परम श्रद्धेय माता-पिता,

भाई-बहन, बान्धव,

एवं शुभेच्छुओं को -

जिन्होंने मेरे सुन्दर भविष्य

का सपना देखा,

यह कृति समर्पित है -

ACOUSTIC ANALYSIS OF SPEECH OF CHILDREN

Kushalraj. P

Reg. No. 6

A DISSERTATION SUBMITTED IN PART FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE (SPEECH AND HEARING)

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ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE-570 006.
MAY 1983.

CERTIFICATE

This is to certify that the Dissertation entitled "Acoustic Analysis of Speech of Children" is the bonafide. work in part fulfilment for degree of M.Sc, Speech *and Hearing of the. student with the Register Number. 6.*

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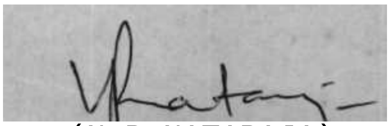
This is to certify that this Dissertation entitled "Acoustic Analysis of Speech of Children"has been prepared under my supervision and guidance..



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DECLARATION

I hereby declare that this dissertation entitled "Acoustic Analysis of Speech of Children" is the result of my own study Undertaken under the guidance of Mr.N.P.Nataraja, Lecture and the in-charge Head of the Department of Speech Pathology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other diploma or degree.

Mysore *Register Number*
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To all those
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CHAPTER I

INTRODUCTION

Speech is a neuromuscular activity. In other words, the output of this activity is the acoustic signals, which are used for cornmunication - as speech. The acoustic characteristics of speech have been found to vary with age. These acoustic features on various aspects of speech production indicate that the accuracy of motor control improves with age until adult like performance is achieved at about 11 or 12 years, somewhat after the age at which speech sound acquisition usually judged to be complete (Kent, 1976) .

"Reviews of the literature concerned with development of speech in children have provided much in formation on grammatical, contextual and syntactic aspects (Miller and Smith, 1968) , but somewhat less on phonetic aspects (Irwin, 1943, 1945, 1948; Morley, 1965, Simon 1957) of speech development. Phonetic studies, particularly since the introduction of the sound spectrograph in 1946, have clarified certain acoustical characteristics of speech sounds (Potter, Kopp and Green, 1947, Joos, 1948, Peterson and Barney, 1952; Potter and Steinberg, 1950; Peterson, 1959), and these characteristics have been confirmed subsequently by acousticsl resonance theory (Dunn, 1950, Stevens and House, 1955, 1961, Fant, 1960; Cooper et al., 1952). Potter and Steinberg (1950) and Peterson and Barney (1952) reported that the vowel formant frequencies of children were about 25% hiqher than those of the adult male and 20% higher than those of the adult female. The rapid anatomical, physiological and psychological development in childhood would, of course, predict that these acoustical features of the speech sounds or phonemes of children could not remain stable over any long period of time. However, there is a scarcity of acoustical studies concerned with the development of speech sounds or phonems in children (Okamura) "Eguchi and Hirsh (1969) .

The present investigation was designed to clarify the way in which speech sounds or phonemes develop in normal children after the initial stages of language acquisition by studying vocal fundamental frequency, formant pattern of vocalic sounds temporal property - VOT. Study of these acoustic parameters of speech sounds have been considered as reflecting, the adjustment of the phonatory apparatus. Shaping of the vocal tract and the timing and co-ordination of articulation. (According to Kent (1976) "Al:thouqh the physiologic and phonetic interpretation of acoustic data are sometimes uncertain, acoustic analysis for appropriate to test certain hypothesis about developmental changes in anatomy, motor control end phonological function". These acoustic analysis have been considered to have application in identification, diagnosis and treatment of developmental disorders of communication, E guchi and Hirsh (1969) have conducted an extensive study to investigate the developmental changes in the vocal fundamental frequency, formant frequencies and other temporal features of speech. This study by Eguchi and Hirsh (1969) has been the source of inspiration for the present investigation.

One, hundred children age ranging from 4-12 years, both males and females with Kannada as mother tongue were considered for study. All the subjects were normal in terms of speech, language and hearing, attending normal schools.

Spontaneous speech was elicited by showing three picture cards. The stimulus card were developed to elicit these sentences idu papu (this is baby) , idu koti (this is monkey) , and idu kempu bana (this is red colour) . Each child was given three trials, all the responses were recorded using tape recorder.

One set of the responses of three sentences, which was considered as good by the experimentor was used for analysis. The analysis was done to obtain fundamental frequency and formant frequencies (F_1, F_2 and P_3) of the vowels /a/, /i/ /u/, /o/ and /e/ from the test sentences. Further analysis was done to note the VOT values of voiceless stop consonants

/p/, /t/ and/k /, occuring in the test sentences. These measurements were done using High Resolution Signal Analyzer (B and K type 2033). Thus for the hundred subjects the fundamental frequency and formant frequencies of five vowels and VOT values for three consonants were obtained.

Necessary statistical treatment has been done to test the hypothesis.

Limitation

1. Only ten males and ten females have been considered for each age group.
2. The age group has been limited to 4-12 years.
3. Intra subject and Intra group variation were not studied.

Hypotheses;-

I a. There is no significant difference between the males and females of the same age group when the mean fundamental frequency of the vowels are compared.

I b. There is no significant difference between the males and females of the same age group when the mean formant frequencies (F_1, F_2 and P_3) of the vowels are compared.

I c. There is no significant difference between the males and females of the same age when the mean VOT of stop consonants are compared.

II a. There is no significant change in fundamental frequency of the vowels with increase in age.

II b. There is no .Significant change in formant frequencies (F_1, F_2 and F_3)of the vowels with increase in age.

II c. There is no significant change in VOT of the stop consonants with increase in age.

III a. There is no significant difference in the fundamental frequency of different vowels,

III b. There is no significant difference in the formant frequencies (F_1, F_2 and F_3)of different vowels.

III c. There is no significant difference in the VOT of different consonants.

Definition

Fundamental Frequency:- is the lowest frequency in the spectra of the vowel as shown by High Resolution Signal Analysis.

Formant Frequencies;- are the frequencies showing the peak intensities in the envelopes 2, 3 and 4 of the spectra of the vowel as shown by High Resolution Signal Analyzer

VOT :- is the duration from the end of the burst of the voiceless stop to the beginning of the following vowel as shown by the High Resolution Signal Analyzer.

Implication of the study

The study provides information regarding the changes in fundamental frequency, formant frequencies (F_1, F_2 and F_3) and VOT with age, in the age range 4-12 years.

The study provides information regarding difference in fundamental frequency, formant frequencies (F_1, F_2 and F_3) and VOT, in the age range 4-12 years, between males and females.

This study provides norms for F_0, F_1, F_2 and F_3 and VOT for the age range 4-12 years for both males and females, which can be used to note the variation in these parameters in clinical population.

CHAPTER II

REVIEW OF LITERATURE

"Today we are able to measure the acoustic or audible aspects of voice with sophisticated equipment. The voice print analyzer, sonograph, airflow meter, pressure recorder and computerized models of the vocal tract enable investigations to confirm earlier empirical findings and unearth new aspects of vocal sound characterization. The physiological aspects of sound production such as breathing patterns, vocal attack, vocal fold vibration, and some resonance qualities can be revealed by acoustic means". (Bunch (1982)).

The literature concerned with development of speech in children have provided much information on grammatical, contextural and syntactic aspects (Miller and Smith, 1966), however less on phonetic aspects (Irwin, 1943, 1945, 1948; Morley, 1965; Simon, 1957) of speech development. Phonetic studies, particularly since the introduction of the sound spectrograph in 1946, have clarified certain acoustical characteristics of speech sounds (Potter, Kopp and Green 1947; Joos, 1948; Peterson and Barney, 1952, Potter and Steinberg, 1950; Peterson, 1959; Babul Basu 1979; Ravishankar 1981; Indira 1982). Studies have also been conducted to study the resonance characteristics of vocal tract and the changes with age and they have confirmed the acoustical resonance theory. (House, 1955, 1961; Fant, 1960; Cooper et al, 1952) Potter and Steinberg (1950) Peterson and Barney (1952). The rapid anatomical, physiological and psychological development in childhood would predict that the acoustical features of the speech sounds or phonemes of children do not remain stable over any long period of time. However, there is a scarcity of acoustical studies concerned with the development of speech sounds or phonemes in children (Okamura, 1966)".

"The past two decades have been witness to an increasing application of acoustic analysis to the study of speech development in children" Kent (1976). However, it can be observed that acoustic data have been collected in three major areas: (1) vocal fundamental frequency (fo), (2) static formant patterns of vocalic sounds, and (3) temporal properties such as voice onset time, rates of formant movement, and segment duration. Sometimes the physiologic and phonetic interpretation of acoustic data are uncertain, but acoustic analysis is appropriate to test certain hypotheses about developmental changes in anatomy, motor control, and phonological function.

Such acoustic analysis have been considered to be useful in knowing more about the developmental disorders and thus in the treatment of developmental disorders of speech.

Therefore the present study aims at investigating three aspects of speech by acoustic analysis i.e., fundamental frequency formant frequency and voice onset time.

Fundamental Frequency

"The act of speaking is a very specialized way of using the vocal mechanism. The act of singing is even more so. Speaking and singing demand a combination and interaction of the mechanisms of respiration, phonation, resonance and speech articulation. The best speakers and singers are often those people who, by natural gift or training, or by a studied blend of both, have mastered the art of optimally using these vocal mechanisms. (Boone,1977).The basic mode of human communication is through speech. This facility has been considered as an over laid function, since the organs designed primarily are to serve other fundamental and vital functions like respiration^ mastication and protection. Sir Richard Paget (1930) convincingly speculates that man invented speech due to the demand of craftsmanship,art and agriculture on his hands and thus eventually forced him to shift his mode of communication from hand signals to vocal symbols, viz. Speech. Speech is a form of language that consists of sounds by utilizing the flow of air expelled from lungs.

The normal voice should possess certain characteristics of pitch, loudness and quality which will make the meaning clear, arouse proper emotional response to ensure a pleasant tonal effect upon the hearer (Berry and Eisenson, 1968).

Some of the investigators restrict the term voice, only to the laryngeal tone, while others include the transfer function of the vocal tract, while still others include articulation and prosody in addition to phonation and resonance.

Judson and Weaver (1942) defines voice as laryngeal vibration plus resonance.

Fant (1960) defines voice as

$$P = ST,$$

where in, P = the speech sound,
S = the source,
T = transfer function of the vocal tract

"While discussing the production of speech, it should be noted that the source s of the formula, P = ST, is an acoustic disturbance superimposed upon the flow of respiratory air and is caused..,.........by a quasi periodic modulation of the air flow due to the opening and closing movement of the vocal folds" (Fant 1960).

Michael and Wendahl (1971) consider three important factors to define voice, they are pulmonary air stream, laryngeal vibration and Transfer function of vocal tract.

Hence the definition is as "the laryngeal modulation of the pulmonic air stream, which is then further modified by the configuration of the vocal tract".

The essential function of larynx has been widely accepted that it has biological functions like preventing the foreign body entering the respiratory tract, building sub-glottal air pressure. Further secondary functions like the vocal cords vibrate during phonation, but the controversy exists as to the mechanism of these vibrations. There are two theories of phonation namely.

1. Myo elastic theory or aerodynamic theory, and
2. Neurochronaxic theory.

Various studies have been reported in defence and refutation of both the theories. According to Fant (1960) the earlier theory i.e.Myoelastic theory is most commonly accepted.

"Just as the sounds of musical instruments are weak without amplification, the tone produced at the glottis is probably not enough to the heard very for away without amplification. . . . . . . .the process which amplifies and augments the laryngeal tone is called resonance" (Fisher 1966)

Observation of wounded individuals with various types of openings in the neck region and experiments with excised larynges provide adequate support that the Sapra glottal resonators (vocal tract) amplify the laryngeal tone and give them the human quality (Judson and Weaver, 1965; Boone, 1971; Berry and Eisenson, 1962; Michael and Wendehl, 1971). When the laryngeal tone consisting of a spectrum of sounds passes through the vocal tract and is transmitted towards the lips, the vocal tract responds better to those components of the laryngeal tone that are at or near its natural frequency. These components will be emphasized and the spectrum of the sound emerging at the lips will show more energy at or around the natural frequency of the vocal tract.

Resonance is dependent on the volume of the cavity, the size of the opening, the length of the opening, and structure of the cavity.

A series of connected passage ways in the neck and head constitute the resonance apparatus for the human voice.

Gray and Wise (1959) thought of the vocal tract as a series of cylindrical sections with acoustical mass and compliance uniformly distributed along each section. Thus, the function of vocal resonators is two-fold. One, to increase the loudness of the laryngeal tone and second, to give human quality to vocal tones.

In humans various resonator's contribution has been extensively studied and it has been considered that the contribution of the Tracheobronchial tree, below the bifurcation of the trachea is negligible in the resonance of laryngeal tone (Judson and Weaver, 1965).

Judson and Weaver (1965) also state that "the influence of laryngeal cavities on resonance is also debatable. The main aim of these cavities is to aid in the production of laryngeal tone". Thus the supra glottal resonators have been considered as mainly contributing to the resonance of the laryngeal tone.

Fisher (1966, pp 95-96) states that "as the vocal tract (from lips to glottis) is not of uniform diameter throughout its length, it does not confirm precisely to the principles of resonance. In an irregular tube of this sort, resonance at any particular moment is influenced by (1) the length of the tube, (2) the cross-section area of the lip opening, (3) the cross-sectional area and locations of constrictions along the length of the tube, and (4) the elasticity of the walls. When constrictions in the passage way occur, the tube is divided into cavities which are coupled together. The cavities can act as separate resonators if the constriction is great and extensive".

The human vocal tract has a wide variety of surfaces; and resonance, to a certain extent, is influenced by the surface structure of the cavity; at one end is the hard surface of the teeth and at the other end is the sponge-like softness of the lung.

These changes in the cavity dimensions reinforce the fundamental tone and overtones of the laryngeal tone. The pharyngeal cavity forms an important resonator. This cavity is subjected to alterations in its size, shape and tension by various activities like movement of the root of the tongue, the action of the superior, middle or inferior constrictors together with thyroid, stylo-pharyngeal and pharyngo palatal muscles.

The oral cavity is yet another important, most modifiable resonator. It can function as a single resonating cavity when tongue lies relaxed on the floor of the oral cavity, or it may be considered as a multiple resonator when it is divided by the tongue into two cavities connected by a small aperture.

Oral cavity can further be sub-divided between tongue and the palate, between tongue and teeth or lips, between lips and teeth.

The nasal cavity plays a significant role when it is coupled with the naso-pharynx, as in the production of nasal sounds. The nasal sinuses play very little role in normal speech volume or quality (Judson and Weaver, 1965). Thus the laryngeal tone, a complex tone that is produced by vibration of vocal folds gets amplified and modified, by the resonators mainly the supra glottal i.e.. the fundamental frequency and over-tones get amplified. The fundamental frequency of voice when perceived auditorily is termed as pitch.

Pitch is the psychological correlate of frequency. Mel is the scale used to quantify pitch. A sound whose frequency is 1000 Hz with an intensity of 40 dB has a pitch of 1000 mels. Hence frequency of a sound does not uniquely determine its pitch (Steven and Davis, 1938). The relationship between frequency and pitch is logarithmic (Judson and Weaver, 1965).

Although pitch is defined often in terms of pure tones, it is clear that noises and other aperiodic sounds, have more or less definite pitches. The pitch of complex tones according to Stevens and Davis (1935) depends upon the frequency of its dominant component, i.e., the fundamental frequency in a complex tone. Plomp (1967) states that even in complex tone, where the fundamental frequency is absent or weak, the ear is capable of perceiving the fundamental frequency based on periodicity of pitch. Emrickson (1959) is of the opinion that the vocal cords are the ultimate determiners of the pitch and that the same general structure of the cords seem determines the range of frequencies that one can produce.

The factors determining the frequency of vibration of any vibrator are mass, length and tension of the vibrator. Thus the mass, length and tension of the vocal cords determine the fundamental frequency of voice.

The changes in voice with age and within the speech of an individual have been subject of interest to speech scientist. The present study is limited to the investigation of changes in fundamental frequency with age, and therefore studies concerned with this are reviewed. Various investigators dating back to 1939 have provided data on various vocal attributes at successive developmental stages, from infancy to old age. Studies by Fairbanks, (1940, 1949), Curry (1940), Snidecor,(1943), Hauley (1949) Mysak (1950), Samuel, (1973), Usha Abraham (1978), Gopal (1980) show that aging trends for males with respect to central tendency is, one of a progressive lowering of pitch level from infancy through middle age followed by a progressive raise in the old age. The voice of new born has been found to be around 400 Hz (Grutzman and Plateau, 1905, Indira, N. 1982) with growth of larynx the childs voice gradually changes. The voice change is most prominant at puberty.

Eguchi and Hirsh (1969) states that "It is well known that the fundamental frequencies of children and adult females are higher than those of the adult male". They further add that "children have a fundamental frequency of about 300 Hz even up to the age of 8 and 10 years. There is no significant difference of fundamental frequency of speech between 7 and 8 years, or between boys and girls of those ages (Fairbanks, Herbert and Hammond, 1949, Fairbanks, Wiley and Larsman, 1949, Potter and Steinberg, 1950, Peterson and Barney, 1952).

The fundamental frequency values are distinguished by sex only after the age of 11 years although small sex differences might occur before that age (Kent, 1976).

The fundamental frequency drops slightly during the first three weeks or so, but then increases until about the fourth month of life, after which it stabilizes for a period of approximately five months. Beginning with the first year, fundamental frequency decreases sharply until' about three years of age, when it makes a more gradual decline reaching to the onset of puberty at 11 or 12 years of age. A sex difference is apparent by the age of 13 years, which marks the beginning of a substantial drop for male voices, the well known adolescent voice change in the case of females, the decrement in fundamental frequency from infancy to adulthood is somewhat in excess of an octave. Where as males exhibit an overall decrease approaching two octaves". Kent (1976). Various studies have been conducted to investigate the changes in fundamental frequency with age. However most of these studies are cross-sectional studies. Therefore, as Kent (1976) states that the above findings may be considered as the representative of the actual developmental course of voice (fundamental frequency) at various age levels. Flatau and Gutzman, 1906; Ringel and Kluppel, 1964; Sheppard and Lane, 1968; Ostwald and Peltzman, 1974; Prescott, 1975; Penold et al, 1974; Mc Glone, 1966; Van Oordt and Dvost, 1963; Eguchi and Hirsh, 1969; Fairbanks, Herbert, and Hammond, 1949; McGlone and McGlone, 1972, Duffy, 1958; Michel, Hollien, and Moore, 1966; Hollien and Paul, 1969; Linke, 1953, Snidecor, 1951, Peterson and Barney, 1952; Boe and Rakotofiringa, 1975; Fairbanks, Wiley and Lassman 1949; Curry, 1940; Hollien and Malcik, 1962; 1967; Hollien, Malcik and Hollien, 1965; Naidr, Zboril and Sevcik, 1965.

Thus the fundamental frequency lowers with advancing age in both sexes. In males marked lowering of fundamental frequency is seen at about 10 years of age, and in females a gradual lowering of fundamental frequency is reported.

Further studies with Indian population has shown that, in males, This lowering in the fundamental frequency is gradual till the age of 10 years, after the age of 10 years, there is a sudden marked lowering in the fundamental frequency, which is attributable to the changes in the vocal apparatus at puberty. And in case of females only a gradual lowering of fundamental frequency is seen (George, 1973; Usha, 1979 and Gopal 1980).

Fundamental frequency changes with anatomical changes as reported by Negus (1949).

Among the several type of organic changes recognised leading to vocal involution, the vocal changes noticed during menopause in females and climacteric in males are most obvious.

With advancing age the vocal range gets reduced through the loss of high tones. The laryngeal tone changes due to biological phenomenon of aging. Terrocal and Azimer ( ) reports that "shortly after 20 years of age the laryngeal cartilages progressively get ossified, the blood vessels undergo arterlosclerotic changes as do all other vessels, and also endocrine function is reduced".

Thus the lowering of fundamental frequency is seen both in case of males and females with age, and these variations are attributed to the anatomical and physiological changes with age.

The study of fundamental frequency has important clinical implications.

Anderson (1962), and Brodnitz (1965), are of the view that -

> "Pitches above optimum are generally associated with strident, shrill, tense voice. Pitches that are deviant in this direction tend to abuse the vocal folds at the point of maximum displacement, the middle of the vibrating vocal cords, This type of traumatic vocalization will exacerbate existing pathology of the cords, such as, neoplasms; will produce laryngitis; and if prolonged will lead to the development of nodules - sometimes called 'Screamer's nodes' .... or Singer's nodes, depending on the nature of abusive conditions; all of which are conductive to screechy voices at high pitches".

The fundamental frequency of the voice in different syndromes have been studied by many investigators, Duffy (1954) analysed the speech of cerebral palsied persons by means of an instantaneous fundamental frequency recorder. He detected pitch characteristics which were related to different types of cerebral palsy.

Most of the acoustic research on esophageal speech has been concerned with the measurement of fundamental frequency. Investigators have studied the source function characteristics of esophageal speech assuming that the principal factors affected by laryngectomy are those of the vibratory source. (Damste, 1958; Nichols, 1968). The vowel formant frequency characteristics of esophageal speech of male and female laryngectomees have been studied by Nancy and Weinberg (1972). Comparisons were made between male and female laryngectomees and between laryngectomees and normals. The results of the study suggest that "the formant frequencies were consistently higher in esophageal speech than in normal speech - regardless of the sex of the speaker".

Burk and Saxman (1965) have studied the voice of male Schizophrenics. They found that the patient group used a significantly, larger fundamental frequency deviation than did their normal controls during impromptu speech but not during oral reading.

In a parallel study by the same authors (1968), the speaking fundamental frequency and rate of speech of adult female Schizophrenics was investigated. Tape recorded samples of oral reading and impromptu speech were compared for the schizophrenic females and normal females. The patient group was found to be using a significantly larger fundamental frequency deviation during oral reading and a significantly slower oral reading rate. Mean fundamental frequency level for the patient group was higher than that of the control group but not significant statistically.

Speaking fundamental frequency of five and six year old children with mongolism has been measured by Weinberg and Zlatin (1970). Results showed that the mean speaking fundamental frequency level for the sample of children with mongolism was significantly higher than the mean speaking fundamental frequency level for the control group.

Vocal fundamental frequency characteristics of mongol children has also been analysed by Montague et al (1974). Few of the mongol children had relatively higher fundamental frequencies. But as a group, no difference was found between the two groups in terms of fundamental frequency.

Investigation of the effects of smoking on the fundamental frequency of adult women was carried out by Gilbert and Weisman (1974). The results indicated that in the reading condition, fundamental frequency for the smokers was significantly lower than fundamental frequency for the non-smokers.

Weinberg et al (1975) described selected speech characteristics of patients with acromegaly. Some of the patients with acromegaly were found to use a low fundamental frequency than the normals. This lowering of fundamental frequency was prominent in female acromegalies than in male acromegalies.

A study was conducted by Asthana (1977) to find the effect of pitch variation and intensity variation on the degree of nasality of cleft palate speakers. The results of the study showed that the cleft palate speakers had significantly less nasality at the higher pitch level than the habitual. But the degree of perceived nasality did not change significantly when habitual pitch was lowered. She has recommended that the optimum pitch of the subjects may be measured to find out whether the pitch that was associated with less nasality was near the optimum pitch.

Formant Frequency

"The peaks in the spectrum of vowels correspond to the basic frequencies of the vibration of the air in the vocal tract. The region of the spectrum in which the frequency corresponds are relatively large and known as formants. The formants of a sound are those aspects of it which are directly dependent on the shape of the vocal tract and are largely responsible for the characteristics quality., ... It is the presence of formants that enables us to recognize the different vowels which are associated with the different positions of the vocal organ" (Ladefoged (1962)).

Singh and Singh (1979) define formant frequency as "the frequency region that is significantly amplified for a continuous period of time is known as a formant frequency.

The formant at the lowest end having a continuous stretch of darkness (on a spectrogram) is called the first formant and is denoted by F_1. The next higher band width with a noticeabl stretch of darkness is the second formant, denoted by F_2 and third higher band width is the third formant, denoted by F_3.

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 peak occurs (Fry, 1979). Formants are the most significant earmarks of sound and every vowel is formed by two or more formant ranges (Bunch, 1982).

"The most significant features of the vowel spectrum are the frequencies and amplitudes of the various formants. These correspond to the resonances of the vocal tract, and they produce peaks in the speech spectrum". (Dennes and Pinson, 1963, p.117).

Two theories have been proposed regarding the vowel production i.e., cavity tone theory and Harmonic Theory. According to cavity tone theory proposed by Willis (1830), "The sound identified as a vowel was dependent only upon the length of the resonating tube and the vowel tone was completely independent of reed tone" (Fundamental frequency) "The vowel heard was the result of an augmentation of certain of the harmonic components of the reed tone" according to Wheatstone (1837), the proponent of Harmonic theory of vowel production.

Scripture (1904) on the basis of a very thorough review and on the basis of his own experiments has concluded that, that the vowel production is 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 is more widely accepted than the Harmonic theory.

There are several indications that fundamental voice frequency may be a significant determinant of vowel quality.

In an experiment with a tone generator, Miller, R.L., (1953) showed that when only a portion of the vowel spectrum is presented, for example, only the first two formants of the [ ] of a child's voice correspond approximately to the position of the first two formant for the [a] of a man. If a man raises his fundamental voice frequency to correspond to that of a child (falsetto), the higher formants are removed by filtering, the acoustical result corresponds very closely to the [ ] of a child with low-pass filtering and may be so interpreted by a listner.

An even more general relation between fundamental voice frequency and vowel perception was observed by Wendahl, R.W., (1959). His experiments were conducted with a series resonance synthesizer, which stimulated the first five formants and was excited by a recurrent impulse. Wendahl employed characteristic resonance positions for various vowels for both men and women speakers, and shifted the fundamental frequency over a wide range. His results showed that when the formant positions were held constant, the vowel value judgements varied with different fundamental voice frequencies. Thus the relationship between F_0 and formants have not been made clear.

In the past, studies on vowel formant frequencies have been reported to clarify some acoustical features of speech sounds. It has been recognised that the vowel formant: represent the acoustical resonant properties of vocal tract as shaped in articulation by the tongue (Potter, Kopp and Green, 1947; Joos, 1948; Peterson and Barney, 1952; Peterson, 1951, 1959; Potter and Steinberg, 1950; Stevens and House, 1961). Identification of the vowel is chiefly dependent on the first and the second formants.

It has be presumed from past that the first formant corresponds to the back cavity and the second formant corresponds to the front cavity of the mouth (Joos, 1948).

Studies of synthesized speech and measurement of this size of vocal tract on X-ray pictures reveals that the first and second formants are not simply acoustic features of front cavity and back cavity in the vocal tract (Fant, 1960).

"The first formant" the frequency of the first formant is generally dependent more on the back cavity volume than on the volume of other cavities. An exception is the vowel [a], where F_1 is affected equally on a percentage basis by a change in the front cavity volume.

Since the back cavity of [a] is much shorter than the front cavity, the percentage increases of F_1 due to the removal of a small unit length section of the back cavity is larger than the shift caused by a removal of a section of the same length in the middle of the front cavity.

F_1 of the vowels [e], [i] and [t] is almost completely determined by the back cavity volume and the narrowest section of the mouth cavity. In the vowels [u],[o] and [a] is somewhat more dependent on the front cavity constriction section. The contribution of F_1 of [u] from the back cavity volume is somewhat larger than that from the front cavity.

"The second formant only in the case of the vowel [t] was the mouth cavity with associated orifices found to be the essential determinant of F_2. F_2 of [i] is clearly a half wavelength resonance of the back cavity. There is a similar but not so apparent tendency of F_2 of [e] to be influenced more by the back than by the front cavity. The second formant of the back vowels [u],[o] and [a] is somewhat more dependent on the front cavity than on the back cavity. Providing the cavity volume changes are introduced on a constant percentage basis.

this tendency is apparent, but if the volume changes are performed by means of a constant length reduction, there is an equal dependency of F_2 on the two cavities for [u] and also for [a]. In the case of [u], F_2 is dependent much more on the relative dimensions of the tongue pass than on the lip section. These two parts of the compound resonator system have about the same effect on F_2 of both [a] and [o]. The lip section is of practically no importance for F_2 of [i] and does not have a very marked influence of [e] either" (Fant, 1960, p.121)

"Needless to say, the vocal tract of a child is smaller in size than that of an adult. But we cannot easily assume that the formants have higher frequencies in proportion to the size of the vocal tract with age as a whole, because different parts of the vocal tract presumably change at different rates" (Eguchi and Hirsh 1969)

The psycho-physiological development is also considered to be one of the factors in determining the variation in formant frequency with age, along with the anatomical changes. Further, the perception of vowels is not depending solely on the formant frequencies but also influenced by many other factors (Peterson 1952).

Kent (1976) reports that "the formant frequencies of children's vowels are higher than the values obtained for adult females and higher yet than the values obtained for adult males. On the one hand, this result is to be expected given the differences in the length of the vocal tract between children and women and between children and men. On the other hand, mathematical prediction of the observed differences has been the subject of several papers, right up to the present. If growth of the vocal tract were uniform, their prediction would be simple enough. However, Fant (1960) argued that there are differences other than size between the vocal tract anatomies of men and women, and that children apparently are more like women in the configuration of their vocal tracts. Hence, as a boy grows into manhood, the changes that occur in the formant structure of his vowels cannot be likened exactly to the changes in resonant frequencies that are observed as a uniform acoustic tube is lengthened. The problem of the scaling of formant patterns is important for speech perception, because of its implication it holds for the recognition BBoBpgavagCEctaeaEEemgmitisR of phonemes and speakers. This issue has been discussed in several papers (Broadbent, Ladefoged, and Lawrence, 1956; Gerstman, 1968; Fujisaki and Kawashima, 1968).

Mol (1963) replotted the data of Peterson and Barney (1952) to reveal an apparently linear change in formant structure among children, women, and men. He ascribed this linear change to the "principle of uniform axial growth".

The principle of uniform growth of this vocal tract is not without preponents (Kent, 1976).

But study by Eguchi and Hirsh (1969) give little support to Mol's principle of uniform axial growth.

Nordstorm and Lindblom (1975) report the linear relationships in the formant data of man, women, and children. They suggest that departures from linearity in the Peterson and Barney (1952) data may be explained by articulatory differences among the speakers, especially because not all of the speakers in the investigation were native Americans.

Formant frequencies of adult male and adult female vowels were compared by means of scale factors based on ratio as follows by Fant (1966)

1) First formant scale factor

$$K_1 = \frac{F_1 \text{ of female}}{F_1 \text{ of male}} - 1 \times 100$$

2) Second formant scale factor

$$k_2 = \frac{F_2 \text{ of female}}{F_2 \text{ of male}} - 1 \quad \times 100$$

Fant (1966) concluded from his calculation that the scale factors relating male and female data vary with the class of the vowels, with the average scale factor about

1896. In addition, he determined that the scale factors for both F_1 and F_2 were low for rounded back vowels, that the scale factor for F_1 was low for any close or highly rounded, and that the scale factor for F_1 was high for very open front or back vowels. Fant (1966) pointed out that these differences are consistent with differences in vocal tract anatomy between males and females, in so far as males have a greater relative length of the pharynx than females.

The scale factors defined above can be used to characterise developmental changes in the formant structures of vowels. Scale factors calculated from the data of Eguchi and Hirsh (1969) indicate that the children often had average F_1 values approaching those for the adult female subjects. In view of this unusual result, the formant frequency values reported by Eguchi and Hirsh (1969) should be treated cautiously. Considering the data for F_2, which are more systematic than those for F_1, during the developmental period of three - 13 years, second formant scale factor changes at the annual rate of *3.4%* for an adult male referent and about 2% for an adult female referent.

Kent (1976) has drawn the following tentative conclusions about child adult scale factors.

1. The scale factor for F_1 is large for the high vowels

but small for the low vowels.

2. The scale factor for F_2 is large for the front vowels but small for the close back vowels.

Bunch (1982) states that the various factors effecting formant frequencies are related of the vibrating frequency of the vocal folds to the resonating frequency of the phanynx and further it depends on the amount of damping. Winckle (1967) while discussing the transfer function of vocal tract states that "when there is severe damping of resonances in the vocal tract there are wider resonance curves for the formants, and therefore a wider excitation zone for the formation of non-harmonic partials".

Sundberg, (1977) is of the opinion that the alterations in the configuration of the vocal tract gives 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 be contributing for the changes in the responses of the cavities in the vocal tract to different frequencies and thus change the formant frequencies. At least 4 formants can be identified in any vowel irrespective of the pitch according to Sundberg, (1977).

Variability in children's Formant Patterns for Vowels

Study by Eguchi and Hirsh (1969) are the only substantial source of data in this area that the intrasubject standard deviations of both F_1 and F_2 for five vowels in five recitations each of the sentences, H e h a s a b 1 u e p e n and I a m t a 1 1 have been calculated. The variability of Standard Deviations of both F_1, and F_2 have been found to decrease with age, uniformly i.e., the variability of S.D's decreased from three to 11 years. The relative values of F_0, F_1 and F_2 reach an asymptotic level at about 11 or 12 years of age,at which age the variability of the children's data is about the same as the variability of the adult data. This has been considered by Eguchi and Hirsh (1969) as the evidence to show that the young children were more inaccurate in articulatory positioning than the older subjects.

Lindblom (1972) questioned Eguchi and Hirsh's assumption that the variability of F_1 and F_2 is descriptive of instability in articulatory positioning. Lindblom (1972) showed that a hypothetical curve relating the error of formant frequency estimation to the fundamental frequency is similar in form to the age dependent standard deviation curve presented by Eguchi and Hirsh (1969). And therefore Lindblom (1972) suggests that the "measurement error might be a significant factor in the variability data derived from the spectrographic measurements. The problem would be easier to evaluate if estimates of the measurement error has been obtained separately for each age group used in the study". However, Eguchi and Hirsh reported measurement errors based only on size different vowels spoken by a 6-year-old child and by an adult male. Therefore the conclusion by Eguchi and Hirsh (1969) have to be considered with some reservation.

As the review indicates, the study of F_0, F_1 and F_2 would provide information on both, the condition and the control of the laryngeal and the vocal tract system. And thus as Kent (1976) states that "Beyond the question of postural stability, formant patterns, either relative or absolute, might have some value in the identification and diagnosis of deviant development. However, many conditions that are sufficiently severe so as to affect formant structure are readily signaled by gross.changes in physical appearance, such as congenital malformations of the head and neck. Perhaps, though, formant patterns can be used as one index of normal anatomical development, especially during the first two years of life, when the distance between the larynx and the oral cavity gradually, increases to form a pharyngeal tube (Negus, 1962; Lieberman et al., 1972; Lieberman, 1973). Abnormalities that affect the development of the pharyngeal cavity conceivably could be detected by appropriate measurements of formant structure".

V O T

Voice onset time (VOT) is one of the parameters among the temporal features of speech. Vot may be defined as "The duration between the release of a complete articulatory constriction or burst transient and the onset of phonation (Lisker and Abramson 1964, 1964; 1967).

According to Kent (1976) "One of the most frequent objects of systematic, quantitative research on speech development is VOT, for stop cognates in syllable-initial position".

VOT has been found to be affected by several variables such as age, articulatory position and language. VOT has been found to be more during early childhood upto certain age (Preston, Yeni-Komshian and Stark 1967, Winter, Korn, Mac Keilage and Preston 1967; Eimas et. al., 1971; Stark 1972; Trehub and Rubinovitch 1972; Kewley-Port and Preston 1974; Zlatin and Koenigsknecht 1975, 1976). It has been stated that "changes in the VOT distributions that occur during the first six years of life appears to the fairly systematic". (Kent, 1976).

The nature of the sound i.e., whether it is voiced or voiceless is determined by the voice onset time. When the voice onset occurs after the articulatory posture in the vocal tract. The sound will be unvoiced while the voice onset occurs before or simultaneously with the release of the articulators, the sound will be considered as voiced. The term voice onset refers to initiation of vocal cord vibration.

VOT has been found to vary with the position of articulation i.e., it has been found to increase consistently as the constriction of articulation moves backwards from lip to velum. Hillman and Gilbert 1977; Port, 1979; Lisker and Abramson (1965) have shown that the mean VOT of / p / 58 m. sec for /t/ 70 m. sec. and / k / m. sec. Prestin, Yeni-Komshian and Stark (1967) reported that the distribution of the values of VOT for children approximated the adult models. Zlatin (1974) studied voicing contrast preceptual and productive VOT characteristics of adults and reported that the analysis of the perceptual data revealed significant differences among labial,apical and velar stops. In production of voiced and voiceless stops reliable differences for mean VOT were shown all cognates and among places of articulatory constriction within voicing category as age increased.

Basu (1979) reported that there was a consistent increase in VOT with respect to the position of articulatory constriction (as it moved backward in the oral cavity) in case of non stutterers. Port (1979) in his study regarding relation between VOT and vowel duration in initial English stops report that the results imply that temporal implementation rules simultaneously influence several acoustic intervals including both VDT and the "inherent" interval corresponding to a segment, either by independent control of the relevant articulatory variables or by some unknown common mechanism".

According to Summerfield and Haggard (1972) VDT decreases with increase in speaking rate.

Another variable affecting the VOT is the age of the speaker. Many studies have been reported with reference to speech development in children giving due importance to VOT as an important temporal feature.

Preston et al (1967) have studied VOT for Lebanese and American infants of, 12 month old and showed that they produced apical stop consonants with essentially the same range of VOT values in the short lag region of the continuum. Between *one* and two years of age group stop productions spread from a relatively narrow unimodal distribution as the American and Lebanese children begin to exhibit differential phonologically appropriate characteristics for their respective languages. It was also found that the magnitude of VOT difference required for distinguishing between prevocalic stop cognates decreases a function of age.

Menyuk and Klatt (1975) in their study on VDT in consonant cluster production by children and adults report that overall timing characteristics were similar for children and adults. VOT generally increased from labial to dental to velar clusters, and was shorter in single tone. Children's VOT averages were generally but not significantly longer than adults in all context and co articulation constriants affected the accuracy with which children produced the stops and liquid portion of a particular cluster. Kent (1976) noted fairly systematic changes in the VOT distributions during the first six years of life. The majority of stops in the early words of the child are characterized by the occurence of a short delay between articulatory release and the onset of vocal fold vibration. Shortly thereafter, the VOT distributions of children begins to assume a form which is similar to that of adult speakers. By the age of six, the ranges of VOT values for voiced and voiceless stops overlap to a greater degree than for adults. Voicing lead (negative values of VOT, for which voicing precedes articulatory release) becomes more common with maturation, especially for hilabials. In addition, the variability of VOT decreases so that adult like stability of production is noted at about eight years of life.

Lisker and Abramson (1964) have studied the VOT in various languages including Hindi, English, Tamil and Marathi for the stop sounds in word initial position. The VOT values obtained did not agree for any two languages, hence language has been found to be a variable in VOT measurement. They have also reported that VOT is less in running speech than in nonsense syllables. Presence of voiceless stop in a stressed syllable makes for a greater lag in the onset of voicing hence, type of speech sample is another variable for VOT measurement. Basu (1979) in his study of VOT in stutterers and non stutterers also using Kannada voiced and voiceless stop sounds in isolations and in spontaneous reading reports that his findings do not agree with the findings of Lisker and Abramson (1964) i.e. VOT in Hindi, English, Tamil and Marathi. Ravishankar (1981), in his study on VOT in different age ranges has used only Kannada as the language to elicit voiced and voiceless stops and has found that results similar to Basu's(1979) investigation. Further that the VOT varies with age.

Zlatin and Koenigsknecht (1976) studied the Development of the voicing contrast: A comparison of VOT in stop perception and production in ten, two year old children, ten six year old children and twenty adults. They report that the mean VOT differed significantly as a function of age. In the case of the adult speakers, it was reported mean VOT for voiced steps was in the short lead range while the average for their voiceless stop productions was in the moderately long lag portions of the VOT continuum. The children of two and six year old used primarity the short lag range for voiced steps and, in general, their average VOT for voiceless cognates was smaller than those of adults . Infrequent occurrence of lead during the production of voiced stop sounds was common in two-and six-year-old children. They have also observed significant differences between voicing categories for all cognate pairs within each age group and a progression of later mean lag times following from the most anterior point of constriction in the vocal tract to the velar position in case of adults and six-year-old children, which agrees with the studies of Lisker and Abramson (1964). There was no significant difference in results with respect to sex in all the groups studied.

The unstable and infrequent occurrences of lead in the production of voiced stops and long lag in the production of voiceless stops during the early period of life is attributed to lack of consistent control over the timing of laryngeal and supra glottal articulatory events.

Graham and House (1971) and Edwards (1974) have opined that the distinctive acoustic cue VOT is helpful to assess the general process of motor skill acquisition, since VOT production distributions appropriate to the childs language are acquired during the period of speech sound learning. Morleys et al (1980) report that as the child acquires productive control over voicing VOT values will change concomitantly.

There are many studies which have considered that involvement of larynx in the causation of stuttering (Travis 1931; Wingate 1970; Adams and Reis 1971; Van Riper 1971; Wyke 1974; Freeman and Ushijima 1975; Hanna, Wilfling and McNeill 1975-). Schwartz (1974) has explained "The core of the stuttering block". According to this model "The disorder is essentially an inappropriate, vigorous contraction of this posterior cricoarytenoid in response to the sub glottal air pressures required for speech". Thus this leads to increased VOT in stutterers. Neurophysiologically VOT can be defined as the activity of posterior crico arytenoid during phonation.

VOT has been found to vary between stutterers and non-stutterers i.e., stutterers have been found to and have longer VOT than normals (Basu, 1979; Agnello and Wingate 1972; Adams and Hayden 1974; Starkweather et al 1976; Hillman and Gilbert 1977; and Miller 1977).

Ravishankar (1981) in his study on VOT in different age ranges has found that there is no significant difference in mean VOT values for voiceless stop sounds with increasing age in both males and females, but not so in case of voiced stop sounds and no statistical difference in VDT mean values was noted between the age range of 4 to 7 years but significant difference was noted in mean value for subjects above 7-8 year group onwards. This was true for both males and females hence no sex difference was reported. There was significant difference in VOT between each voiceless stop and its voice counter part for both males and females at all age groups. A consistent increase in mean VOT values with respect to the point of articulatory constriction is seen for all subjects above 7 years of age.

Thus the review indicates that the VOT is determined by the anatomical and the neurophysiological condition of the speech mechanism. Therefore any deviations in VOT would indicate the possible abnormalities in neurophysiological and/or, anatomical maturation. As the VOT has been found to vary between stutterers and non-stutterers, measurement of VOT may become a useful tool in differential diagnosis of stuttering and may be used to evaluate various stuttering therapies.

The study of fundamental frequency, formant frequency and VDT for the purpose of identifying the developmental disorders at an early age, has been attempted. And the results are encouraging indicating **the** possibilities of usefulness of measurement of the above parameters in diagnosis and differential diagnosis of various speech disorders. Therefore the present study proposed to investigate, fundamental and formant frequencies and VOT in Indian population of younger age group with the view of using this data for clinical purposes.

CHAPTER III

M E T H 0 D 0 L 0 G Y

The study was aimed at investigating the developmental changes in fundamental frequency, formant frequency and voice onset time in children of both the sexes. The study consisted of the following steps. *

Step 1. Selection of subjects

Step 2. Selection of Test Material

Step 3. Recording of the speech samples

Step 4. Selection of speech samples for analysis

Step 5. Analysis of speech sample for the measurement c

a) Fundamental frequency

b) Formant frequency

c) Voice onset time.

Step 1: Selection of subjects.

Subjects ranging from 4 to 12 years of both the sexes were randomly selected for the study. All the subjects had Kannada as their mothertongue and none of them had any speech and hearing problems. The subjects were examined for possible oropharyngeal deformites and were found to have no deformity hence all the subjects were included for the study. The subjects were the children from

i) Demonstration primary school,

ii) Nursery school, Manasagangothri.

The following table shows the distribution of subjects in various age groups.

Age years	Sex		Total
	Males	Females	
4-5	10	10	20
5-6	10	10	20
7-8	10	10	20
9-10	10	10	20
11-12	10	10	20
Total	50	50	100

Step 2: Selection of Test Material.

Three sentences in Kannada which could be picturised were selected.

ಇದು ಪಾಪು.

(This is a baby)

ಇದು ಕೋತಿ.

(This is a monkey)

ಇದು ಕೆಂಪು ಬಣ್ಣ.

(This is red colour)

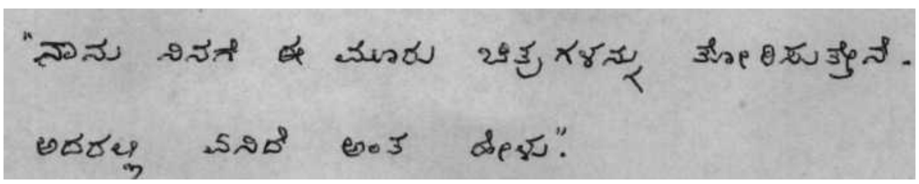
These sentences were selected as they were found to be with in the vocabulary of the children age range 4-12 years further, it was found to be easy to elicit spontaneous speech (as answers to the question what is this, by showing the picture cards).

These sentences consisted of five vowels, representing variety of tongue position in vowel articulation as follows

/a/ from papu
/i/ from Koti
/o/ from Koti
/u/ from Kempu
/e/ from Kempu

In additionthe stop consonants /p/, /t/, /k/ were included in the word papu, koti and kempu for the purpose of measurement of VOT.

Each subject was instructed as follows inKannada.



("I will show you three picture cards and I want you to tell me what you see in the picture").

Whenever the expected answer was not elicited the child was provided with the answer and it was used as a trial for example some children did not use the word papu or Koti such children were provided with the words which the investigator wanted them to say.

Each subject was presented the stimulus cards randomly and the investigator asked them to say what they saw in the picture by asking the question

ಇದು ಏನು?

(what is this)

The responses were recorded using National Panasonic tape recorder (Model RQ 2175) and Sony CHF-9O Cassette in the Speech Laboratory of All India Institute of Speech and Hearing, Mysore.

Each subject was presented the three picture cards three times i.e., for each subject three responses were recorded three times. Interval of approximately one minute was provided between successive presentation of stimulus cards.

All the children (i.e., one hundred) underwent the experiment. Thus a total of nine hundred responses or sentences were recorded as spoken by one hundred children age ranging from 4 to 12 years. This was considered as the material for analysis to measure fundamental frequency

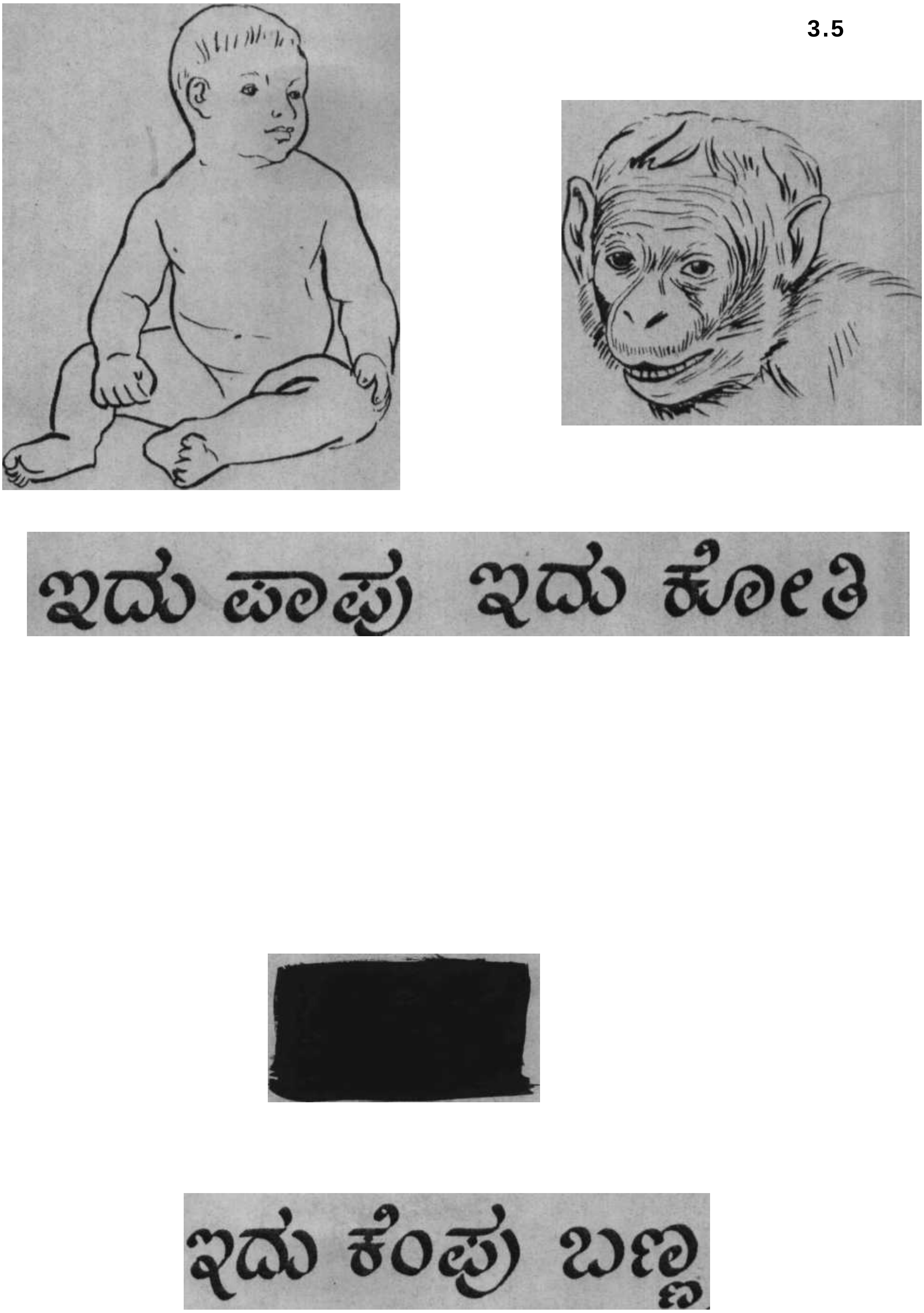


Fig. 1. Stimulus cards used.

formant frequencyand VOT.

Step 4: Selection of speech sample for analysis.

Of the nine sentence spoken by each subject three responses representing three different sentences were selected on the basis of presence of less interfering noise, absence of a discrete observable plosive release, and/or inappropriate productions (for example, shouted, whisphered or grossly exaggerated responses). These utterances of the subjects were transferred from the cassettes to a spool tape (TDK, AUDUA L-1800) using Uher (Model SG 630 Logic) tape recorder. Line recording technique was used for selecting and transferring the speech samples from the cassette to the spool tape.

Step 5: Analysis of speech samples, and measurement of fundamental frequency, formatt frequency and VOT were done using High Resolution signal Analyzer B and K.

There are various objective methods to evaluate the fundamental frequency of the vocal cords. Stroboscopic procedure, Pardue pitch meter, High speed cimenatograph, Electroglottography, Ultrasonic recordings, stroboscopic Laminography (STROL), Cepstrum pitch detection, The 3 M Plastiform Magnetic Tape viewer, spectography, Digi pitch, Pitch Computer.

To measure formant frequency available objective methods are several Amplitude Weighting, Spectrum Transformation,

Photo 1. Display of the Instrument used for the study
HIGH RESOLUTION SIGNAL ANALYZER. B & K 2033.

Strongest Harmonic evaluation, Digital computation of the Cepstrum, Dimensional analysis of vocal spectra.

To measure VOT the available objective techniques are two: Optical oscilloscope method. Vide band spectrogram method.

No literature was available to the investigator regarding the use of High Resolution signal Analyzer for the measurement of fundamental frequency, formant frequency and VOT.

A pilot study was carried out to evaluate the reliability and validity of High Resolution Signal Analyzer B and K type 2033 (HRSA - B and K 2033 in the measurement of F.F, Formant frequency and VOT (Picture no.1 shows the equipment used for the study). Five male and five female objects were selected who had no speech and hearing abnormalities for this purpose.

The subjects were presented with three picture cards which were used with other test subjects, and using the same procedure as described earlier In Step 3 and 4, the responses were recorded and selected for analyses.

Wide band spectrograms were obtained for three sentence by each subject.

The fundamental frequency was measured using Digi pitch which is the optional part of the spectrograph (Voice Identification Inc. Mark VII)

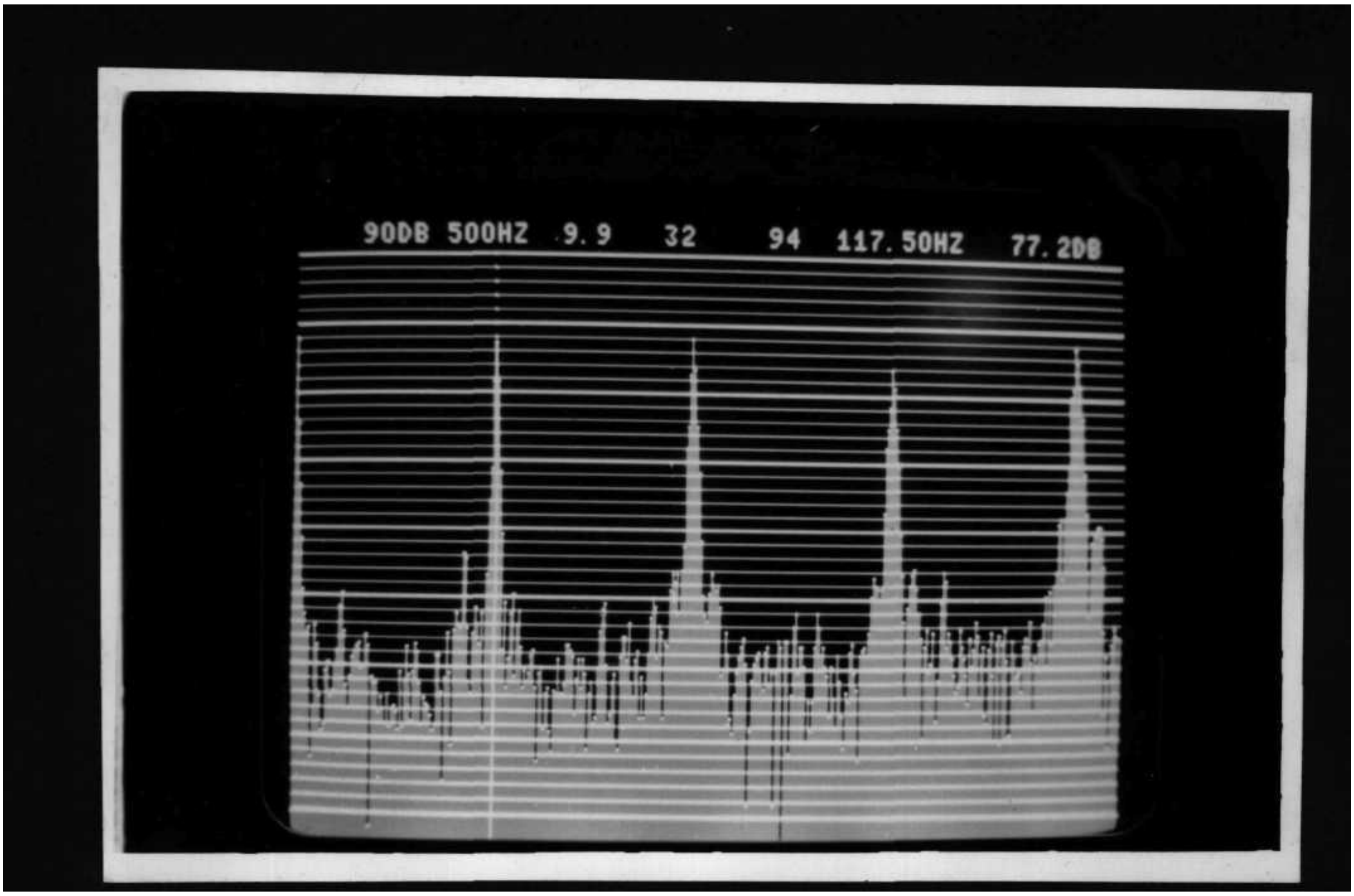


Photo 2. Display of the fundamental frequency for vowel /a/.

The signal from the spectrograph was fed to the Digi pitch through line input, the digi pitch gave the digital display of the fundamental frequency i.e., of the vowels /a/, /i/, /u/, /o/ and /e/, from the three sentences of each subject. The extraction of the vowel from the sentence was possible using the " Signal Gate" facility available In the spectrograph.

The same signal was fed to the HRSA from spectrograph through line input when HRSA was having the following settings

Input - "Direct" - connects the Direct Input to the input amplifier.

Trigger - "Free Run - makes operation of the HRSA Independent of any triggering conditions. Records are taken and transformed at the fastest rate compatible with the HRSA calculation procedures.

F.S.Frequency - 1 H_2 to 5 KH_2 is selected for the use.

Weighting - "Hanning" - causes the time domain record to the transformed modified by a Hanning ($Cosine^2$) weighting.

Record - "Cont" - causes new records to be continuously taken and transformed according to the triggering conditions set.

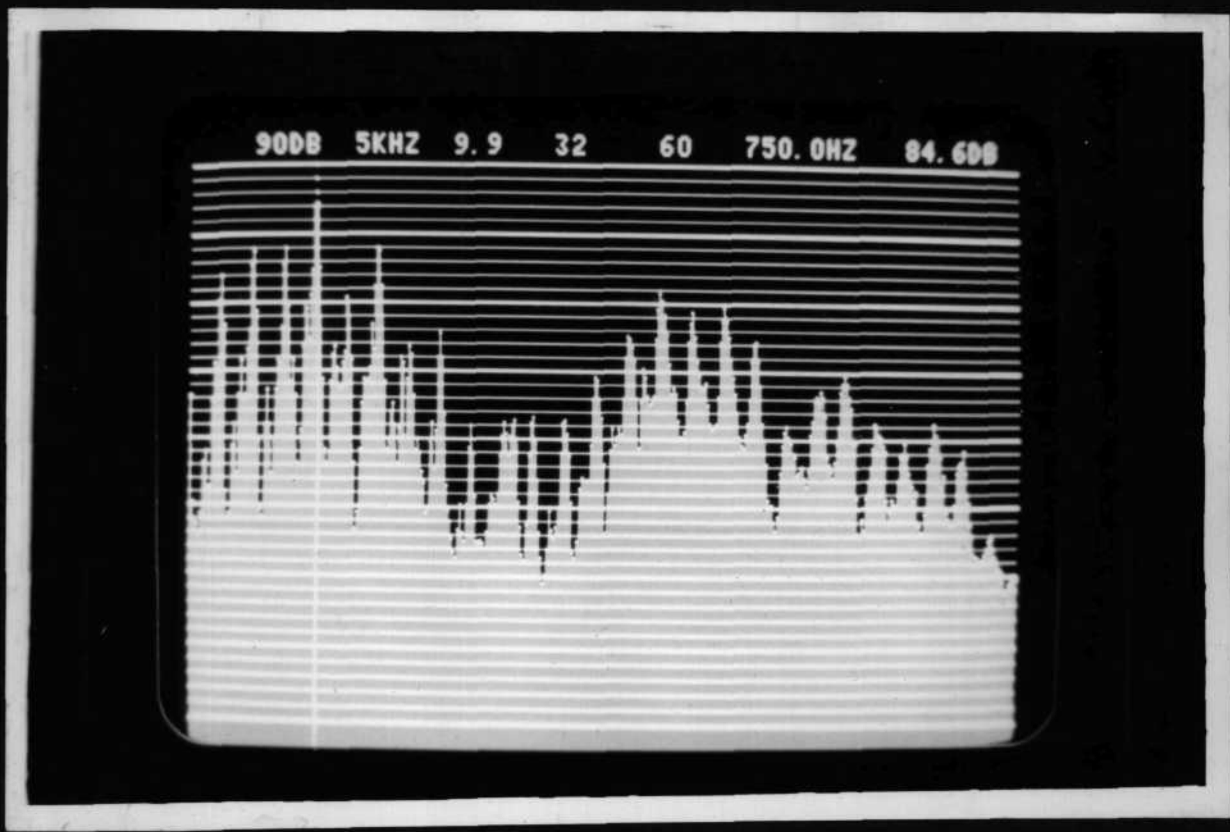


Photo 3. Display of the formant frequencies of vowel /a/.

Input Function - "Inst Spectrum" - causes the input function to the DISPLAY SELECTOR to be the instantaneous spectrum.

Scale Brightness - Controls the brightness of the scale on the HRSA display screen and can be adjusted depending on the need.

Making the above setting on the HRSA, the signal gated from spectrograph (voice Identification Inc., VII) was fed directly. The signal fed were vowels /a/ /i/ /u/ /o/ and /e/ individually. As a particular vowel kept appearing on this display screen of HRSA, in form of visual display, the "Stop" key was pressed which stops recording and transformation, retaining the most recent complete record (as shown in photo No.2 for vowel /a/).

The Cursor was moved towards the first peak, and the readings for frequency were obtained by digital display under the head 'Selected frequency' and the intensity also determined under the head "Selected level". Thus for all the five vowels the fundamental frequency was obtained. To confirm the fundamental frequency, the cursor was moved to the next peak, which happened to be a multiple of the first peak.

To obtain the formant frequencies f_1, f_2 and f_3 the key on the "input function", "Averaged Spectrum" was switched on keeping the earlier display as it was. Averaged spectrum causes the input function to the display selectoa to be the averaged spectrum. Peaks were seen on the display screen at different frequency levels. By moving the Cursor, to the highest peak excluding to the first peak which corresponds to the fundamental frequency, in each envelop, the peak frequencies were determined and these were considered - as f_1, f_2 and f_3 respectively from the head "Selected frequency". Thus for each of the five vowels the first three peak (formant) frequencies were determined (as shown in photo No.3 for vowel /a/). To find the VOT of the stop consonants /p/ from papu, /k/ from Koti and Kempu and /t/ from koti. The following setting were made on this HRSA.

1. Input same as earlier.
2. Full scale level - 2.82 volts. This indicates the full scale level display on the HRSA display screen in volts peak. Assuming that the input gain, etc, is adjusted such that the HRSA internal reference reads 100 dB or 100 mv.
3. frequency
4. Input function - 1 H_2 - 200 H_2 "Time" - causes the input function to the display selector to be the time function.

The signal was fed from spectrograph without any gating. As soon as the required word appeared on the display screen. The 'Stop' Key was applied. The cursor was to the point on the horizontal line to the last dot as it was considered as the

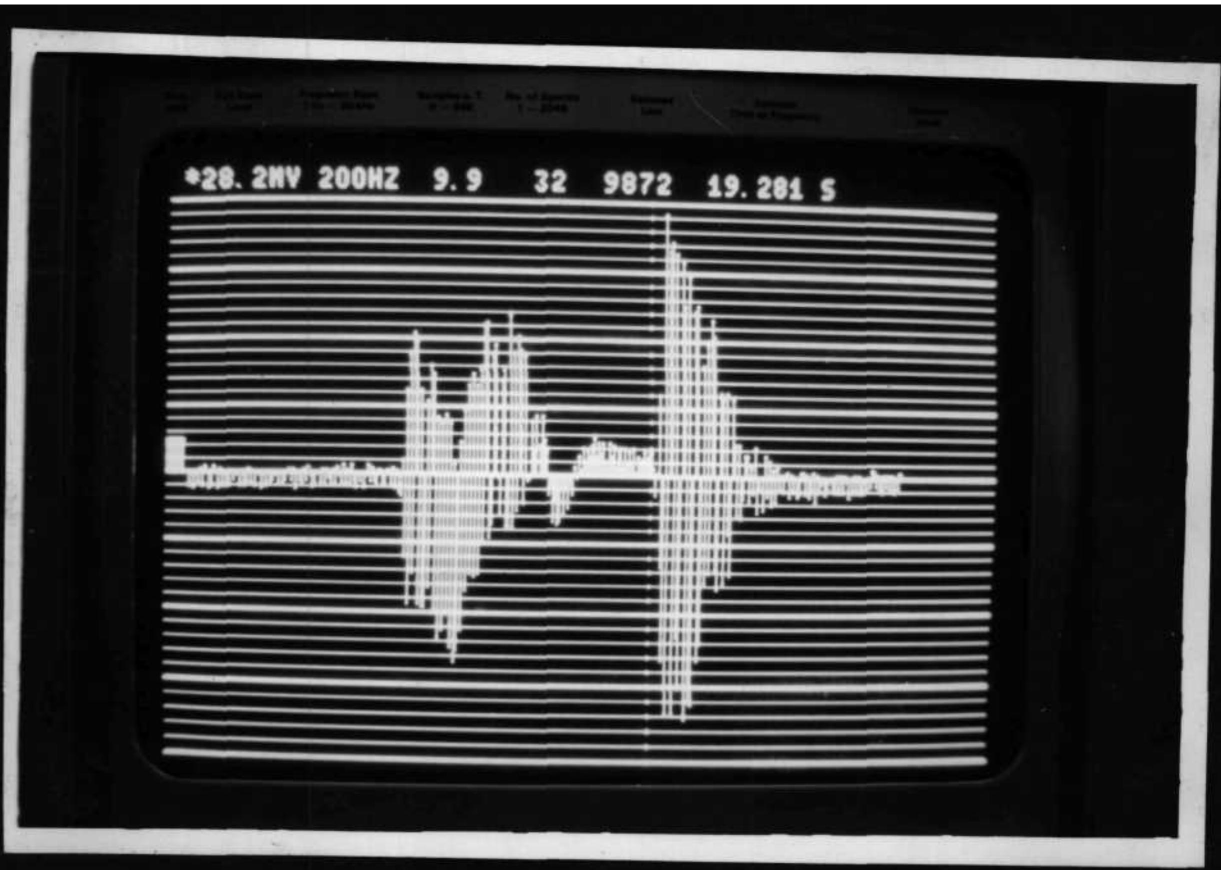


Photo 4. Display of VOT for stop consonant /p/.

representation of the stop burst, this gave the initial reading in mi seconds i.e. the end of the release of stop consonant and then the cursor was moved to the point where the regular vertical striations appeared on the display screen as this was considered as corresponding to the beginning of the vowel. Picture no.4, shows the VOT measurement for /p/ as in papu (the display is of the word papu).

The time reading at this point was noted and the difference between this reading and initial one was considered as VOT for that particular consonant. Using this procedure VOT for all the four stop consonants, from the three test sentences were determined.

Thus the fundamental frequency, formant frequency and VOT for the same vowels and consonants of the test sentences were determined using spectrograph and HRSA.

The results obtained usisg both these above methods were compared for each of the ten subjects and no significant differences were found on comparison. Therefore the method of measuring fundamental frequency formant frequency and VOT using HRSA was considered to be reliable and valid.

The speech samples of all the hundred children i.e., the five vowels /a/, /i/, /u/, /e/ and /Ø/ and the stop consonants /p/, /t/ and /k/ from three of the test sentences which were recorded as responses were subjected to analysis using the procedure as in pilot study.

Thus f_0, f_1, f_2 and f_3 for all the five vowels and VOT for all the three stop consonants for hundred subjects were obtained.

To find out the reliability speech samples of ten subjects was selected randomly from the population of hundred subject of the study. These samples were analysed again using the same procedure. No significant differences were found between the earlier and the present measurements, Thus the procedure of measurement of f_0, f_1, f_2 and f_3 and VOT for total population was considered to be reliable.

Thus it was established that it is possible to use High Resolution Signal Analyzer B and K 2033 to determine. fundamental frequency, formant frequencies and VOT of a given speech sample.

CHAPTER IV

RESULTS AND DISCUSSION

The objective of the study was to determine the fundamental frequency for vowels /a/, /i/, /u/, /o/ and /e/, formant frequencies of these vowels and VOT for the stop consonants /p/, /t/ and /k/ in the age group of 4 to 12 years in both males and females. These vowels & consonants were segmented from the words of the test sentences spoken by children.

Fundamental Frequency (F.F)

Table I shows the mean fundamental frequency with standard deviation for the five vowels i.e, /a/, /i/, /u/, /o/ and /e/, for both males and females of the age group 4-12 years.

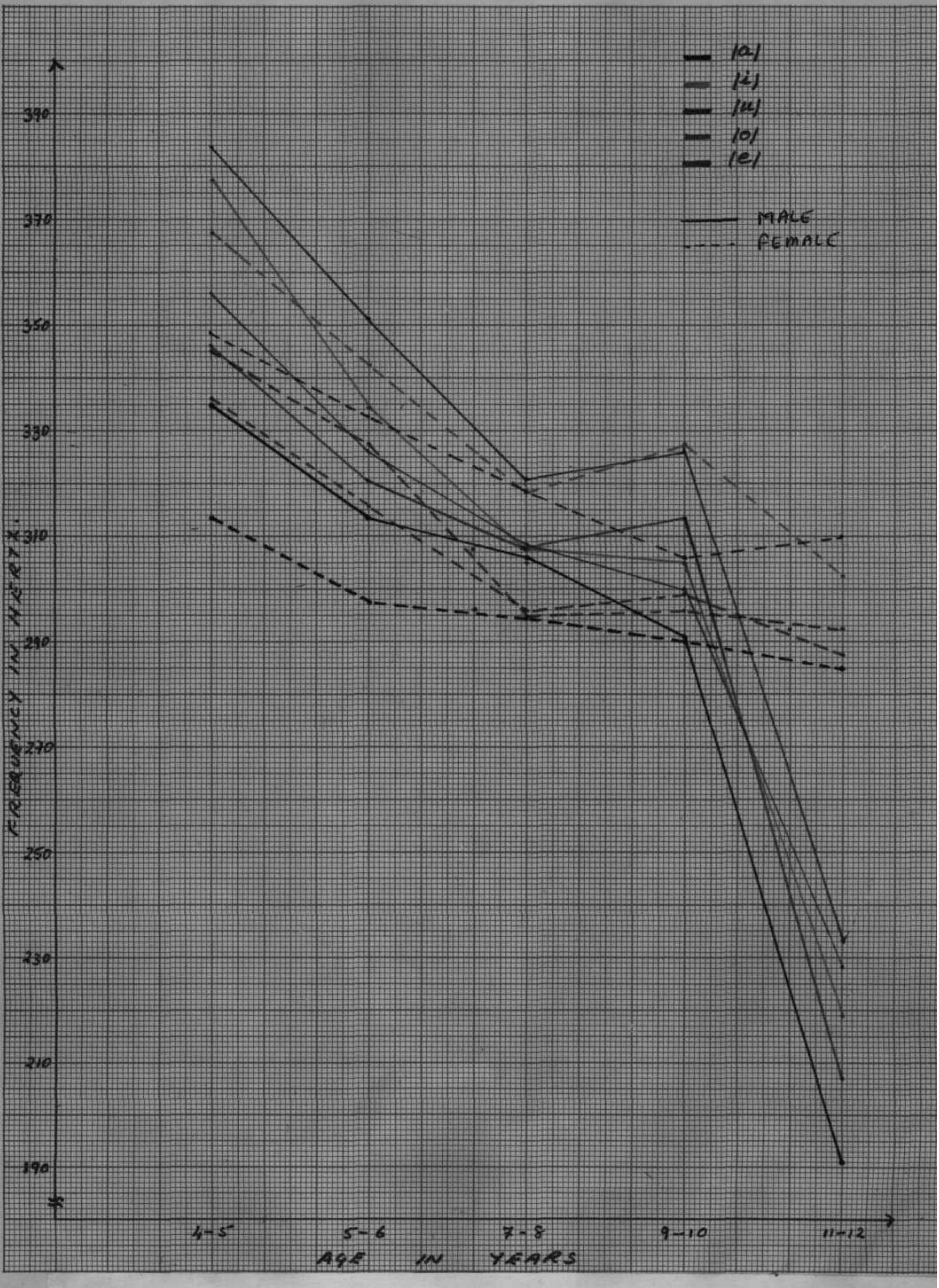
Age group 4-5 years

The males of the age group 4-5 years had shown a mean F.F. of 335 Hat, for the vowel /a/, being the lowest and a mean F.F. of 383.75 Hz for the vowel /u/ being the highest among the five vowels. The vowels /e/, /o/ and /i/ had shown a mean F.F. in between these two i.e., 346.25 Hz, 356.25 Hz and 377.50 Hz respectively. Even though /i/ is a high frequency vowel when compared with other vowels, in this group /u/ had shown higher frequency than /i/.' On examination of

Table I - Showing the Mean Fundamental frequency and Standard Deviation for vowels /a/, /i/# /u/, /o/ and /e/ in males and females of different age groups.

			Males					Females				
years	Subjects M F		/a/	/!/	/u/	/o/	/e/	/a/	/*/	/u/	/o/	/e/
4-5	10+10	Mean	33S.OO	377.50	383.75	356.25	346.25	313.75	367.50	348.75	345.00	336.25
		S.D.	42.82	56.46	56.33	38.75	43.32	34.08	45.72	44.66	29.58	31.98
5-6	10+10	Mean	313.50	334.50	351.30	326.40	320.50	297.50	342.75	332.50	327.50	315.75
		S.D.	38.94	47.23	40.66	39.67	36.31	25.26	39.29	40.67	27.03	32.07
7-8	10+10	Mean	306.25	307.50	321.25	308.75	307.50	294.75	318.75	318.75	295.00	296.25
		S.D.	38.38	40.05	50.97	42.51	39.62	30.31	40.40	36.92	28.39	31.76
9-10	10+10	Mean	291.25	305.00	326.25	330.00	313.75	290.00	327.50	306.25	296.00	299.00
		S.D.	37.46	38.28	44.66	53.68	34.59	21.40	40.31	38.21	24.33	22.20
1-12	10+10	Mean	190.10	219.00	233.00	228.35	207.00	235.00	302.50	310.00	292.50	287.50
		S.D.	19.08	22.40	24.32	18.53	30.07	14.19	21.89	15.81	15.81	13.78

FUNDAMENTAL FREQUENCY IN HERTZS.



Graph A. Showing the comparison of mean F_o of all the five vowels, of males and females of different age groups.

Table II - Showing the significance of difference of Mean fundamental frequency between males and females of the same age group.

Years	/a/	/i/	/u/	/o/	/e/
4-5	R	R	R	R	R
5-6	R	R	R	R	R
738	R	R	R	R	R
9-10	R	R	R	R	R
11-12	A	A	A	A	A

A - Significant at 0.05 level.

R - Not significant at 0.05 level.

the standard deviations of this age group of different vowels it can be stated that the group selected for the study was a representative one.

In case of females of this age group the vowel /i/ shows the highest mean F.F., 367.50 Hz and vowel /a/ shows the lowest mean F.F., 313.75 Hz. Other vowels /u/, /o/ and /e/ are showing mean F.F. of 348.75 Hz, 345 Hz and 336.25 Hz respectively. This group can also be considered as a representative of general population as the S.D.s are low.

A comparison of mean F.F. of the five vowels between males and females of this age group, using significance of mean test shows that there was no significant difference between males and females for all the vowles as whown in Table II. Thus the hypotesis I a stating that there is no significant difference between the males and females of the same age group when the mean F.F. of the vowels are compared is accepted.

<u>Age group 5-6 years.</u>

the
In /males the mean F.F. of /a/ was the lowest, 313.30 Hz and /u/ had highest, 351.30 Hz. Which is similar to earlier group of males and the mean F.F. of /i/, /o/ and /e/ are 334.5 Hz , 326.40 Hz and 320.50 Hz respectively. S.Ds in this group were low enough to state that the sample of this group was a representative of the general population.

Females of this group had shown the least value of mean F.F. for /a/, 297.50 Hz and /i/ showing 342.75 Hz as the highest mean FF in this group. A lowering of mean F.F was seen from /u/, /A/ and /e/ i.e. 332.50 Hz, 327.50 Hz and 315.75 Hz. S.Ds are also low, thus this group forms a representative of the population.

Table II showing the comparison of mean FFs of males and females of this group indicate no significant difference between the two at 0.05 level. Thus hypothesis Ia is accepted.

Age group 7-8 years

The males of this group had shown the same pattern of results as the earlier two groups of males, i.e, the mean F.F is lowered from /u/ to /o/, and then to /e/ and /i/ and finally to /a/, the mean F.F. being 321.25 Hz, 308.75 Hz, 307.50 Hz 307.50 Hz and 306.25 Hz.

The same pattern of mean F.F. for the five vowels as in the previous two groups had been shown by the females of this grow too. However the vowels /i/ and /u/ had shown the highest mean F.Fs 318.75 Hz. Thus lowering from /e/ to /a/ with /o/ in between i.e. 296.25 Hz 295 Hz and 294.75 Hz, being the mean F.F of /e/, /o/ and /a/.

The S.Ds of this group for both males and females were low, suggestion of being population representatives. The hypothesis Ia was accepted for this group also.

Age group 9-10 years.

As seen earlier the males of this group also had fallen in line with them by showing highest mean of for /u/ and least for /a/ and /e/, /i/ and /o/ falling in between. The mean F.F were 326.25.Hz, 313.75 Hz, 305 Hz, 300 Hz and 291.25 Hz respectively.

The female population of this group showed again /i/ as having the highest mean F.F value and /a/ as the lowest. The other vowels were in between viz., /i/ 327.50 Hz, /u/ 306.25 Hz, /e/ 299.Hz, /o/ 296 Hz and /a/ 290 Hz.

These male and female subjects can be considered as representative of the population by virtue of low S.D scores. Table II shows that there was no significant difference in mean FFs across the sex of this group. Hence hypothesis I a stood accepted.

Age group 11-12 years

190.10 Hz, 207 Hz, 219 Hz, 228.35 Hz and 233 Hz were the mean F.Fs of the vowels /a/, /e/, /i/, /o/ and /u/ respectively. The vowels /a/, /e/, /o/, /i/ and /u/ can be arranged in ascending order of mean F.F and the females also had changed theirorder unlike earlier female groups. However there was similarity between males and females of this group in terms of mean E.F.S of vowels i.e. /a/ showing lowest and /u/ highest. The other vowels being in between. The mean F.Fs for /a/ of

females of this group was 285 Hz, /e/ was 287.50 Hz, /o/ 292.50
/i/ 302.50 Hz and /u/ 310 Hz.

The subjects of this group are also representative of the general population like others groups of this study, It is interesting to note that the S.Ds for all the vowels, both for males and females are considerably low, when compared to S.Ds shown by all other groups.

The males and femals diverge in terms of mean F.F. all the five vowels. Further the statistical analysis, as depicted in table II, shows that there was significant difference between the males and females of this group in terms of females having higher mean F.F of vowels /a/, /i/, /u/, /o/ and /e/. Hence the hypothesis Ia is rejected with reference to this group.

The inspection of table I on the whole warrants that the vowel /a/ has the lowest mean F.F for all age groups in both males and females. The vowel /u/ had shown the highest value of mean. F.F among the five vowels studied, in all the male groups. However the females had shown a tendency of producing vowel /i/ with highest mean F.F among all the vowels, except the females of the group 11-12 years, who had shown, like males the highest mean F.F in producing vowel /u/, and females age group 7-8 year had shown, the same mean F.F for both vowels /i/ and /u/.

All the male groups except for those in the 9-10 years group had shown a higher mean F.F. for the vowel /o/ when compared to mean F.F of vowel /e/. The females of the group 4-5 years, 5-6 years, and 11-12 years have shown a higher mean F.F for vowel /o/ than for the vowel /e/.

Thus in general the five vowels that are being studied can be arranged in asceding order of the mean F.F, for both males and females, for the ages ranging from 4-12 years as follows: /u/, /i/, /o/, /e/ and /a/.

The comparisons of the mean F.Fg of all the five vowels shown by males and females of different age groups shows" that there was no significant difference between males and females in terms of mean F.F. except in the age group 11-12 years, where the females had shown a higher mean F.F. than their counterparts. Thus the hypothesis Ia is accepted with reference to age group 4-10 years but rejected with reference to 11-12 years. Therefore it can be concluded that the males and females do not differ, in terms of fundamental frequency upto the age of 11 year as shown in Graph A. However, in general the females of all the age groups showed a higher mean F.F. then the males.

The comparison of mean F.F. for the vowel /a/ of the present study with the earlier studies of the F.F. of vowel /a/ in isolation by Samuel (1973), Usha (1978) and Gopal (1980), on the Indian population, shows that, the mean F.F. of the vowel /a/ is higher in the present study in all the age groups i.e. from 7-11 years both in case of males and females. This may be because of the fact that the vowel /a/ analysed in the present study was segmented from the word of the test sentence and not in isolation as in earlier studies.

The studies by Samuel (1973), Usha (1978) and Gopal (1980) on the Indian Population had indicated that there was no significant difference between males and female between the age group 7-10 years in terms of mean F.F. The results of the present study. Corroborates with the the above findings. Further a significant difference between the mean F.Fs of males and females above 10 years had been found in the present study. A similar report had been given by earlier investigators (Samuel, 1973; Usha, 1978; and Gopal, 1980).

To test the hypothesis IIa stating that, "there is no significant difference between the age groups in terms of mean F.Fg of all the five vowels for both males and females of different age groups were compared using significance of mean difference test.

When the mean F.F. of males of 4-5 years age group was compared with mean F.F. of other higher age groups it was found that, there was no significant difference in mean F.F between the age group 4-5 years and 5-6 year for all the vowels. However, the mean F.F. for vowels /e/, /o/, /i/ and /u/ of the age group 7-8 years showed a significant difference, whereas for the vowel /a/ there was no significant difference between the age group 4-5 years and 7-8 years. The mean F.Fs of all the vowels except /e/, of the age group 9-10 years showed significant difference when compared with the mean F.Fs of the vowels of the age group 4-5 years. A significant decrease in mean F.F. of all the vowels in the age group 11-12 years was found when compared to 4-5 years as shown in the tables III a,-e. Thus the hypothesis II a is rejected.

The mean F.Fs of males for all the five vowels of the age group 5-6 years, were compared with 7-8 years, 9-10 years and 11-12 years groups. No significant differences between the age groups 5-6 with 7-8 years and 9-10 years was noticed. The age group 5-6 years showed higher mean F.F for all vowels when compared with 11-12 years group as shown in The table III a-e.

No significant difference in mean F.Fs of all the five vowels was found when the males of the group 7-8 years were compared with 9-10 years. As depicted by the tables II a-e, these is significant difference in the mean F.Fs between the age groups 7-8 years and 11-12 years.

It is evident from the tables I and III a-e that there is significant difference in mean F.F for the age group 9-10 years, when compared with 11-12 years for all the vowels in case males, with sudden lowering of the F.F.

Table IIIa - Showing the significance of difference between mean across age group and sex of F_0 for vowel /a/.

Years	4-5	5-6	7-8	9-10	11-12
Males					
4-5		R	R	A	A
5-6			R	R	A
7-8				R	A
9-10					A
11-12					
Females					
4-5		R	R	R	A
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05 level

R - Not singificant at 0.05 level

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Table 111b - Showing the significance of difference between mean across age group and sex of F^ for vowel /i/.

Males

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A		A
5-6			R	R	A
7-8				R	A
9-10					A
11-12					

Females

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	A	A
5-6			R	R	A
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05 level.

R - Not significant at 0.05 level.

Table IIIc - Significance of difference between mean across age group and sex of F_0 for vowel /u/ are shown.

Males Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	A	A
5-6			R	R	A
7-8				R	A
9-10					A
11-12					
Females					
4-5		R	R	A	A
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05 level.

R- Not significant at 0.05 level.

Table IIId - Showing the significance of difference between Means, across age group and sex of F_0 for Vowel /o/.

Males.

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	A	A
5-6			R	R	A
7-8				R	A
9-10					A
11-12					

Females

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	A	A
5-6			A	A	A
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05 level.

R - Not significant at 0.05 level

Table IIIe - Showing the significance of difference between Means, across age groupand sex of F for vowel /e/.

Males

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	R	A
5-6			R	R	A
7-8				R	A
9-10					A
11-12					

Females

Years	4-5	5-6	7-8	9-10	11-12
4-5		R	A	A	A
5-6			R	R	A
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05 level

R - Not significant at 0.05 level.

Thus the hypothesis, that there is no significant difference between the age groups in terns of mean F.F. has been partly accepted and partly rejected with reference to males.

In other words the age group 4-5 years is not differing from the age group 5-6 and 7-8 years but shows a significant difference with age group 9-10 years and 11-12 years. Similarly the age group 5-6 years is not differing from 7-8 years and 9-10 years but does differs from 11-12 years group.7-8 years group has shown a significant difference from 11-12 years group but not with 9-10 years group. A significant difference is found between 9-10 years and 11-12 years group. Thus it can be concluded that there is no statistically significant difference between the successive age groups, except between the 9-10 years and 11-12 years group.

These results when studied with the table I. indicates, that there was gradual decrease in the mean F.F of males with age and sudden decrease in mean F.F in the higher age group, 11-12 years, studied. Similar results have been reported by the earlier investigators both on Indian population and non Indian population (Fairbanks, 1949; Duffy 1950; Curry, 1940; Samuel, 1973; Usha, 1978 and Gopal 1989).

In case of females, the inter group comparison of mean F.Fs for all the vowels i.e. 4-5 years with all the higher age groups, 5-6 years with the older age groups, 7-8 years with their senior group, and 9-10 years with 11-12 years group, indicates, as shown in tables I and III a-e the following results:

1. The age group 4-5 years shows no significant difference of mean F.F. of all the vowels, when compared with 5-6 year group. However the mean F.Fs of the vowels /e/, /u/, /i/, show a significant difference with the mean F.F. of the age group 7-8 years. The mean F.F. of the same age group for all the vowels, except (a) has shown significant difference with the mean F.F of the age group 9-10 years. The mean F.Fs of all the vowels have been significantly different between the age groups 4-5 years and 11-12 years.

2. The mean F.Fs of the vowel /a/, /e/, /i/ and /u/ of the age group 5-6 years has shown no significant difference with the age groups 7-8 years and 9-10 years. The vowels /e/, /o/ and /i/ produced by the age group 5-6 years has been found to be significantly different from the same vowel produced by age group 11-12 years in terms of mean F.F, as indicated in the tables I, IV a-e.

3. No significant difference was observed for any of the vowels when comparing 7-8 years group with 9-10 years and 11-12 years groups.

4. Similarly no statistically significant difference was seen between the age group 9-10 years, compared with 11-12 years for all vowels in term of mean F.F.

Thus the hypothesis II a is partly accepted and partly rejected with reference to females studied i.e, there is no significant difference between any two successive age groups. However the lower age groups have shown significant difference with higher age groups. When these results are viewed in the light of the mean F.Fs given in table I it can be stated that there was a gradual decrease in the mean F.F.

The present results are in agreement with earlier reports (Samuel 1973, Eguchi and Hirsh 1969; Kent, 1976; Usha, 1978 Gopal, 1980).

With regard to changes in F.F. Eguchi and Hirsh (1969) state that " It is well known that the fundamental frequencies of children and adult females are higher than those of the adult males. The fundamental frequencies of the vowels of an adult females are about one octave higher than that of the adult male. Children have a fundamental frequency of about 300 Hz even upto the age of 8 and 10 years. There is no significant difference of fundamental frequency of speech between 7 and 8 years, or between boys and girls of those ages" (Similar views have been expressed by Fairbanks, Herbert and Hammond, 1949; Fairbanks, Wiley and Lassman, 1949; Potter and Steinberg, 1950; Peterson and Barney, 1952; Samuel, 1973; Usha, 1978; and Gopal 1980; Gopal (1980)has concluded from his study of males and females, age ranging from 7-25 years that "there is a gradual lowering of F,F. with advancing age both in case of males and females. However, the change is gradual upto the age of 10 years, after which there is a sudden markedd decrease in the F.F. and no significant difference is found between males and females upto 10 years. Only after this age there is a significant marked difference between the males and females".

The results of the present study are in full agreement with above findings.

Formant Frequency

The second part of the analysis consisted of measurement of formant frequencies, i.e. F_1, F_2 and F_3. In the present study the peaks in the spectra of the vowel displayed on the screen of HRSA with the key of "Averaged Spectrum" on in the "input function" was considered as the formant frequencies . The peak in the first envelope was considered as F , in the second envelope F_1 and F_2, F_3 in third and fourth respectively. As stated in Chapter III on Methodology, the formant frequencies determined using this procedure was confirmed by analysing the same vowels spectrographically. Further the present procedure was considered as a more accurate method of determining formant frequencies as the HRSA gave the digital display of the point at which the curser was stationed, both in terms of frequency and intensity. Using this procedure F_0, F_1 , F_2 and F_3, were determined for all the five vowels /a/, /e/, /u/, /o/ and /i/, extracted from the words of the test sentences uttered by all the hundred subjects, age ranging from 4-12 years.

Table IV a-e and graphs B 1-3 shows the mean F_1,F_2 and F_3 for all the five vowels /a/, /i/, /u/, /o/ and /e/, for all the age groups both males and females.

Table IV a - Showing the mean values and standard deviation of F_1, F_2 and F_3 for vowel /a/

		Males			Females		
		F_1	F_2	F_3	F_1	F_2	F_3
4-5	M	826.25	1617.5	2532.5	852.5	1521.25	2728.75
5-6	S.D	160.99	293.87	108.84	138.54	189.76	283.85
5-6	M	643.75	1343.7	2437.4	734.95	1465	2610
	S.D	106.92	158.9	93.97	165.24	209.26	231.89
7-8	M	760	1465	2756.25	741.25	1610	2543.75
	S.D	168.47	117.6	179.49	107.54	314.9	57.51
9-10	M	911.25 .	911.25	1493.75	2S2.5	1581.25	2573.75
	S.D	129.7	166.59	176.62	125.94	291.32	186.01
11.12	M	840	1396.25	2610	781.5	1605	2600
	S.D	144.55	133.1	212.36	188.78	323.35	207.75

Table IV b: Showing the mean values and Standard deviations of F_1, F_2 and F_3 for vowel /i/

		Males			Females		
	F	F_1	F_2	F_3	F_1	F_2	F_3
4-5	M	455	2166.5	2856.25	445	2128.75	2758.75
	S.D	66.98	335.69	186.64	61.58	272.34	130.58
5-6	M	446.2	2181.2	2953.65	393.75	2127.5	2771.2
	S.D	117.32	371.33	344.68	60.94	233.29	156.03
7-8	M	387.5	2145	2863.75	391.25	2183.75	2707.5
	S.D	48.95	170.8	161.67	54.98	280.13	233.94
9-10	M	413.75	2307.5	2871.25	388*75	2291.25	2931.25
	S.D	71.31	330,9	178.67	54,15	189.94	180.87
11-12	M	492.5	2356.4	2778.75	366.25	2303.75	2740
	S.D	61.3	213.18	120.34	45.66	160.95	119.14

Table IV cs Showing the mean values and s-tandard deviations of F_1, F_2 and F_3 for vowel /u/.

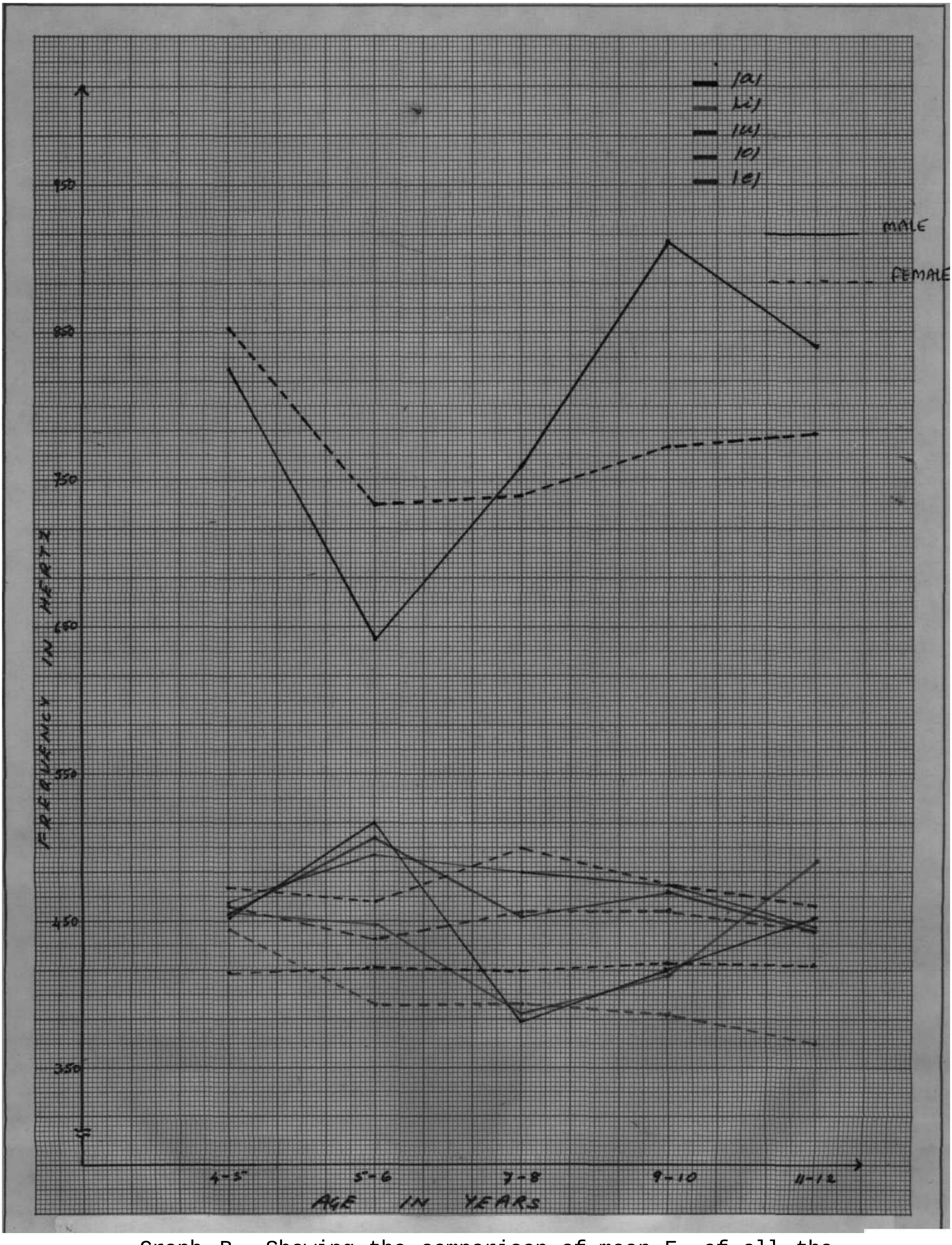
		Males			Females		
		F_1	F_2	F_3	F_1	F_2	F_3
4-5	M	453.75	1021.25	2367.5	415	910	2387.5
		60.4	249.31	222.06	62.30	182.75	303.17
5-6	M	518.75	1028.75	2408.75	421.25	983.75	2363.7
		103.64	290.07	573.25	59.36	246.78	198.97
7-8	M	381.25	756.25	2315	417.5	482.5	2353.25
		44.59	42.18	268.22	59.28	121.08	196.45
9-10	M	417.5	936.25	234.5	422.5	845	2392.45
		78.22	219.01	97.04	76,56	143.5	168.15
11-12	M	452.5	1020	2432.5	421.25	1042.5	2393.75
		52.97	240	165.64	55.92	375	344.41

Table IV d : Showing the mean values and standard deviations of F_1, F_2 and F_3 for vowel /o/.

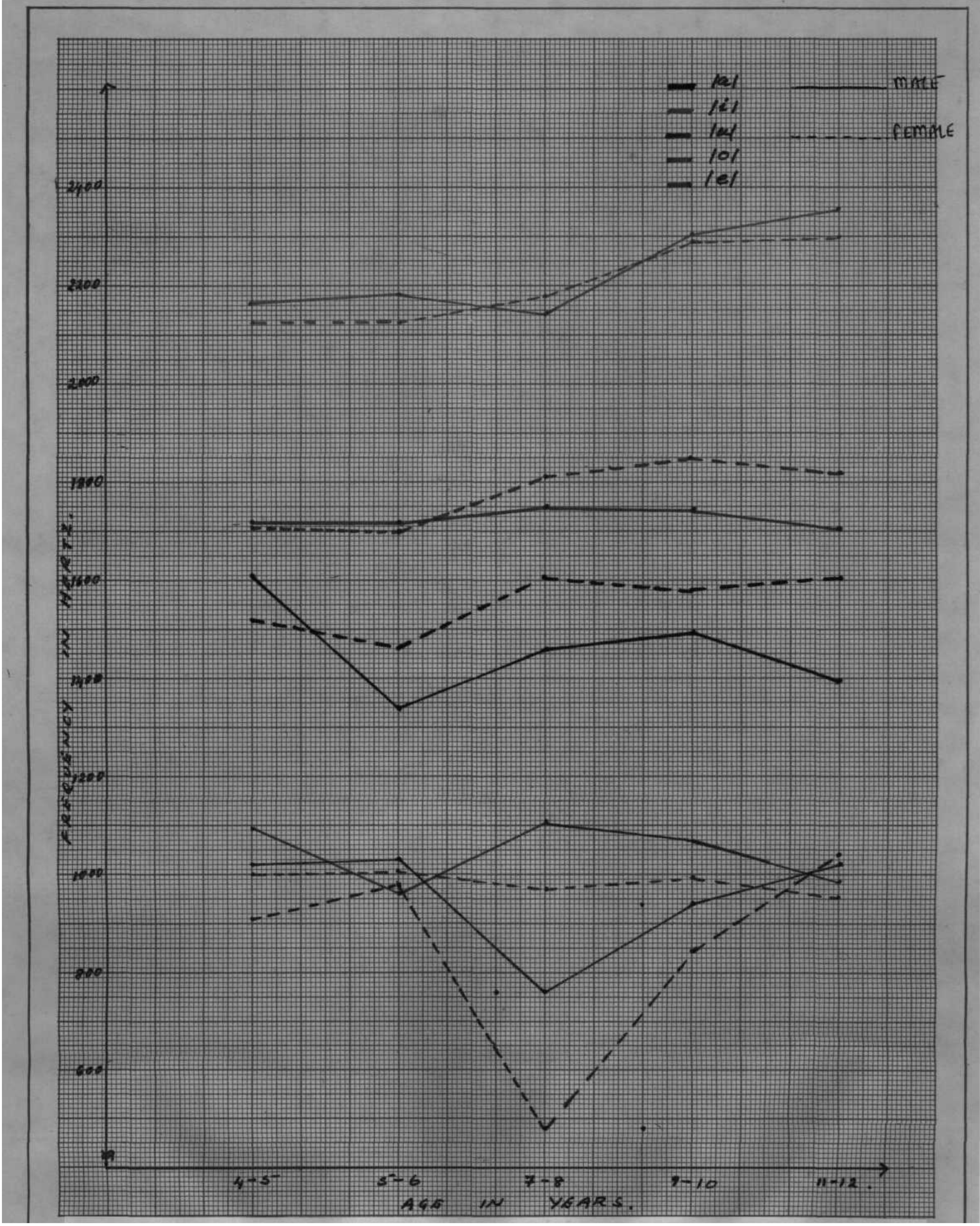
		Males			Females		
		F_1	F_2	F_3	F_1	F_2	F_3
4-5	M	462	1098.75	2198.75	472.5	1025	2606.25
		49.30	181.09	226.34	73.55	168.33	190.69
5-6	M	495	965	2176.1	462.5	1067.5=	2168.65
		73.18	205.22	292.6	31.23	160.6	224.7
7-8	M	482.5	1112.5	2186.5	500	972.56	2323.75
		65.4	227.46	320.13	42.49	76.07	279.12
9-10	M	475	1066.25	2495.5	475	993.75	2128.75
		56.83	155.46	195.59	66.41	77.78	340.35
11-12	M	448.75	988.75	2153.75	460	956.25	2105
		63.04	234.78	186.99	72.84	84.83	133.49

Table IV e: Showing the mean values and standard deviations for vowel /e/.

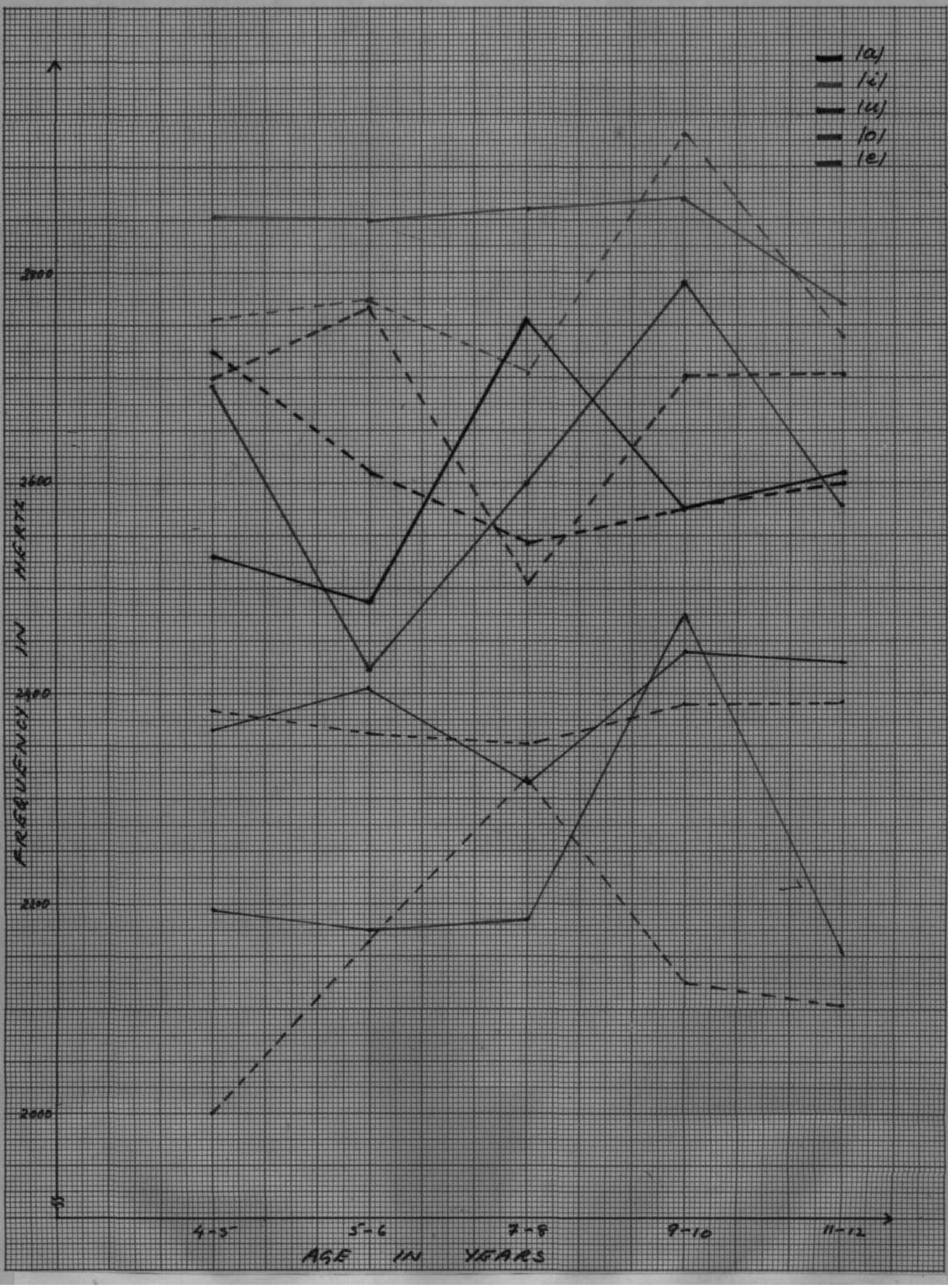
		Males			Females		
		F_1	F_2	F_3	F_1	F_2	F_3
4-5	M	455	1722.45	2693.75	461.25	1715	2702.5
		37.82	295.63	427.29	34.59	257.11	248.45
5-6	M	506.2	1721.75	2423.7	443.75	1702.4	2767.45
		86.39	281.53	267,58	54.82	282.49	331.19
7-8	M	453.75	1750	2602.5	445	1805	2508.75
		57.75	241.52	405.68	59.28	171.41	112.8
9-10	M	470	1748.75	2790	457.5	1852.3	2652.5
		53.42	354.8	291.65	69.52	155.6	305.55
11-12	M	442.5	1608.75	2580	443.75	1722.5	2652.5
		43.78	211.56	284.87	74.83	318.02	165.18



Graph B_1. Showing the comparison of mean F_1 of all the five vowels, of males and females of different age groups.



Graph B_2. Showing the comparison of mean F_2 of all the five vowels, of males and females of different age groups.



Graph B_3. Showing the comparison of mean F_3 of all the five vowels of males and females of different age groups.

Table V: Showing the significance of means of various vowels and their formant frequencies between males and females of the same age group.

Years	/a/			/i/			/u/			/o/			/e/		
	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3	F_1	F_2	F_3
1-5	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
5-6		R	A	R	R	R	A	R	R	R	R	R	R	R	A
7-8	R	R	A	R	R	R	R	A	R	R	R	R	R	R	R
9-10	A	R	R	R	R	R	R	R	R	R	R	A	R	R	R
11-12	R	R	R	A	R	R	R	R	R	R	R	R	R	R	R

A - Significant at 0.05 level

R - Not significant at 0.05 level.

4-5 years group

The F_1 of vowel /a/ in males has been found to be the highest among all the vowels in the male group i.e. 826.25 Hz. The F_1 of other vowels range from 453 Hz to 462.5 Hz. Vowel /i/ presents the highest frequency at F_2 (2166.5 Hz) when compared to other vowels, next being /e/ with 1722.45 Hz, /u/ shows the lowest F_2 i.e., 1021.2 5 Hz, /a/ and /o/ coming in between with 1617.5 Hz and 1998.5 Hz. F_3 of /i/ was the highest 2856.25 Hz among the 3rd formants for all the vowels, with /o/ showing the lowest (2198.75 Hz) /e/, /a/ and /u/ were in between having 2693.75 Hz, 2532.50 Hz. and 2367.5 Hz. respectively. Thus the results indicate that only F_1 of vowel /a/ has higher frequency and differs from all other vowels. Not much difference was observed among all other vowels. F_2 of /i/ has shown a considerable difference from other vowels. Similarly F_2 of vowel /e/ differs from F_2 of /u/ and /o/ but not from that of /a/. Again /i/ has differed from other vowels in terms of F_3 as it has highest frequency. Not much difference is found ' in F_3 of /e/ and /a/. However these two differ from /u/ and /o/. Vowel /u/ has also shown a greater F_3 value than /o/.

In general the S.Ds of F_1, F_2 and F_3 of all the vowels show that there is not much variablility in the formant, frequencies among the male subjects of the group 4-5 years.

The females of the same age group have shown the same tendency as far as F_1 for all the vowels is concerned. F_2 and F_3 have been the replica of male group for all the vowels, which is evident from the tables IV a-e and Graph B 1-3. Thus not much difference was expected between the male and female groups for all the five vowels in terms of F_1 , F_2 and F_3. Further this has been confirmed by the statistical analysis using significance of difference of means as shown in table V .

5-6 years group:

The males of this age group have also shown a higher F_1 (643.75 Hz) in vowel /a/ than in other four vowels . The other four vowels have not shown much variation in F , ranging from 518.75 Hz to 446.20 Hz. i.e. from vowel /u/ to /i/, with /e/ and /o/ in between, with frequencies 506 Hz and 495 Hz respectively. F_2 of this group has also shown similar tendencies as the earlier age group i.e. /i/ showing highest frequency (2181.20 Hz) and /o/ showing the lowest (965 Hz) with /e/, /u/ and /a/ in the ascending order between /i/ and /a/ as indicated in the table F_3 of the vowel /i/ has been the highest (2953.65 Hz) as in previous age group /a/, /e/, /u/ and /o/ have been arranged in the decreasing order in terms of frequencies of F_3 of this group.

Like in the earlier group the F_1 of /a/ has shown a greater difference from F_1 of all other vowels. Not much variation is noticed in F_1 of the other four vowels. F_2 also, like in the previous group has shown highest frequency in vowel /i/ and differs from all other vowels with a difference of approximately 1000 Hz. Among the other vowels. F_2 has not shown much difference which is clear from the inspection of the table IV a-e. Again the vowel /i/ has shown the highest frequency in F_3 and differs from F_3 of other vowels by more than 500 Hz. The vowel /a/, /u/ and /e/ do not show much variation in terms of F_3, F_3, of vowel /o/ has been lowest, around 2000 Hz.

The females of this group has shown 734.95 Hz as the F_1 of /a/ovowel, which is the highest in the group, the next being F_1 of /o/, (462.5 Hz), /e/, /u/ and /i/ are in descending order with 443.75 Hz. The study of F_2 of this group shows /i/ having highest frequency of 2127.50 Hz. /u/, /o/, /a/ and /e/ have shown F_2 in ascending order i.e. 983.75 Hz 1067.50 Hz, 14.65 Hz and 1702.40Hz respectively. The F_3 of this group has shown that /i/ has the maximum frequency value followed by /e/, /a/, /u/ and /o/. The females of this group have shown same tendencies regarding inter vowel comparison of F_1, F_2 and F_3, as in males of this age group.

On looking at the table IV a-e and graph B 1-3 it has been conculded that there is very little variation.

Refering table V it shows that F_3 of /a/, F_1 of /u/ and F_3 of /e/ are significnatly different in males and females otherwise for no other formant frequency of any other vowel there is difference of mean value in this group.

<u>7-8 years group</u>

The males of this group again have shown that the vowel /a/ has the highest F_1 (760 Hz) when compared with other vowels /o/ and /e/ have shown almost similar F_1 (482.50 Hz for /o/ and 453.75 Hz for /e/) whereas /i/ and /u/ have shown same F_1 (387.50 Hz, and 381.25 Hz). Thus the vowel /a/has the highest F_1. As in the previous groups F_2 of /i/ has been the highest having 2145 Hz. The lowest F_2 has been shown by vowel /u/ (756.25 Hz). In between these two vowels /o/, /a/ and /e/ have been placed with 1112.50 Hz 1465 Hz and 1750 Hz. Thus in terms of F_2 the vowel /i/ differs from all other vowels with highest frequency and there is approximately 300 Hz difference between the F_2 of the other vowels. Again vowel /i/ has shown the highest F_3 among the five vowels, next highest F_3 has been shown by /a/ than in /a/, /u/ and /o/ (2863.75 Hz, 2756.25 Hz, 2602.50 Hz, 2315 Hz and 2186.50 Hz).

As in the previous group the females of the age range 7-8 years have also shown /a/ as having highest F_1 (741.25 Hz), and /i/ as having lowest F_1 (391.25 Hz). In descending order based on the frequencies of F_1. /o/, /e/ and /u/ were found. (500 Hz, 455 Hz and 417.50 Hz) as can be seen from the table IV a-e and graphs B 1.3. Vowel /a/ differs from other vowels by a minimum of 250 Hz in terms of F_1 and the differences in frequencyeis of F_1 of other vowels have shown variations within 110 Hz, rangigg from 500 Hz to 391.25 Hz. Again the vowel /1/ has presented the highest R_2 (2183.75 Hz) followed by /e/, /a/, /o/ and /u/ with frequencies, 1805 Hz 1610 Hz, 972.56 Hz and 482.5 Hz The F_2 of /i/ has differed from F_2 of /e/ by about 300 Hz and the /e/ to /a/ difference is about 200 Hz, /a/ to /o/ difference is about 600 Hz and difference between /o/ and /u/ is about 500 Hz. Thus it has been seen that F_2 of this group has great variations, within the F_2 of all the five vowels. When compared to F_2 of all the five vowels of all earlier groups. F_3 of vowel /i/ is the highest and of vowel /o/ is lowest (2323.75 + 2707.50 Hz) with vowels /a/, /e/ and /u/ being placed in between in the descending order based on the frequency of the F_3. The F_3 of vowel /i/ does not show much difference from F_3 of vowel /a/ and /e/. The vowels /a/ and /e/ do not differ much from /u/ and /o/.

The S.Ds as shown in table IV a-e indicate that the variability of the group was not much.

Table V indicate that there is not much of statistical difference between males and females of this age group for any of the formant frequencies i.e. F_1, F_2 and F_3 of any of the five vowels except for F- of/a/ and F_2 of /u/.

Age group 9-10 years

The males of this gropp as earlier groups have shown /a/ as having highest F_1 (911.25 Hz) and lowest for /i/ with 313.75 Hz. The F_1 of the other vowels are /o/ 475.Hz, /e/ 470 Hz and /u/ 417.5 Hz. The vowel /a/ differes from /o/ by 475 Hz. The difference between /o/, /u/ snf /e/ has not been much. /i/ has varied from other vowels i.e, /o/, /u/ and /e/ by more than 100 Hz. As seen earlier the F_2 of vowel /i/ has the highest frequency (2307.5 Hz) and lowest is that of /u/ being 936.25 Hz. The F_2 of other vowels were /e/ 1748.75 Hz, /a/ 1493.75 and /o/, 1066. 25 Hz. Considerable difference has been found between F_2 of /i/ and /e/ i.e. about 600 Hz. Not much difference was noticed between /e/ and /a/ but /o/ has a considerably lower frequency than /a/.

The females of this age group, like all other earlier groups have shown F_1 for vowel /a/ as maximum value when compared with the F_1 at other vowels, the F_1 of /a/ being 772.50 Hz, followed by the F_1 of /o/, /e/, /u/ and /i/, The difference between /a/ and /i/ being about 400 Hz. Not much difference was observed within /u/, /o/ and

/e/. F_2 followed the same pattern of values i.e. /i/ being highest, as in males of this group. In descending order /i/ was 2291.25 Hz, /e/ 1852.30 Hz. /a/ 1581.25 Hz /o/ 993.75 Hz and /u/ 845 Hz. The difference between successive vowels being approximately 450 Hz, 300 Hz, 600 Hz and 150 Hz. The F_3 of the highest vowel in case of males is /i/ (2931.25 Hz) so also in females, the lowest F_3 being for vowel /o/ (2128.75 Hz) . In between were /e/ with 2652.50 Hz, /a/ with 2573.75 Hz. and /u/ with 2392.45Hz. The difference between /i/ F_3 and /e/ F_3 is about 300 Hz, /e/ and /a/ F_3 differ by about 100 Hz, and /a/ F_3 differ by /u/ with approximately 175 Hz. Whereas /u/ is greater than /o/ by about 275 Hz.

The S.D values of the age group 9-10 years indicate that the sample selected has limited variability. Hence this proves to be a representative of the general population, as shown in table IV a-e.

Table V shows no significant difference between the mean values of F_1 , F_2 and F_3 for all the five vowels /a/, /e/, /u/, /o/ and /i/, between males of females of this age group, except for a significant difference of F_1 for vowel /a/.

Age group 11-12 years

The males of this group have also followed the tradition of having the F_1 value of vowel /a/ as highest with 840 Hz.

The values of F_1 for other vowels being /i/ 492.50 Hz, /u/ 452.50 Hz, /o/ 448.75 Hz and /e/ 442.5 Hz. It is evident from the table IV a-e that the difference between $_{F1}$ of vowel /a/ and other four vowels was approximately 450 Hz. There w as very less variation within the vowels /i/, /u/, /o/ and /e/ in terms of F_1. The F_2 values of vowel /u/ has maintained its superiority, over other vowels, in terms of frequency (2356.50 Hz). The lowest value of R_2 is of vowel /o/ having 988.75 Hz. Hence a gap of more than 1300 Hz. Difference between F_2 of /t/ and /e/ was about 750 Hz, between /e/ and /a/ was about 200 Hz, between /a/ and /u/ was 375 Hz and finally between /u/ and /o/ being only 32 Hz.

The F_3 values of the vwels in ascending order were /i/ 2778.75 Hz /a/ 2610 Hz., /e/ 2580 Hz., /u/ 2432.50 Hz, and /o/ 2153.75 Hz. The variation was not as much as in the F_2 of this group. However, the difference between highest and lowest F_3 values was 625 Hz.

Among the females of this group also /a/ carried the highest F_1 value (781.50 Hz), followed by /o/ with 460 Hz., /e/ with 443.75 Hz., /u/ with 421.25 Hz and lastly /i/ with 366.25 Hz. The difference between highest and lowest vowel being approximately 415 Hz. The variation with for vowels /o/, /e/, /u/ and /i/ was within 100 Hz. The F_2 had followed the same pattern as the males of this group which can be seen by refering to table IV a-e, the

the difference between /i/ and /o/ being about 1350 Hz. The values of F_2 of all the vowels were /i/ 2303.75 kHz /e/ 1722.50 Hz. /a/ 1605 Hz. /u/ 1042.5 Hz. and /o/ with 956.25 Hz. The F_3 of /i/ was the highest (2740 Hz) as in the earlier groups but it has been followed, here, by /e/ with 2652.50 Hz unlike in earlier groups by /a/, which had a F_3 of 2600 Hz. In this group /o/ was 2105 Hz and /u/ was 2393.75 Hz i.e. more than about 290 Hz compared to /o/. The difference between the highest and lowest vowels was about 635 Hz.

By referring to table IV a-e and graph B_{1-3} it can be stated that there w as limited varaition in the subjects selected of this group.

Table V indicates that there was no significant difference between males and females for any of the formant frequencies i.e, F_1, F_2 and F_3, for all the five vowels except for /a/ for F_3

Thus the analysis of the data on formant frequencies has indicated that the F of vowel /a/ has the highest frequency and /i/ showing the lowest formant frequency among all the vowels of both the sexes in the age range 4-12 years. The vowel /i/ has shown the highest F_2 and F_3 among all the vowels in both the males and females of all age groups. Whereas the vowels /u/ and /o/ show the lowest frequencies on F_2 and F_3. Thus the hypothesis III b stating that there is no significant difference between the formant frequencies of different vowels is rejected.

In general comparison between the males and females reveals no significant difference among the F_1 ,F_2 and F_3 of all the five vowels in the age range studied. The hypothesis I b stating that there is no significant differences between the males and females of the same age roup when the mean formant frequencies (F_1, F_2 and F_3) of the vowels are compared is accepted.

Tables VI to X (a, b, c) shows the results of comparison of mean F_1, F_2 and F_3 of males and females of different age groups for all the five vowels.

The comparison of F_1 of the males of 4-5 years of vowel /a/ with higher age groups i.e 5-6 years, 7-8 years 9-10 years and 11-12 years shows no significant difference except with 5-6 years. The 5-6 years age group shows significant difference with 9-10 years, and 11-12 years but not with 7-8 years age group. No significant difference between 11-12 years was found with 788 years, but significant differences was found between 9-10 years with 7-8 years. No significant difference between 9-10 years and 11-12 years was observed. The females pf this age group (4-5 years)have shown no significant difference with any of the groups.

F_2 of the vowel /a/ by the age group of 4-5 years has differed significantly from the F_2 of 5-6 years and 11-12

Table VI a: Showing the significance of difference between means across age groups and sex for vowel /a/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		A	R	R	R
5-6			R	A	A
7-8				A	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-6				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VI b: Showing the significance of difference between means across age groups and sex of F_2 for vowel /a/

Males

Years	4-5years	5-6years	7-8years	9-10years	11-l2years
4-5		A	R	R	A
566			R	R	R
7-8				R	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	11-l2years
4-5		R	R	R	R
5-6			R	R	R
7-0				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VI c: Showing the significance of difference between means across age groups and sex of F_3 for vowel /a/

Males

Years	4S5years	5-6years	7-8years	9-10years	11-12years
4-5		R	A	R	R
5-6			A	A	A
7-8				R	R
9-10					R
11-12					

Females

Years	4S5years	5-6years	7-8years	9-10years	11-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VIIa: Showing the Significance of difference between means across age groups and sex of F_1 for vowel /i/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		A	A	A	R
5-6			R	R	A
7-8				R	A
9-10				R	A
11-12					

Remales

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	A	A
5-6			R	R	R
7-8				R	R
9-10					R
11-12		-			

A - Significant at 0.05

R - Not significant at 0.05

Table VIIb: Showing the significance of difference between means across age groups and sex of F_2 for the vowel /i/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	A
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VIIc: Showing the significance of difference between means across age groups and sex of F_3 for vowel /i/.

Males

Years	4-5years	5-6years	738years	9-10years	ll-12year
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	738years	9-10years	ll-12year
4-5		R	R	R	R
5-6			R	A	R
7-8				A	R
9-10					A
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VIIIa: Showing the significance of difference between means across age groups and sex of F_1 for vowel /u/.

Years	4-5years	5-6years	7=8years	9-10years	ll-12years
Males					
4-5		R	A	R	R
5-6			A	A	R
7-8				R	A
9-10		-			R
11-12					
Females					
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VIIIb: Showing the significance of difference between means. Across age groups and sex of F_2 for vowel /u/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	A	R	R
5-6			A	R	R
7-8			A	A	A
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	A	R	R
5-6			A	R	R
7-8				A	A
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table VIIIc: Showing the significance of difference between means. Across age groups and sex of F_3 for vowel /u/.

Hales

Years	4-5years	5-6years	7-8years	9-10years	11-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

Females

4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A- significant at 0.05

R - Not significant at 0.05

Table IX a: Showing the significance of difference between means. Across age groups and sex of F_1 for vowel /o/.

Males

Years	4-5years	5-6years	7=8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	7=8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			A	R	R
7-8				R	R
9-10					R
11-12					

A - Significant at 0.05

R - Not significant at 0.05

Table IXb: Showing the significance of difference between means, across age groups and sex of F_2 for vowel /o/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6					
7-8				R	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6		R	R	R	R
7-8				R	R
9-10					R
11-12					

A - significant at 0.05 level.

R - Not significant at 0.05 level

Table IXc: Showing the significance of difference between means across age groups and sex of F_3 for vowel /o/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	A	R
5-6			R	A	R
7-8				A	R
9-10					A
11-12					

Females

4-5		R	A	R	R
5-6			R	R	R
7-8				R	A
9-10					R
11-12					

A- Significant at 0.05 level

R -Not significant at 0.05 level.

Table Xa: Showing the significance of difference between means across age groups and sex of F_1 for vowel /e/.

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
Males					
4-5		R	R	A	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					
Females					
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10				*	R
11-12					

A - Significant at 0.05 level

R - Not significant at 0.05 level.

Table Xb: Showing the significance of difference between means across age groups and sex of F_2 for vowel /e/.

Males

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

Females

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
4-5		R	R	R	R
5-6			R	R	R
7-8				R	R
9-10					R
11-12					

A- Significant at 0.05 level.
R - Not significant at 0.05 level

Table Xc: Showing the Significance of difference between means across age groups and sex of F_3 for vowel /e/.

Years	4-5years	5-6years	7-8years	9-10years	ll-12years
Males					
4-5		R	R	R	R
5-6			R	A	R
7-8				R	R
9-10					R
11-12					
Females					
4-5		R	A	R	R
5-6			A	R	R
7-8				R	A
9-10					R
11-12		-			

A - Significant at 0.05 level

R - Not significant at 0.05 level

years groups. No other significant differences was found between the age groups. No significant differences between the females of any age groupr was observed when F_2 of /a/ was compared.

F- of vowel /a/ of males of the age group 4-5 years has differed from 7-8 years only, as it can be seen from the table VI c. The 5-6 year group had presented F_3 which differed from all other groups significantly. No significant difference between the higher age groups with reference to F_3 of /a/ was observed. The females of have shown no significant difference for any age group among themselves in terms of F_3 of vowel /a/.

The table VII a indicate that the F_1 of vowel /i/ for the age group 4-5 years, does not differ from 11-12 years but differs significantly from all other age groups. Where as the same formant frequency of 5-6 years has shown no significant difference with the age groups 7-8 years and 9-10 years but showed a significant difference with 11-12 years. The F_1 of the age group 7-8 years has not differed from 9-10 years but with 11-12 years. Significant difference is found between 9-10 years &- 11-12 years in terms of F_1. The females of the age group 4-5 years were compared for F_1 of vowel /i/, and it was found that they did not differ from any of the age groups, except the group 4-5 years with the higher age groups i.e. 9-10 years and 11-12 years. The study of table VII b shows that the F_2 of /i/ of males did not differ among any of the age groups, except that 7-8 years showed a significant difference with 11-12 years. Similarly the females have also shown that there was no significant difference among any of the age groups.

The males of all the age groups have presented the same F_3 value for vowel /i/. However this females had shown a slight change i.e. 5-6 years with 9-10 years, 7-8 years with 9-10 years and 9-10 years with 11-12 years had shown significant difference in terms of F_3.

The F_1 of vowel /u/ shows significant difference between 4-5 years with 7-8 years, 5-6 years with 7-8 years and 9-10 years, 7-8 years with 11-12 years, as can be seen from table VIII a. No other significant differences were observed. The females had not shown any difference in the values of F_1 for vowel /u/ amongst them.

Table VIII b shows that in case of both males and females, F_2 of vowel /u/ had differed significantly, when 4-5 years was compared with 7-8 years and when 5-6 years group was compared with 7-8 years, and 7-8 years was compared with 9-10 years 11-12 years. No other differences were noticed.

The males and females of all age groups showed no significant differences among themselves, when F_3 of vowel /u/ was considered.

The table IX a shows the comparison of F_1 of vowel /o/ for both males and females, among different age groups. No significant differences was observed for any of the group except that the females of 5-6 years differed from females of 7-8 years.

When F_2 of vowel /o/ was compared within themselves in terms of age group no difference was noticed as depicted in table IX b.

The vowel /o/ had presented F_3 in the age group 9-10 years, which differs from all other age groups in males, where as no other age groups had shown difference among themselves, as it can be made out from table IX c. In case of females the F_3 of vowel /o/ has shown differences only between the age group 7-8 years with 4-5 years and 44412 years .

The examination of the tables X a, b, c, shows the results of F_1 , F_2 and F_3 of vowels /e/, when compared across, the age groups of both males and females shows no significant differences in F_1 and F_2. On comparison for both males and females among themselves. However F_3 of 5-6 years age group of males had shown difference when compared with 9-10 years. Where as in the female group the F_3 of the vowel /e/ of 7-8 years differed from 4-5 years, 5-6 years and 11-12 years.

Thus in general it can be concluded that the F_1, F_2 and F_3 of the vowel /a/, /i/, /u/, /o/ and /e/ do not show statistically significant differences among the age groups between males and females. Further no statistically significant difference were found between male and females of the age groups studied i.e. from 4-12 years. The results of present study warrant the conclusion that the F_1 of vowel /a/ was significantly higher than F_1 of other vowels and F_2 and F_3 of /i/ and /u/ had shown higher frequencies than F_2 and F_3 of other vowels. However these are not consistent in all the age group of both the sexes. Hypothesis II b is accepted, stating that there is no significant change in formant frequencies (F_1, F_2 and F_3) with increase in age.

Eguchi and Hirsh (1969) after an extensive study of formant frequencies in different vowels produced by , the different age groups have concluded that, the gradual but marked decrease in F_2 as contrasted with the more stable F_1 is seen. However in the present study such gradual decrease in F_2 or stabilised F_1 were not observed. They further state that "another feature that stands out is that the first formant frequency for /a/ appears to be independent of age". This feature has been found in the present study also. Individuals mean formant frequencies do not appear to become more like each other with increase in age of the subjects, as per the results of the present study. A similar report has been made by Eguchi and Hirsh (1969).

In the discussion on vowel production and formants Eguchi and Hirsh (1969) state that "One simple notion from the past was that the first formant corresponds to the back cavity and the second formant corresponds to the front cavity of the mouth (Joos, 1948). However, it has also been reported that the formants generated by different talkers speaking the same vowel have different frequencies and that formants generated in producing different vowels may have the same frequency. A theory based on absolute values for vowel formant frequency has great difficulty Stevens and House, 1963 . Various investigators have considered as a basis for this confusion, size of vocal tract, dialect and many other factors".

- Similarly not much variation is found between the age groups and sexes in terms of F_1, F_2 and F_3 and among the vowels. This can be explained on the anatomical development of different parts of voice and speech organs in children as pointed by Negus (1949). It occurs at different rates at different ages, For example, the development of larynx is considered to be most rapid between the ages 3-5 years and then becomes more gradual until puberty is reached. Similarly as pointed out by Samuel (1973), the development of the vocal tract is gradual upto the age of puberty, Thus the changes seen in the acoustical properties of the vocal tract are very gradual, particularly between 5 and 12 years. The results of the present study of F_0, F_1 , F_2 and F_3 in children, age ranging from 4-12 years, also indicates that, the acoustical properties of the vocal tract change gradually. As stated by Eguchi and Hirsh (1969), these are only few studies on vowel formant frequency of children (Potter and Steinberg, 1950; Peterson and Barney, 1952), especially on the development of formant frequu+r encies (Potter;.and Peterson, 1948; Okamura, 1966). Thus it is difficult to compare results of the present study with any other similar studies, as the data regarding the formant frequencies of this age group were not available to the present investigator. However, as the formant frequencies had not shown any change with age, the results of present study were compared with the results of earlier investigators reporting formant frequencies for higher age groups. The results of the present study were in agreement with that of others (MenonK.M.N., Jenson, P.J., and Dev, D, 1969; Fry, D.B. 1976 and Shukla, 1981)

VOT

The final phase of analysis was measurement of voice onset time in three consonants. The stop consonants /p/, /t/ and /k/ were taken from the words of the test sentences, /p/ from Papu, /t/ from Kot and /k/ from Kempu as well as from Koti. The VOTs were measured for these consonants using HRSA, as described in Chapter III, Methodology.

Age group 4-5 years.

The mean values of VOT for males and females are given in the table XI. It is evident from the table XI that /t/ consonant had the maximum duration of VOT, being 35 m.sec. /k/ of the word Koti had 28.24 m.sec. and /k/ from Kempu had 27.90 m.sec. Thus there was no significant difference in /k/ VOT of both Kempu and Koti. Lowest duration of VOT was found for /p/ being 13.90 m. sec.

In the female group, of this age range, similar findings were seen i.e. /t/ had largest duration with 26.6 m.sec. %k% in Kempu had 20 m. sec and /k/ in Koti was 20.6 m. sec. and lastly /p/ had 15.3 m.sec. As stated earlier /k/ consonant had no difference even among female members of this group.

The S.Ds can be observed from table XI which show limited variability except for /t/ in females which was slightly higher than others.

Table XI. Showing the Mean duration and Standard deviation of stop consonants in males and females.

<table>
<tr><th></th><th></th><th colspan="4">Males</th><th colspan="4">Females</th></tr>
<tr><th></th><th></th><th>|K|empu</th><th>/K/oti</th><th>Ko/t/i</th><th>/p/apu</th><th>|K|empu</th><th>/k/oti</th><th>Ko/t/i</th><th>/p/apu</th></tr>
<tr><td>4-5</td><td>M</td><td>27.9</td><td>28.24</td><td>35</td><td>18.9</td><td>20</td><td>20.6</td><td>26.6</td><td>15.3</td></tr>
<tr><td></td><td></td><td>4.61</td><td>5.61</td><td>3.37</td><td>4.28</td><td>4.62</td><td>6.52</td><td>8.85</td><td>3.37</td></tr>
<tr><td>5-6</td><td>M</td><td>22</td><td>19.86</td><td>26.1</td><td>13.77</td><td>18.28</td><td>20.6</td><td>24</td><td>14.88</td></tr>
<tr><td></td><td></td><td>7.8</td><td>8.24</td><td>7.81</td><td>4.65</td><td>5.07</td><td>4.09</td><td>5.21</td><td>2.75</td></tr>
<tr><td>7-8</td><td>M</td><td>20.94</td><td>17,93</td><td>23.21</td><td>15.66</td><td>20.13</td><td>23.1</td><td>27.5</td><td>15.5</td></tr>
<tr><td></td><td></td><td>5.11</td><td>44.01</td><td>4.07</td><td>3.02</td><td>6.64</td><td>3.78</td><td>6.33</td><td>2.76</td></tr>
<tr><td>9-10</td><td>M</td><td>22.3</td><td>20.4</td><td>23.8</td><td>15.9</td><td>28.05</td><td>27.9</td><td>35.7</td><td>18.3</td></tr>
<tr><td></td><td></td><td>6.06</td><td>5.10</td><td>3.81</td><td>3.28</td><td>3.67</td><td>6.87</td><td>8.23</td><td>3.65</td></tr>
<tr><td>11-12</td><td>M</td><td>23.7</td><td>20.7</td><td>25.2</td><td>13.9</td><td>23.5</td><td>22.2</td><td>28.5</td><td>14.6</td></tr>
<tr><td></td><td></td><td>10.65</td><td>4.42</td><td>6.83</td><td>2.26</td><td>5.25</td><td>5.78</td><td>6.98</td><td>2.72</td></tr>
</table>

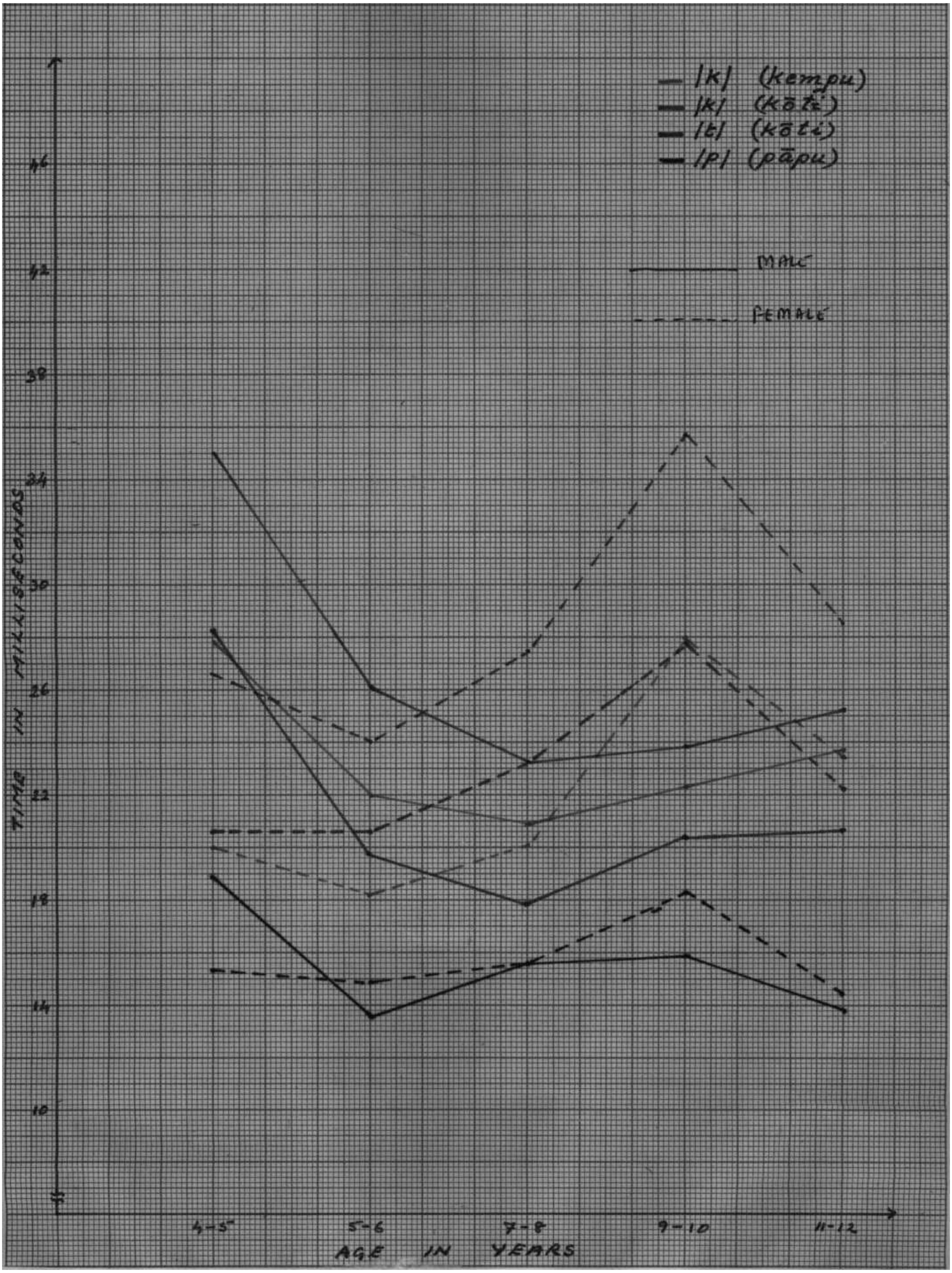
Table XII Showing the significance of difference of means between males and females for VOT of /p/, /t/, and /k/.

	/k/ kempu	/k/ koti	/t/ koti	/p/ papu
4-5years	A	A	A	A
5-6years		R	R	R
7-8years	R	A	R	R
9-10years		A	A	R
ll-12years	R	R	R	R

A - Significant at 0.05 level

R - Not significant at 0.05 level.

/



Graph C. Showing the distribution of VOTs for various stop sounds for males and females of different age groups.

Refering table XII which shows the significance of mean difference for all the four stop consonants of all the age groups, it was evident that there was a significant difference for all the stop consonants between males and females of this group.

Age group 5-6 years

The males of this group like the earlier groups had shown maximum duration (26.10 m.sec) for /t/ consonant, least for /p/ consonant being 13.77 m. sec, /k/ of Kempu was 22. m.sec. and /k/ of Koti was 19.86 m. sec. There was a difference of approximately 2 m. sec. between the two

As seen in table XI it is evident that females of this group had followed the earlier pattern of VOT, duration of /t/ being longest (24 m.sec). The duration of /p/ was 9.12 m.sec. less than that of /t/, which was 14.88 m. sec. The /k/ of Kempu showed 18.28 m. sec. and /k/ of Koti showed 20.6 m. sec. Hence, as earlier, in males of this group there was a difference of 2 m.sec. as it was present in females, but here /k/ of Koti was higher unlike in the male group.

The S.Ds of males of this age group were found to be slightely more variable than the females. However, there was no significant difference between males and females for the VOT values of corresponding consonants.

Age group 7-8 years

/t/ consonant with 23.21 m. sec. duration followed by /k/ of Kempu with 20.94 m.sec., /k/ of Koti with 17.93 m. sec. and /p/ with 15.66 m. sec. were the VOT values obtained by male members of this age group. In this group, pattern of duration for various stop consonants had been the replica of earlier male groups, with /k/ of Kempu being 3 m. sec. higher than /k/ of Koti. /t/ remained with highest duration and /p/ was last with least duration, /t/ consonant in female group was 27.5 m.sec., /k/ of Koti was 23.10 m.sec., /k/ of Kempu was 20.13 m. sec. and /p/ was 15.50 m. sec, hence a replica of earlier female groups in terms of order of consonants along the duration of VOT. As mentioned in the age group 5-6 years, here also it was found that the /k/ difference in Koti and Kempu was reversed i.e. in males /k/ of Kempu was more by 3 m.sec. and in females /k/ of Koti was more by 3 m. sec.

The S.Ds of males as shown in table XI are reasonably lower than the earlier male groups. But females showed a more variability than earlier female groups. However males and females of this group showed more variability on /k/ of Kempu. The females showed more variability for /t/.

On inspection of table XII it is clear that /k/ of Koti had a significant mean difference when compared between males and females of this group. The other stop consonants /t/, /p/ and /k/ of Kempu, did not show any statistical difference in means.

Age group 9-10 years.

The males had the VOT for the various consonants as follows: /t/ highest with 23.80 m. sec., /k/ of Kempu 22.30 m.sec, /k/ of Koti 20.40 m.sec. and /p/ as 15.90 m.sec. The difference between the two /k/ values was approximately 2 m.sec. as shown in table XI.

Looking at table XI, it is evident that the VOT for the females, of this group had been a replica of earlier female groups, ie. /t/ highest duration (35.7 m.sec), /p/ lowest duration (18.3 m.sec). Here /k/ of Kempu had a duration of 28.05 m.sec. and /k/ of koti had 27.90 m.sec. Unlike the earlier female group where /k/ of Koti was more than /k/ of Kempu, but like the males of this age group, the females also showed a difference of about 2m.sec. between /k/ of Kempu and /k/ of Koti with /k/ of Kempu being higher than /k/ of Koti.

The table XI shows that there was variability in males for stop consonant, /k/ of Kempu and Koti more than other consonants. In case of females /k/ and /t/ of Koti showed more variability than the other two consonants.

Table XII indicates that /k/ and /t/ of Koti are significantly different for miles and females of this group in

Hypothesis Ic, is accepted, stating that there is no significant difference between males and females of the same age group when the mean VOT of stop consonants are compared.

Table XIII shows the results of comparison of mean VOT values of all the four consonants of different age groups of both males and females. The males of 4-5 years of age have differed siginificantly from all others age groups presenting higher VOT values for all the consonants. No other age group has shown any significant variations with other age groups. The females had shown as can be made out from table XIII inconsistent variations. Group 9-10 years has shown significant difference with all other age groups and had presented greater VOT values than other groups. Hypothesis II c i.e. there is no significant change in VOT of the stop consonants with increase in age is accepted, as no consistent variation with age were noticed both in males and females.

In conclusion it can be stated that /t/ occurring in the medial position in the word Koti has consistently shown higher VOT values, next being /k/ occuring both in Kempu and Koti and finally /p/. occuring in papu showed the least values in both males and females.

According to the study by Ravishankar (1981) /k/ had the highest mean VOT /p/ had lowest VOT and /t/ occuring in between in both males and females, age ranging from

Table XIII Showing the significance of mean difference for all the stop consonants between the age groups

Males

Years	5-6	7-8	9-10	11-12
4-5	A	A	A	A
5-6		r	r	r
788			r	r
9-10				r
Females				
4-5	r	r	A	r
5-6		r	A	r
7-8			A	r
9-10				A

A - Significant at 0.05 level

r - Not significant at 0.05 level.

4-10 years. This study had considered the consonants in isolation. The table XIV shows a comparison of mean VOT values.

The comparison of the VOT values of the present study with the previous studies on Indian population using Kannada shows that there is not much difference in the VOT values of /p/ both in males and females in the age ranges studied. The VOT Values of /p/ have been higher than the adult VOT values given by Basu (1979). This may be because of the fact that Basu had studied the VOT values of voiceless stop consonants in reading in isolation where as in the present study, VOT of the voiceless consonants had been studied from spoken words. Similarly /t/ has shown higher values than the previous studies. But surprisingly the VOT values for /k/ in the present study have been lower than that of previous studies. These differences may be attributed to the kind of sample studied the and place of consonant in the word.

Many investigators (Lisker and Abramson 1964; Hillman and Gilbert, 1977; Basu, 1979 and Ravishankar, 1980) have reported that there was a consistent increase in VOT with respect to position of articulatory constriction (as it moved backward in the oral cavity). However, in the present study this has not been found to be true. As /t/ has shown higher VOT values than /k/. This may be because of the fact that, the VOT values had been measured using /t/ occuring in the medial position of the word (Koti).

Table XIV - showing the comparison of mean VOT values obtained by various studies, with present study.

Males	|p|		|t|		|k|	
	R.S.	P.S.	R.S.	P.S.	R.S.	P.S.
Years						
4-5	18.40	18.90	22.40	35.00	41.00	28.07
5-6	18.00	13.77	18.40	26.10	42.40	20.93
7-8	18.40	15.66	17.40	23.21	38.60	19.42
9-10	16.00	15.90	23.00	23.80	40.00	21.30
Females						
4-5	14.20	15.30	18.00	26.60	27.00	20.30
5-6	20.20	14.88	20.40	24.00	42.00	19.44
7-8	10.20	15.50	11.80	27.50	24.80	21.61
9-10	20.00	18.30	22.60	35.70	45.00	27.97
Adult males	10.06*		13.93*		30.96	

R.S. = Ravishankar (1981)

P.S. = Present Study '

* ==Babul Basu (1979)

While discussing the results of their study with respect to VOT, Eguchi and Hirsh (1969) state that "the mean time intervals measured here do not change systematically with age, and also that, there is wide variation among individuals pronouncing the same phonetic sequences. These two observations are in accord with . . . . other investigators, with respect to VOT". Similar findings have been observed in the present study for example VOT of /k/ by the same group of subjects in two different words, had shown variations.

Earlier studies have indicated that there was no significant difference in VOT values for voiceless stops with increase in age in both males and females (Ravishankar 1981). The present study had also indicated that there was no significant difference in the VOT values with increase in age both in case of males and females. Further this study had also shown that, there was no significant difference in the VOT, values between males and females of the same age group. The same results have been reported by Ravishankar (1981).

Kent (1976) in his tutorial on Anatomical and Neuromuscular maturation of the speech mechanism: evidence from acoustic studies states that the measurement of F_0, formant frequencies and VOT, have applications to the identification and diagnosis of developmental disorders.

The study of F_0, has been found to be useful in early identification, diagnosis and treatment of various speech and language disorders. (Kent, 1976; Samuel, 1973; Gopal, 1980) Similarly a study of formant frequencies has been considered as a useful tool In identification and diagnosis of developmental disorders (Kent, 1976; Eguchi and Hirsh 1969). As VOT reflects the ability of an individual to control the neuromuscular system of speech, the study of VOT contributes to the understanding of various speech pathologies (Kent, 1976; Eguchi and Hlrsh, 1969; Basu, B, 1979; and Ravishankar, 1981).

Thus, the results of present study will be useful in identification, diagnosis and treatment of various Speech and Voice disorder.

CHAPTER V

SUMMARY AND CONCLUSIONS

The acoustic analysis to study the speech development in children has been found to be useful, as such studies, reflect 1. the adjustment of phonatory apparatus, 2. the shaping of the vocal tract and 3. the timing and co-ordination of articulation and thus provide evidence regarding the anatomical and neuromuscular maturation of speech mechanism. This information has been found to be useful in early identification, diagnosis and treatment of various speech and language disorders.

The present investigation was undertaken to study the F_0, formant frequencies (F_1, F_2 and F_3) and voice onset time in hundred children age ranging from 4-12 years both males and females.

Three sentences were elicited from each child by showing three picture cards (picture showing a baby, a monkey and red colour). Thus the three sentences idu papu. (ಇದು ಪಾಪು (ಇದು ಕೋತಿ). idu koti and idu kempu banna (ಇದು ಕೆಂಪು ಬಣ್ಣ). were elicited and considered as spontaneous speech for the purpose of the study Each child was given three trials. All the speech samples were recorded using tape recorder of the spectrograph (VIC VII). One of these samples was considered for analysis.

Five vowels /a/, /i/, /u/, /e/ and /o/ extracted from these test sentences using signal gate of the spectrograph were analysed to obtain F_0, F_1, F_2 and F_3 with the help of High Resolution Signal Analyzer (B and K 2033). further the voiceless stop consonants /p/ /t/ and /k/ in the words of the test sentences were analysed using HRSA to obtain VOT values for all the subjects.

Procedure to obtain F_0, formant frequencies (F_1, F_2 and F_3) and VOT using HRSA was validated by analysing the speech samples of 10 adults males and 10 adult females both spectrographically and using HRSA, The procedure using HRSA was found to be valid and reliable.

After the necessary statistical treatment, the following conclusions were drawn.

1. The fundamental frequency both in case of males and females decreases with age, males showing a sudden decrease around 11 years of age.

2. No significant difference in fundamental frequency was found until the age of 11 years between males and females.

3. The F_0 in vowel /a/ has been the lowest in both males and females and highest /u/ for males and /i/ for females among the five vowels studied.

4. No sex difference was found in teams of formant frequencies in the age range studied.

5. No systematic variations in formant frequencies, of all the five vowels, with increasing age were observed.

6. P.. of vowel /a/ was found to be highest among all the vowels in both males and females, through out the age range studied.

7. F_2 and F_3 of vowels /i/ and /u/ were found to be having the highest frequencies.

8. No variations in VOT values for the voiceless stop con sonants studied with age was noticed in both the sexes.

9. No sex difference was found In VOT values through out the age range studied.

10. No systematic variation in VOT values with the articulatory constriction moving backwards from lips was found.

Recommendations

1. To study these acoustic features with wider age range and a larger number of subjects.

2. This study may be tried with various other languages.

3. To study these features in comparison tb clinical population.

4. To study these acoustic features in repeated utterances of the same subject.

5. To study other acoustic features, like duration of vowels and words along with these acoustic features.

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