group 2 were 81.2 dB R, 7.6 and 27 dB R respectively. In group 3 the mean, SD and range for males were 50.5 dB R, 4.5 and 28 dB R and for females the mean, SD and range were 50.5 dB R, 5.9 and 32 dB R respectively.

From Table 4.54 and Graph 66 it was clear that in both males and females Io of vowel /e/ was highest in group 2 followed by group 1 and then group 3. SD in males decreased with increase in age. That is group 1 to group 3. SD in females was highest in group 2 followed by groups 1 and 3. The range of Io for the vowel /i/ also decreased from group 1 to group 3 and then to group 2. In females groups 1 and 3 had an equal range with group 2 having a lesser range.

In case of males, comparison across different groups showed that there were significant differences for Io of vowel /e:/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 2 had significantly higher Io compared to males of groups 1 and 3. Males of group 1 had higher Io than group3. Hence the hypothesis stating that "there are no significant differences between males of groups I and 2, groups 1 and 3 and groups 2 and 3 in terms of Io of the vowel /e:/ in Kannada" was rejected.

The results of one way ANOVA showed that in females there were significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for Io of vowel /e:/. Females of group 2 had significantly higher Io compared to females of groups 1 and 3. Females of group 1 had higher Io than females of group 3. Therefore the hypothesis stating that "there is no significant difference between females of groups 1 and 3, groups 1 and 2 and 2 and 3 in terms of Io of vowel /e:/ in Kannada" wasrejected.

When males and females of each group were compared, it was found that relative intensity was significantly higher in females of group 1. Hence the hypothesis stating that "there is no significant difference between males and females for Io of/e:/ in groups 1 in Kannada" was rejected. And in groups 2 and 3 there was no significant difference in Io across gender. Hence the hypothesis stating that "there are no significant differences between males and females for Io o f/e:/in groups 2 and 3 in Kannada" were accepted.

Vowel /a/: Table 4.55 depicted that the mean Io of vowel /a/ in males of group 1 was 74 dB R and the SD and range were 9.7 and 53 dBR and for females they were 75.4 dB R, 8.1 and 50 dB R respectively. Males of group 2 showed the mean as 81.3 dBR, SD as 8.1 and range as 82 dB R . The mean, SD and range for females of group 2 were 80.6 dB R, 8.4 and 44 dB R respectively. Group 3 males had a mean 49 dB R, SD of 4.3 and range of 28 dB R and for females they were 49.4 dB R, 5.3 and 27 dB R respectively.

		/a/		/a:/	
		M	F	M	F
Group 1	Mean	74	75.4	73.1	76.2
	SD	9.7	8.1	10.7	7.9
	Range	53	50	55	29
Group 2	Mean	81.3	80.6	82.4	80.9
	SD	8.1	8.4	6.1	7.9
	Range	82	44	23	26
Group 3	Mean	49	49.4	51.5	52
	SD	4.3	5.3	10.3	8.9
	Range	28	27	59	51

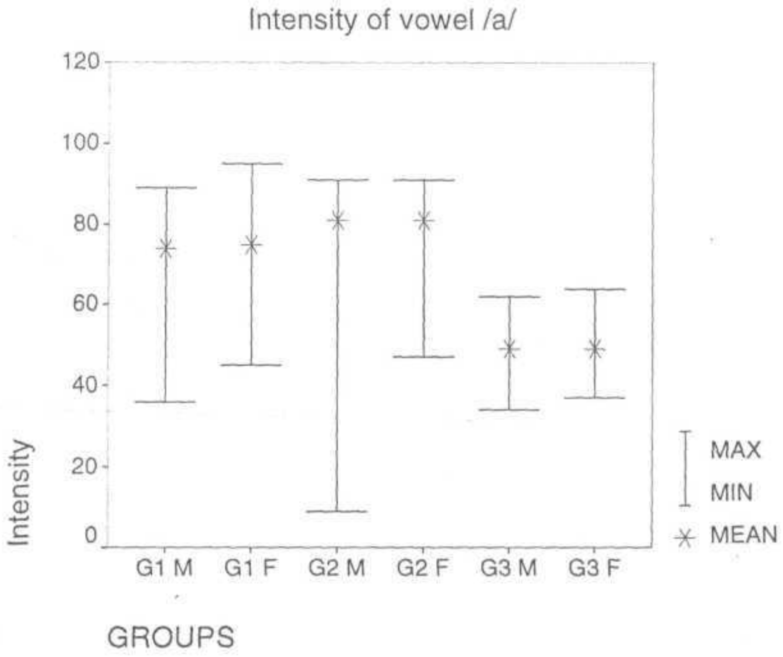
Table 4.55 : Mean , SD and Range of Io for central vowels of males and females in 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

It was evident from Table 4.55 and Graph 67 that in both males and females Io was highest in group 2 followed by group 1 and then group 3. SD in males decreased from group 1 to group 3. SD in females was highest in group 2 followed by groups 1 and 3. The range of Io for the vowel /a/ also decreased from group 1 to group 3 and then to group 2 in both males and females.

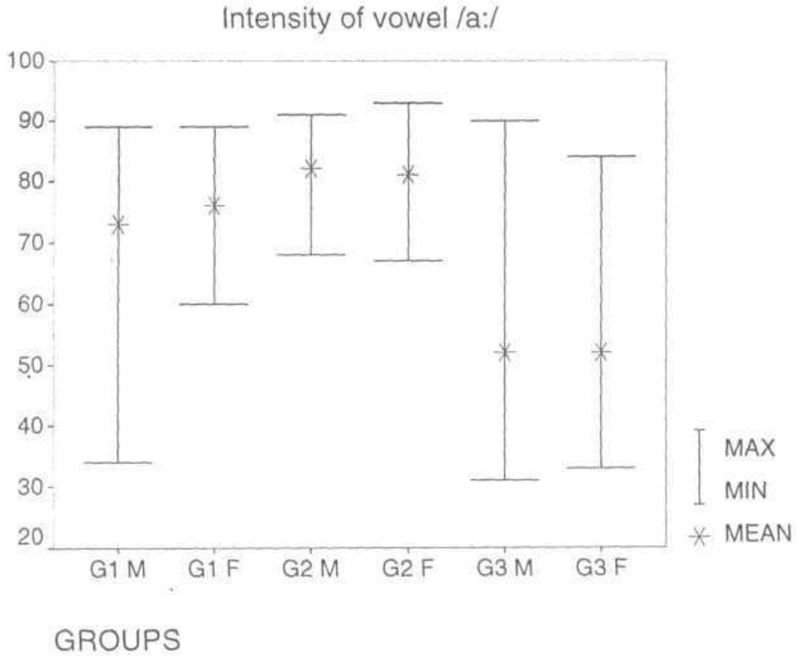
Comparisons across males of the three groups using ANOVA showed that there was significant difference for Io of vowel /a/ between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3. Males of group 2 had significantly higher Io compared to males of groups 1 and 3. Males of group 1 had higher Io than group3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2, groups 1 and 3 and groups 2 and 3 in terms of Io of the vowel /a/ in Kannada" was rejected.

Similar comparisons across females revealed that there were significant differences between females of groups 1 and 3 , groups 1 and 2 and groups 2 and 3 for Io of vowel /a/. Females of group 2 had significantly higher Io compared to females of groups 1 and 3. Females of group 1 had higher Io than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and 2 and 3 in terms of Io of vowel /a/ in Kannada" was rejected.

There were no significant differences in Io between males and females in groups 1, 2 and 3. Hence the hypothesis stating that "there are no significant differences



Graph 67



Graph 68

between males and females for Io of /a/ in groups 1, 2 and 3 in Kannada" was accepted.

Vowel /a:/: From Table 4.54, it was clear that the mean Io of vowel /a:/ in males of group 1 was 73.1 dB R and the SD and range were 10.7 and 55 dB R and for females they were 76.2 dB R, 7.9 and 29 dB R respectively. The mean, SD and range for males of group 2 were 82.4 dB R, 6.1 and 23 dB R and for females they were 80.9 dB R, 7.9 and 26 dB R respectively. Males of group 3 had the mean as 51.5 dB R, SD as 10.3 and range as 59 dB R . The mean, SD and range for females of group 3 were 52 dB R, 8.9 and 51 dB R respectively.

Table 4.54 and Graph 68 showed that in both males and females Io decreased from group 2 to group 1 and then to group 3. SD in males decreased from group 1 to group 3 and then to group 2. In females SD was same in groups 1 and 2 and group 3 had a higher SD than the other two groups. The range of To decreased from group 3 to group 1 and then to group 2 in both males and females for vowel /a:/.

When the three male groups were compared using ANOVA, it was disclosed that there was significant difference for Io of vowel /a:/ between groups 1 and 3, groups 1 and 2 and groups 2 and 3. It was found that males of group 2 had significantly higher Io compared to males of groups 1 and 3 and males of group 1 had higher Io than males of group 3. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2, groups 1 and 3 and groups 2 and 3 in terms of Io of the vowel /a:/ in Kannada" was rejected.

Similarly on comparison of the three female groups, it was found that there were significant differences between groups 1 and 3, groups 1 and 2 and groups 2 and 3 for Io of vowel /a:/. Females of group 2 had significantly higher Io compared to females of groups 1 and 3. Females of group 1 had higher Io than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and 2 and 3 in terms of Io of vowel /a:/ in Kannada" was rejected.

On comparison between males and females of the three groups, it was observed that there were significant differences in lo in groups 1, 2 and 3. In groups 1 and 3 males had significantly higher Io whereas in group 2, females showed higher relative intensity. Hence the hypothesis stating that "there are no significant differences between males and females for Io of /a:/ in groups 1, 2 and 3 in Kannada" was rejected.

Vowel /u/: Table 4.55 showed that the mean Io of vowel /u/ in males of group 1 was 73.3 dB R and the SD and range were 10.4 and 52 dB R and for females of group 1 they were 74.9 dB R, 7 and 33 dB R respectively. In group 2 males the mean was 81.6 dB R, SD was 6.4 and range was 24 dB R and for females they were 80.3 dB R, 7.9 and 29 dB R respectively. The mean, SD and range for males of group 3 were 50 dB R, 7.4 and 72 dB R and for females of group 3 were 49.2 dB R, 5.8 and 33 dB R respectively.

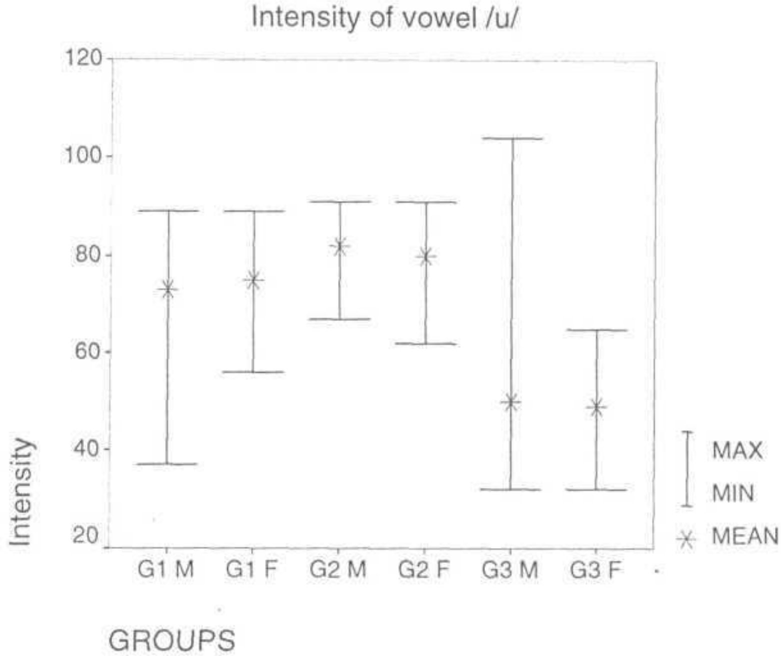
On examination of Table 4.55 and Graph 69 , it was seen that in both males and females Io was highest in group 2 followed by group 1 and then group 3. SD in males decreased from group 1 to group 3 and further to group 2. In females SD was highest in group 2 and next in the order were groups 1 and 3. The range of Io for the vowel /u/ was highest in group 3 and next in order were groups 1 and 2 in males. In females the range was equal in groups 1 and 3 and group 2 had a lower range than the other two groups.

		/u/		/u:/		/o/		/o:/	
		M	F	M	F	M	F	M	F
Group 1	Mean	73.3	74.9	75.7	76	72	77.4	74.9	77.6
	SD	10.4	7	9.3	7.2	11.9	6.9	11.5	7.3
	Range	52	33	52	38	48	29	55	38
Group 2	Mean	81.6	80.3	82.9	81.2	82	81.5	83	82.2
	SD	6.4	7.9	5.9	7.9	6	8.1	5.7	7.4
	Range	24	29	17	28	18	26	17	21
Group 3	Mean	50	49.2	50.8	50.5	51.6	51.8	51.7	52.2
	SD	7.4	5.8	5.4	6.4	11.4	6.1	4.8	5.4
	Range	72	33	30	31	94	31	29	28

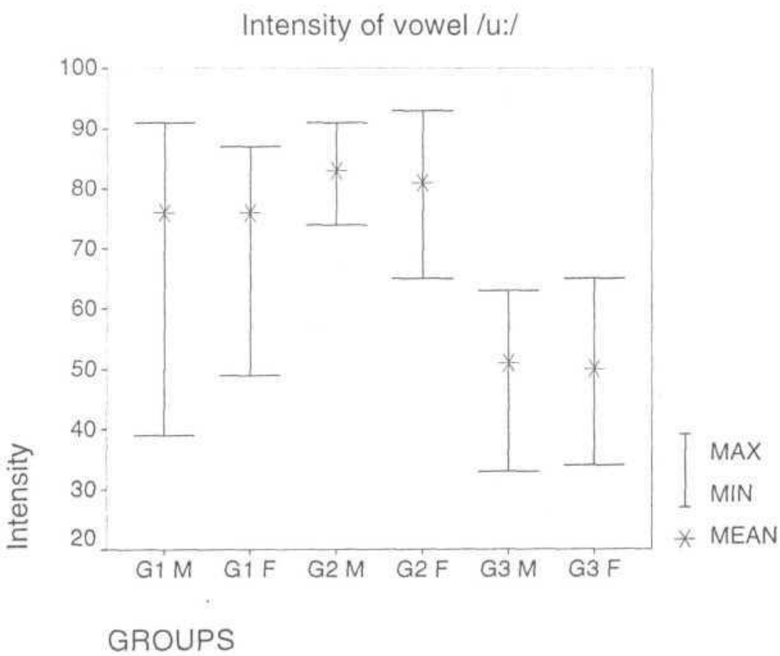
Table 4.55a: Mean, SD and Range of Io for back vowels in males and females of 7-8 yrs (Group 1), 14-15 yrs (Group 2) and adults (Group 3)

On comparison of males of the three groups using one way ANOVA, it was observed that group 1 males had significantly higher Io than group 3 and lower Io than group 2 males. Also group 2 had significantly higher Io than group 3 in males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 2, groups 1 and 3 and groups 2and 3 for Io of the vowel u/ in Kannada" were rejected.

Statistical comparison using A,NOYA across the female groups revealed that there were significant differences for Io of vowel /u/ between females groups 1 and 3 , groups



Graph 69



Graph 70

1 and 2 and groups 2 and 3. Females of group 2 had significantly higher Io than groups 1 and 3 and females of group 1 had higher Io than group 3. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 for Io of vowel /u/ in Kannada" was rejected.

When across gender the comparisons were made, it was noticed that the three groups showed no significant differences in terms of Io between males and females. Hence the hypothesis stating "that there are no significant differences between males and females for Io of Ai/ in groups 1, 2 and 3 in Kannada" was accepted.

Vowel /u:/: On scrutiny of Table 4.55, it can be inferred that the mean Io of vowel /u:/ in males of group 1 was 75.7 dB R and the SD and range were 9.3 and 52 dB R respectively. The mean, SD and range for females of group 1 were 76 dB R, 7.2 and 38 dB R respectively. In group 2 males the mean, SD and range were 82.9 dB R, 5.9 and 17 dB R respectively and the mean, SD and range for females of group 2 were 81.2 dB R, 7.9 and 28 dB R respectively. In group 3, males had the mean, SD and range as 50.8 dB R, 5.4 and 30 dB R respectively and females had the mean, SD and range as 50.5 dB R, 6.4 and 31 dB R respectively Io of vowel /u:/.

From the Table 4.55 and Graph 70, it can be seen that in both males and females Io was highest in group 2 followed by group 1 and then group 3. SD in males decreased with increase in age . In females SD was highest in group 2 arid next in order were groups 1 and 3. The range of Io for the vowel /u/ was highest in group 3 and next in order were groups 1 and 2 in males. In females the range decreased with age but group 2 had a lower range than group 3.

When males of the three groups were compared using one way ANOVA, it was seen that males of group 2 had significantly higher Io than males of groups 1 and 3. And group 1 had significantly higher Io than group 3. So the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups I and 2 and groups 2 and 3 in terms of Io of vowel /u:/ in Kannada" was rejected.

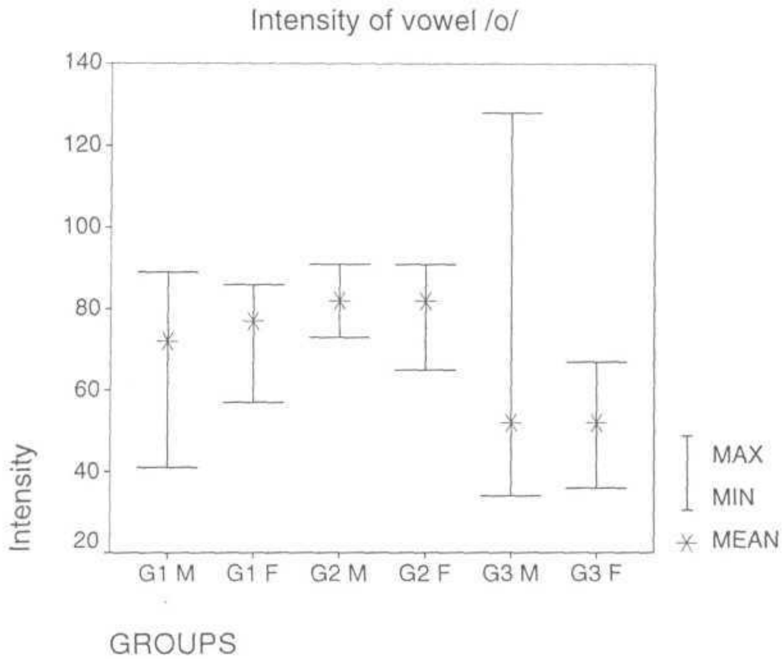
On comparison across the female groups also it was noticed that females of group 2 had significantly higher Io than females of groups 1 and 3. And females of group 1 had significantly higher Io than females of group 3 for vowel *In:/.* Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of the vowel /u:/ in Kannada" wasrejected.

When males and females of each group were compared, it was observed that there was no significant difference in Io for any of the three groups. Hence the hypothesis stating that "there are no significant differences between males and females for Io of /u:./ in groups 1, 2 and 3'" was accepted.

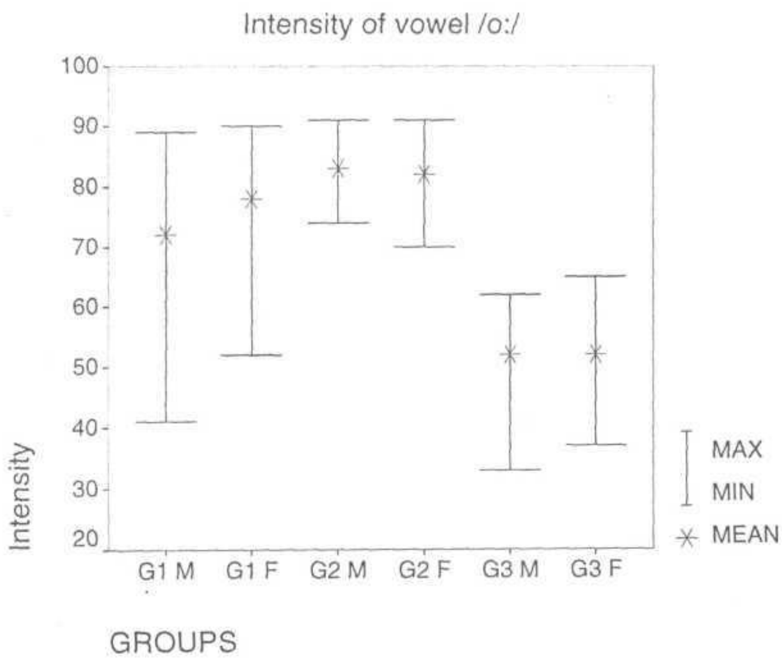
Vowel /o/: On perusal of Table 4.55, it was found that the mean lo of vowel /o/ in males of group 1 was 72 dB R and the SD and range were 11.9 and 48 dB R and for females had a mean of 77.4 dB R, SD of 6.9 and range of 29 dB R.. Group 2 males had a mean of 82 dB R, SD of 6 and range of 18 dB R and for females they were 81.5 dB R, 8.1 and 26 dB R respectively. In males of group 3, the mean, SD and range were 51.6 dBR, 11.4 and 94dBR and for females they were 51.8 dBR, 6.1 and 31 dBR respectively.

From the inspection of Table 4.55 and Graph 71, it was known that in both males and females Io was highest in group 2 followed by group 1 and then group 3. SD in males was highest in group 1 followed by group 3 and 2 respectively. In females SD was highest in group 2 and next in order were groups 1 and 3. The range of Io for the vowel /o/ was highest in group 3 and next in order were groups 1 and 2 in both males and females.

When males of the three groups were compared using one way ANOVA, it was seen that males of group 2 had significantly higher lo than males of groups 1 and 3. And males of group 1 had significantly higher Io than group 3 males. Therefore the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of vowel /o/ in Kannada" was rejected.



Graph 71



Graph 72

Similar comparisons across the female groups showed that females of group 2 had significantly higher Io than females of groups 1 and 3. And females of group 1 had significantly higher Io than group 3 females for vowel *lol*. Thus the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of the vowel /o/ in Kannada" was rejected.

On comparisons across gender of the three groups, it was observed that females of group 1 showed significantly higher Io than their male counterparts. Hence the hypothesis stating that "there is no significant difference between males and females for Io of /o/ in group 1 in Kannada" was rejected. And there was no significant difference in Io between males and females in groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between males and females for Io of *lol* in groups 2 and 3 in Kannada" was rejected.

Vowel /o:/ Table 4.55 depicted that the mean Io of vowel /o:/ in males of group 1 was 74.9 dB R and the SD and range were 11.5 and 55 dB R and for females had a mean of 77.6 dB R, SD of 7.3 and range of 38 dB R. Group 2 males had a mean of 83 dB *R*, SD of 5.7 and range of 17 dB R and for females they were 82.2 dB R, 7.4 and.21 dB R respectively. In males of group 3, the mean, SD and range were 51.7 dB R, 4.8 and 29 dBR and for females they were 52.2 dB R, 5.4 and 28 dB R respectively.

Table 4.55 and Graph 72 depict that in both males and females Io for /o:/ was highest in group 2 followed by group 1 and then group 3. SD in males was highest in group 1 followed by group 2 and 3 respectively. In females SD was highest in group 2 and next in order were groups 1 and 3. The range of Io for the vowel /o:/ was highest in group 1 and next in order were groups 3 and 2 in both males and females.

From comparisons of males of different groups, it was observed that males of group 2 had significantly higher Io than males of groups 1 and 3. And males of group 1 had significantly higher Io than group 3 males. Hence the hypothesis stating that "there are no significant differences between males of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of vowel /o:/ in Kannada" were rejected.

Similar comparisons across the females of different groups showed that females of group 2 had significantly higher Io than females of groups 1 and 3. And females of group 1 had significantly higher Io than group 3 females for vowel /o:/. Hence the hypothesis stating that "there are no significant differences between females of groups 1 and 3, groups 1 and 2 and groups 2 and 3 in terms of Io of the vowel /o:/ in Kannada" was rejected.

On comparisons across the gender, it was disclosed that females of group 1 showed significantly higher Io than their male counterparts. Hence the hypothesis stating that "there is no significant difference between males and females for Io of/o/ in group 1 in Kannada" was rejected. And there were no significant differences in Io between males and females in groups 2 and 3. Hence the hypothesis stating that "there are no significant differences between males and females for Io of /o:/ in groups 2 and 3 in Kannada" was rejected.

Tables 4.56 and 4.57 shows the presence or absence of significant difference in Io between the three age groups.

Males	/i/	/I:/	/e/	le:l	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl Vs G2	P	P	P	P	P	P	P	P	P	P	10/10
Gl Vs G3	P	P	P	P	P	P	P	P	P	P	10/10
G2 Vs G3	P	P	P	P	P	P	P	P	P	P	10/10

Table 4.56 : The results of test for significance of difference between the three age groups in males for Io at 0.05 level

Females	/i/	/I:/	/e/	/e:/	/a/	/a:/	/u/	/u:/	/o/	/o:/	Total
Gl vs G2	P	P	P	P	P	P	P	P	P	P	10/10
Gl vs G3	P	P	P	P	P	P	P	P	P	P	10/10
G2 vs G3	P	P	P	P	P	P	P	P	P	P	10/10

Table 4.57 : The results of test for significance of difference between the three age groups in females for Io at 0.05 level

Tables 4.56 and 4.57 showed that Io was significantly different across the three groups. It was observed that group 2 had the highest intensity values for all the vowels and next in order were group 1 and group 3 respectively in both males and females. The standard deviation for Io decreased with increase in age in males for all the vowels. But in females the overall variability was highest in group 2 and then decreased to groupl and then to group 3 . The results obtained on Io suggested that there was an increase in Io from children to adolescents and further marked decrease to adults in both sexes.

Mvs F	*/i/*	**/I:/**	*/e/*	*/e:/*	**/a/**	**/a:/**	**/u/**	*/u:/*	**/o/**	**/o:/**	**Total**
Gl	A	P	*A*	P	A	P	A	**A**	P	P	5/10
G2	A	A	*A*	A	A	P	A	**A**	**P**	**A**	2/10
G3	A-	A	*A*	A	A	P	A	A	P	A	2/10

Table 4.58 : The results of test for significance of difference between males and females for Io at 0.05 level

It is clear from Table 4.58 that there was no significant difference in Io across gender for most of the vowels in the three groups. In a few instances where the significant difference were noticed, the female subjects produced vowels with higher intensity than males in all the groups.

Vowels	**Group 1**		**Group 2**		**Group 3**	
	M	**F**	**M**	**F**	**M**	**F**
a	74	75	81	81	49	49
a:	73	76	82	81	52	52
i	73	75	82	81	49	49
I:	73	75	81	80	49	47
u	73	75	81	80	50	49
u:	76	76	83	81	51	51
e	74	76	82	81	49	49
e:	74	77	83	81	51	51
0	72	77	82	82	52	52
o:	75	78	83	**82**	52	52

Table 4.59: Relative intensity (Io) for all the three groups

To summarize the results on relative intensity from Table 4.59:

a) No clear cut pattern in intensity emerged for different vowels.

b) Adolescents showed highest intensity for all the vowels followed by children and adults.

In the present study of vowels of Kannada, it was observed that children used higher intensity levels than adults. Study by Stathopoulos and Sapienza (1993) showed that at the comfortable and loud intensity levels, children produced significantly higher treacheal pressures than adults. In the present study no gender differences were observed in terms of intensity. This finding is in support of Tang and Stathopoulos (1995) whose study indicated that vocal efficiency were affected by vocal intensity and age, but not by gender. Venkatesh (1995) has reported that Io was found to be approximately same in adult males and females. Table 4.59 depicts the values of relative intensity obtained in the present study on vowels in Kannada for all the three groups.

The results on relative intensity of vowels in Kannada led to the following conclusions:

a) Children had significantly higher Io than adults. However adolescents used the highest intensity.

b) There was no difference across males and females for Io in all the three groups.

Effect of consonant environment on the vowels:

1. **Effect of consonant** environment on FO:

On overall observation it was observed that FO was not affected significantly by the consonant environment in all the groups. This may be because the FO measurements were made at the mid point of the vowel which reduces the effect of the preceding and following consonants.

2. **Effect of consonant environment on F2:**

F2 was highest in the environment of affricates and dentals and lowest in the environment of bilabials and velars for all the three age groups. Among the nasals, higher F2 was seen in the environment of dental /n/ compared to /m/ for all the three groups of subjects.

3. **Effect of consonant environment on Vowel Duration:**

On the whole, it was observed that in the environment of bilabials and dentals, the vowel duration was longest and shortest in the environment of velars and affricates for all the three groups of subjects.

Variability across trials: As said earlier in methodology, all the subjects in the present study were asked to read the test material (73 test words embedded in a carrier phrase) three times. Significance of variance was calculated across the three trials for all the parameters in the 30 subjects. The results obtained are presented in the following Table 4.6P. It was observed that the variability across trials decreased with increase in age which reflected neuromuscular maturity. In conclusion, the present data supported the idea that the development of speech production skills occur over a substantial period of time and the variability in articulation gets reduced by adulthood. Venkatesh (1995) also reported that there was no significant differences across trials for the temporal and spectral parameters of speech in adults.

	Group 1	**Group 2**	**Group 3**
A	F0, F3, Io	-	-
a:	F0, Io	-	-
I	Io	F1.F2	-
I:	-	-	-
U	FO, F2, F3, Io	-	-
u:	Io	-	-
E	FO.Io	F2	-
e:	F0, Fl, Io, Vd	—	Fl
0	Fl,Io	-	-
o:	F0, Fl, F3, Io	-	-

Table 4.60: Parameters which had significant difference across the three trials in the three groups

Conclusions:

The purpose of the study was to investigate acoustic characteristics of vowels in Kannada of children, adolescents and adults as a function of age and sex. The study revealed that there was a developmental trend for vowel duration, word duration, formant frequencies and fundamental frequency for the vowels in Kannada. No such trend was found with relative intensity of the vowel. It was also seen that a male-female difference was present for all the parameters except in intensity. Females showed longer vowel and word durations in all the three groups. In children formant frequency 1 and fundamental frequency was higher in males and formant frequencies 2 and 3 were higher in females. In adolescents and adults, formant frequencies and fundamental frequency were higher in the female subjects compared to their male counterparts.

Thus the purpose of the present investigation on vowels in Kannada was achieved. The developmental changes in terms of both the temporal and spectral parameters of speech with reference to vowels in Kannada were noticed.

SUMMARY AND CONCLUSIONS

CHAPTER 5

SUMMARY AND CONCLUSIONS

To understand the speech sounds of a language in order to rehabilitate the speech and hearing handicapped effectively and efficiently, it is necessary to learn about the articulatory and acoustic nature of the speech sounds. The speech sounds are perceived by the human being as acoustic events. These acoustic events are the consequence of articulatory movements. Hence the study of acoustic characteristics of speech sounds will give information about the articulatory nature of the sounds and also how these sounds are perceived (Picket 1980). Acoustic analysis of speech sounds provides information about the speech characteristics like fundamental frequency, formants and their band widths, vowel duration and consonant duration. The speech sounds are mainly classified into vowels and consonants. The vowels are produced by voiced excitation of the vocal tract. In speech, vowels are acoustically dominant because of their higher energy and longer duration than the consonants. Vowels are the result of interaction of minimally obstructed vocal tract and vocal fold vibration. Different vowels are produced by the modulation of laryngeal acoustic energy by various configuration of the vocal tract.

Children learn to speak using different sounds of the language, used around them as they grow. The mastery of production of speech sounds depends on the articulatory maneuver of the speech organs which is acquired with the maturation of the nervous system with increasing age. Inability to master the articulation of speech sound would reflect the possible problems in the nervous systems, apart from other factors

In the present study an attempt has been made to study the acoustic characteristics of vowels in Kannada with increase in age. Hence with anatomical changes of the speech organs, substantial changes in the acoustic characteristics of speech are also expected. There are several studies in the literature which have probed the developmental changes in the temporal and spectral parameters of speech (Hollien & Shipp 1972; Fant, 1973; Muller & Engerbretson 1977; Singh and Murray, 1978).

In recent years a number of acoustic studies have observed that children's speech segments, syllable, words etc. tend to decrease in durations and also become less variable from younger to older groups of subjects (Kent & Forner, 1980; Smith 1978, 1992, 1994; Smith et al 1983;Tingley and Allen 1975; Chermak & Schneiderman 1986). They are typically assumed to be due to neuromuscular maturation; to greater experience with the process of speech production or to a combination of both maturation and experience. Basic physiologic properties like brain maturation and neuronal transmission, as well as higher level motor programming and other linguistic and non linguistic factors (Tingley & Allen, 1975; Sharkey & Folkins, 1985; Schwartz, 1988; Smith 1992) have also been considered to be contributing to the decrease in duration and variability.

Therefore attempts have been made to note these characteristics in normal as well as abnormal children in an order to find out the possibilities of using these information to differentiate the normal from abnormal and to plan effective and efficient rehabilitation of the speech and hearing handicapped.

As the vowels are longer in duration and higher in energy they are more often studied than the consonants. Ladefoged (1975) states that even though the vowels of different languages are perceived as same, there are subtle differences between them. These differences can be studied by the acoustic analysis of the speech sounds. Hence, the study of acoustic characteristics of a language becomes important. In English and other Western languages many have studied the acoustic characteristics of the vowels of their respective languages. But there are very few developmental studies particularly, regarding the acoustic characteristics of Indian languages and more specifically in Kannada.

The present study aimed at studying the developmental changes in the temporal and spectral characteristics of vowels in Kannada language (Mysore dialect) used by normal children, adolescents and adults. For this purpose the acoustic analysis of vowels in Kannada language in /CVCV/ environments was carried out.

The following temporal and spectral parameters which would reflect changes related to speech development were considered.

1. Temporal parameters
    a. Duration of the vowel (VD)
    b. Duration of the word having the test vowel (WD)

2. Spectral parameters
    a. Formant frequency 1 (Fl)
    b. Formant frequency 2 (F2)
    c. Formant frequency 3 (F3)
    d. Fundamental frequency at the mid point of the vowel (IFO)
    e. Intensity at the mid point of the vowel (10)

Thus the objective of the present study was to determine some temporal and spectral characteristics of vowels of Kannada language in three different age groups. Therefore ten normal subjects with Kannada as their mother tongue in each of the three age groups, 7-8 years (children-Group 1), 14-15 years (adolescents-Group 2) and 20-30 years (adults- Group 3) were considered for the present study. Each group had five male and five female subjects. Totally there were 30 subjects. The subjects uttered three randomized lists of 73 sentences in a sound treated room. These sentences had meaningful disyllabic word ($C_1V_1C_2V_2$). These words had one of the twelve non aspirated consonants in Kannada as C_1 and one of the ten vowels as VI. The spoken sentences were digitized directly using 12 bit ADC at 16,000 Hz sampling rate and stored on the secondary memory of the computer.

The recorded test words were presented to three trained listeners to judge the correctness of the test vowel produced. The sentences rejected by the judges were re-recorded in the same way. From 30 subjects totally 6570 sentences were recorded. The data obtained was further subjected to detailed statistical analysis using one way ANOVA. The results obtained on each of the parameters were as follows:

The findings on **vowel duration** in Kannada can be summarized as:

a) Vowel duration decreased from children to adults..
b) Variability and range of vowel duration also followed suit.
c) In all the three groups females had longer vowel duration than their male counterparts.
d) The developmental trend was more stronger in short vowels than in long vowels.
e) Long vowels were almost twice the duration of short vowels in adults.

Word duration:

a) Word duration decreased from child to adult in both males and females
b) The variability and range also decreased with increase in age
c) However the mean value of word duration, standard deviation and range were less than adults in the adolescent group
d) Females had longer word duration in all the three groups.

Formant frequencies:

a) Formant frequencies (Fl, F2 and F3) decreased from children to adolescents markedly and there was further gradual decrease to adults.

b) And the drop in formant frequencies were more in F2 and F3 than in Fl from children to adults. Fl was more stable and appears to be fairly independent of age.

c) The variability of Fl and F2 was higher for central vowels whereas for F3 the variability was higher for the back vowels in all the groups. However for all the vowels variability in formants decreased with age.

d) When males and females of each group was compared, in children, Fl was found to be higher in males. In adolescents and adults, Fl was higher in females compared to their male counterparts. F2 and F3 were higher in females for all the three groups.

Fundamental frequency :

a) It was observed that there is a decrease in F0 from children to adolescents and further marked decrease to adults in both sexes.

b) There was significant difference in F0 across males and females for the three age groups.

c) In 7-8 years group, males had higher FO than females where as in 14-15 years and adults, females had significantly higher FO than their male counterparts.

d) The range and variability of FO decreased as a function of age. However because of the rapid development of the larynx between 13-15 years the range and variability of FO were higher in the adolescent boys.

Relative intensity:

a) Children had significantly higher Io than adults.

b) There was no significant difference across males and females for Io in all the three groups.

Implications of the study:

a) This study provides details of the acoustics of Kannada vowels in different age groups and therefore, can be used in the diagnosis and treatment of speech and hearing disorders.

b) This data is useful in synthesizing Kannada speech sounds and recognition of the same.

Recommendations:

a. Study can be repeated with more number of subjects and different age ranges
b. Methodology can be adopted to study the developmental changes in other Indian languages.
c. Clinical applications of the findings of the present study can be attempted.

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APPENDIXES

APPENDIX 1

೧. ಕಸು	kasu	(a) strength (b) mental ability to sustain the stress
೨. ಕಾಸು	ka:su	(a) money; the smallest coper coin (b) to make hot, to heat, to warm
೩. ಕಿಸು	kisu	(a) widely opened (b) to be angry
೪. ಕೀಸು	ki:su	(a) scraping; scratching (b) to make thin, to scrape, to polish (c) coil of palmyra leaf put in the ear lobe
೫. ಕುಸು	kusu	(a) to bend
೬. ಕೂಸು	ku:su	(a) an infant, child; a babe (b) a maiden; a young virgin
೭. ಕೆಸು	kesu	(a) a stem less plant with large leaves and edible tubers; the cocco Aram colocasia. L.
೮. ಕೇಸು	ke:su	(a) a certain stuffed material (b) colour, (similar to brik red colour)
೯. ಕೊಸೆ	kose	(a) to embrace sexually (b) a way of mounting the horse
೧೦. ಕೋಸು	ko:su	(a) cabbage (b) a measure of distance (c) the state of being crooked or curved

೧೧. ಗಟ	gata	(a) an imitating sound
೧೨. ಗಾಟ	ga:ta	(a) largeness, bigness (b) multitude
೧೩. ಗಿಟ	giṭa	(a) an imitative sound
೧೪. ಗುಟ	guṭa	(a) an imitative sound (b) to grunt (c) to bellow as a bull or an ox
೧೫. ಗೂಟ	gu:ṭa	(a) the milky shrub enphorbia neriifolia willd
೧೬. ಗೊಟ	goṭa	(a) a sound imitation of that produced by drinking liquids
೧೭. ಗೋಟ	go:ṭa	(a) harassing (b) pestiferous person
೧೮. ಚಲ	čala	(a) firmness of character (b) resoluteness (c) constancy in pursuing a purpose
೧೯. ಚಾಲ	Ča:la	(a) the state of being movable or in motion (b) shaking
೨೦. ಚೀಲ	Či:la	(a) bag
೨೧. ಚುಲ	Čula	(a) raising (b) rising (c) diving in to
೨೨. ಚೆಲ	Čela	(a) abbreviated for beauty (b) beautiful boy

೨೩. ಚೇಲ	če:la	(a) cloths or garment
೨೪. ಚೋಲ	čo:la	(a) a short jacket or bodice
೨೫. ಜಡಿ	jadi	(a) to wave (b) to brandish (c) as a sword
೨೬. ಜಾಡಿ	ja:di	(a) a common cumbly, especially for spreading out on the ground and sitting upon
೨೭. ಜಿಡಿ	jidi	(a) to wave (b) to brandish (c) as a sword
೨೮. ಜೂಡಿ	ju:di	(a)
೨೯. ಜೇಡಿ	je:di	(a) a sort of pipe clay
೩೦. ಜೋಡಿ	jo:di	(a) a state of being united or connected (b) a pair or couple
೩೧. ಟಣ	aṇa	(a) an imitative sound used in leaping
೩೨. ಟಾಣ	a:ṭṇa	(a) the head station of a district (b) police station
೩೩. ಡಗೆ	dage	(a) heat (b) glow (c) sultriness or deceit

೩೪. ಡೇಗೆ	de:ge	(a) a hawk (b) falcon
೩೫. ಡೊಗೆ	doge	(a) to make a hole (b) to excavate
೩೬. ತರ	tara	(a) a line (b) a row. succession, order, kind
೩೭. ತಾರ	ta:ra	(a) crossing (b) passing over (c) floating, swimming, descending
೩೮. ತಿರ	tira	(a) to turn
೩೯. ತೀರ	ti:ra	(a) a shore, a bank (b) margin, brink, edge
೪೦. ತುರ	tura	(a) quick, swift
೪೧. ತೆರ	tera	(a) the state of being balled or heaped one upon other (b) a mass
೪೨. ತೋರ	to:ra	(a) bigness, largeness, plumbness
೪೩. ದರ	dara	(a) rate, price
೪೪. ದಾರ	da:ra	(a) a string, a thread
೪೫. ದುರ	dura	(a) a battle, a war
೪೬. ದೂರ	du:ra	(a) distant, far from, remote, long
೪೭. ದೊರ	dora	(a) a large battle drum

೪೮. ನಲ	nala	(a) pleasure
೪೯. ನಾಲ	na:la	(a) water channel
೫೦. ನಿಲ	nila	(a) side post of the door
೫೧. ನುಲ	nula	(a) twisting
೫೨. ನೆಲ	nela	(a) ground
೫೩. ಪಡಿ	padi	(a) a measure of capacity
೫೪. ಪಾಡಿ	pa:di	(a) a settlement
		(b) a hamlet
೫೫. ಪಿಡಿ	pidi	(a) to seize, to lay hold of, to catch
೫೬. ಪೀಡಿ	pi:di	(a) a generation
೫೭. ಪುಡಿ	pudi	(a) powder
೫೮. ಪೇಡಿ	pe:di	(a) a coward
೫೯. ಪೋಡಿ	po:di	(a) a slice, a bit
೬೦. ಬರ	bara	(a) coming
೬೧. ಬಾರ	ba:ra	(a) a strap of leather
೬೨. ಬಿರ	bira	(a) walking fast
೬೩. ಬೀರ	bi:ra	(a) hero
೬೪. ಬೂರ	bu:ra	(a) fine sugar

೬೫. ಬೆರ	bera	(a) mingle
೬೬. ಬೇರ	be:ra	(a) figure, image
೬೭. ಬೋರ	bo:ra	(a) a trap
೬೮. ಮಡು	madu	(a) deep water (b) a deep place in a river
೬೯. ಮಾಡು	ma:du	(a) to do
೭೦. ಮಿಡು	midu	(a) to suffer
೭೧. ಮುಡು	mudu	(a) wearing flower
೭೨. ಮೂಡು	mu:du	(a) to rise
೭೩. ಮೇಡು	me:du	(a) a hillock

APPEXDIX 2

Details of the software programs used in the study

Waveform display: Displaying the sound pressure waveform is one basic functions of most devices **for** speech analysis. From such a display one can determine duration and relative amplitude. One can judge periodicity, and from the duration of the periods one can estimate the fundamental frequency.

Typically one can select positions of the waveform for closer inspection and for editing.

Measuring duration; By moving the cursors along the waveform display and by listening to the signal between the cursors, the duration of a particular utterance is measured. However, the main limitation is difficulty of judging exactly where a speech segment begins and ends. This problem can be partially solved by carefully listening to the signal.

Fourier Analysis: Fourier analysis takes its name from the mathematician Jean Baptiste Joseph Fourier. Fourier showed that periodic waveforms, no matter how complex, can be analyzed as the sum of an infinite series of sinosoidal components, varying in amplitude and phase. Each component is an integral multiple of the fundamental. Fourier analysis transforms a periodic amplitude by time waveform into a frequency waveform known as spectrum. This is a graph of the amplitude of the various frequency components.

The limitations of Fourier analysis are given below. First, Fourier's theorem applies to periodic waves, whereas speech sounds are only quasi periodic. Any sound which dies out is not truly periodic. Second, Fourier was talking about continuous waveforms, whereas in digital analysis we are dealing with discrete samples from such a waveform. **Third,** carrying out Fourier's analysis, as he developed it is computationally difficult, even though we settle for a finite number of consonants, of course.

The solution offered to these problems is adopting Fourier analysis to a quasi periodic waveform by windowing (gradually increasing and decreasing the amplitude of the signal rater tan turning it on and off abruptly). There are Discrete Fourier Transforms (DFTs) which apply to sampled data, and one type of DFT is a Fast Fourier Transform (FFT), which desk top computers can do rapidly.

Now digital analysis consists of an FFT of samples from a waveform. It yields a spectrum showing the amplitude of each harmonic of the fundamental. Fourier analysis makes it possible for us to identify the essential properties of speech sounds.

Linear prediction: A more recently developed method of analysis is linear prediction or linear predictive coding (LPC). LPC builds upon the fact that any sample in digitized speech is partly predictable from its immediate predecessors, speech does not vary wildly from sample to sample. Linear prediction is just the hypothesis that any sample is a linear function of those that precede it.

Linear predictive coding is a model of the sequence of samples that make up a signal, a representation of the signal over time. However, a set of linear prediction co-efficient as an equally valid interpretation in terms of frequency. It is the frequency response of a digital filter derived from those coefficients. Linear predictive analysis, like a Fourier transform, relates a representation in time to one in frequency. A key difference is that a Fourier spectrum represents harmonics of the fundamental, while an LPC spectrum represents formant frequencies and it's amplitudes (resonances). In the Fourier spectrum, formant frequencies can only be inferred from the frequencies of high-amplitude harmonics, a problem which becomes severe for speech with a high fundamental frequency.

Most LP analysis today are models of resonances only, not anti-resonances. But the vocal tract does introduce anti resonances, especially in the production of nasal and lateral speech sounds. For this reason, linear predictive analysis is not a good choice for analyzing such sounds. Similarly, LP analysis depends upon the linearity of the signal. But, speech is the combination of linear and non linear signals. Stop sounds are transient signals, where the LP analysis is not accurate.

Computational Methods: In addition to using spectrographs and other devices designed specifically to analyze speech, researchers are now programming ordinary computers to track FO in a speech signal. There are many types of such programs, for the simple reason that none of them is perfect. Three main approaches are cepstral analysis, auto correlation analysis and pattern recognition. The most commonly used one is auto correlation techniques.

Auto correlation: Two series of numbers are said to be highly correlated if they increase and decrease together. When we sample a speech signal digitally, we get a series of numbers, each one representing the amplitude of the sound pressure waveform at a particular moment.

To say that this waveform is periodic is to say that there is a repeated pattern of increases and decreases. If we were to compute the correlation between this waveform and an exact copy of the waveform (thus auto correlation), the two copies would of course, be perfectly correlated. .

If the correlation of the signal is completed with a slightly delayed copy of itself, the correlation would be highest when the delay, known as the lag, was close to one pitch period. If the correlation is computed at lags which range over probable pitch periods (say, from 10ms to 3 ms, corresponding to lOOHz to 300Hz in FO), peaks in the correlation at the actual pitch period (and its multiples) will be obtained. This is the essential idea of auto correlation pitch analysis. It works because in voiced speech, compared to unvoiced sounds, the formant structure does not change drastically within a few milliseconds, so that successive periods resemble each other. In unvoiced sounds auto correlation over a short term will normally yield no regular peaks. Quasi periodic voiced speech does not affect auto correlation because, relatively slow changes does not disturb auto correlation analysis.

In auto correlation the formants affect the location of correlation peaks. The solution offered is low-pass filtering to effectively eliminate formants at frequencies higher than the highest expected FO. But in some instances the frequency of Fl is lower than FO, which disrupts auto correlation analysis by changing the shape of the waveform. Despite these difficulties, auto correlation is one of the more reliable methods of determining FO.