FUNDAMENTAL FREQUENCY CHANGES DURING PUBERTY IN INDIAN POPULATION

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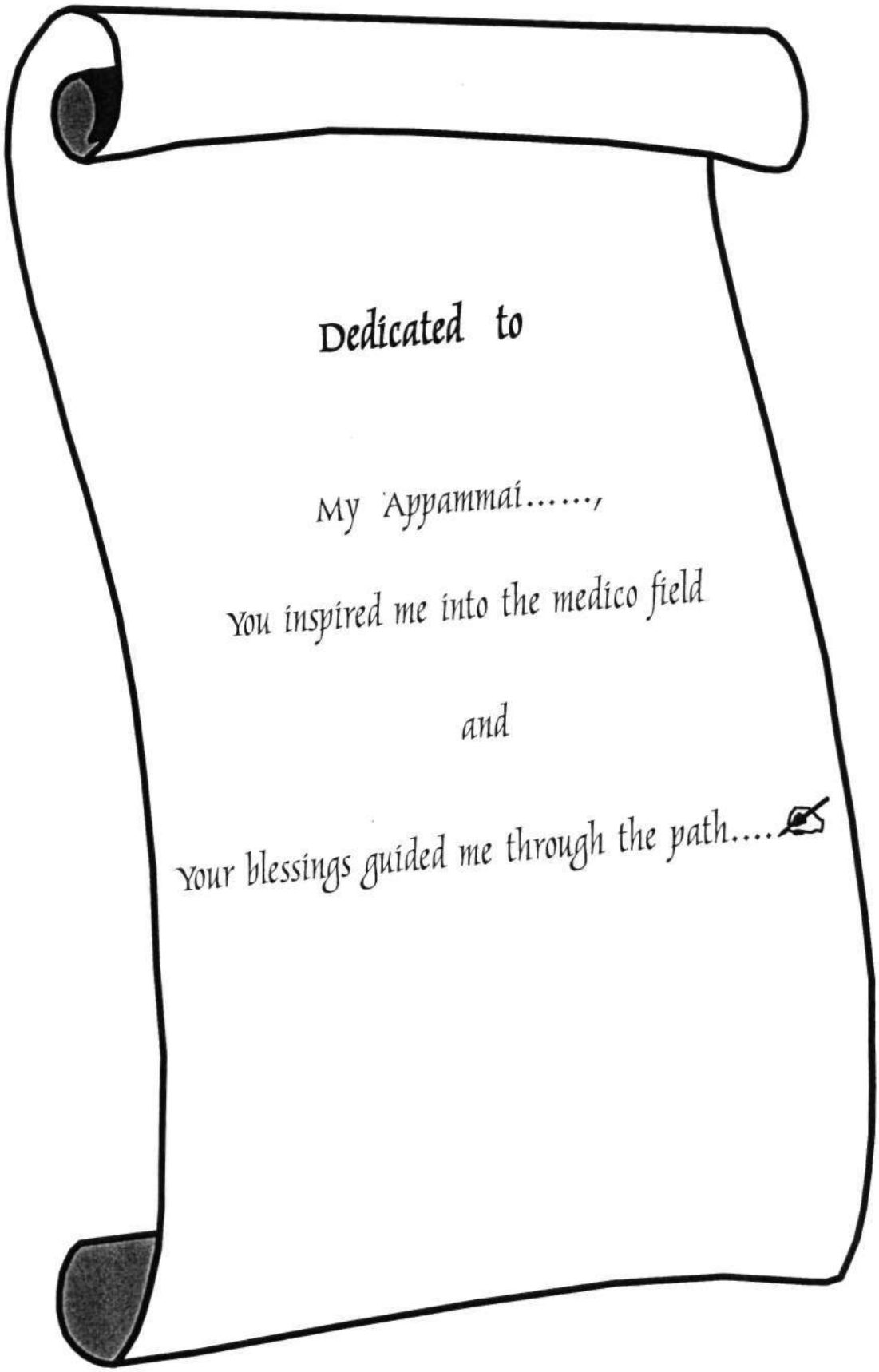

Dedicated to

My Appammai.....,

You inspired me into the medico field

and

Your blessings guided me through the path....

C E R T I F I C A T E

This is to certify that this dissertation entitled **"FUNDAMENTAL FREQUENCY CHANGES DURING PUBERTY IN INDIAN POPULATION"** is a bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student (Register No. MSHM0120).

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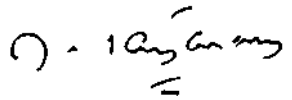
May, 2003

C E R T I F I C A T E

This is to certify that this dissertation entitled "FUNDAMENTAL **FREQUENCY CHANGES DURING PUBERTY IN INDIAN POPULATION"** has been prepared under my supervision and guidance. It is also certified that this dissertation has not been submitted earlier in any University for the award of any Diploma or Degree.

Guide



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DECLARAT ION

This dissertation entitled **"FUNDAMENTAL FREQUENCY CHANGES DURING PUBERTY IN INDIAN POPULATION"** is the result of my own study under the guidance of Dr.M. Jayaram, Director, All India Institute of Speech and Hearing, Mysore and has not been submitted earlier in any University for the award of any Diploma or Degree.

Mysore

May, 2003

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Chapter 1

INTRODUCTION

The process of phonation is the first complex motor act that heralds the infant's entry to the world and is not uncommonly the last an individual achieves at the end of human life (Fawcus, 1991). Phonation is the physical act of sound production by means of vocal fold interaction with the exhaled airstream. The audible sound produced due to phonation is termed voice (Aronson, 1990).

Voice is the primary means of one's expression. It serves a variety of communication purposes right from the beginning of life itself. Apart from being a means of communicating verbal messages, voice also serves as a powerful conveyor of personal identity, emotional state, education and social status (Greene and Mathieson, 1995). Just like a fingerprint, the human voice and speech pattern is amazingly distinctive (Boone, 1997).

Pitch or frequency is the key element of ones vocal "fingerprint", one of the characteristics that makes ones voice distinctively his or her own. Even without seeing a person, the pitch of the voice helps to tell immediately, whether the speaker is a male or female and roughly, what his or her age might be (Boone, 1997).

The fundamental frequency or pitch of the voice is controlled by parameters such as length and thickness of vocal folds. Fundamental frequency is directly related to how many vibratory cycles the vocal folds make in one second. A short, thick, somewhat lax fold vibrates at a much lower rate (producing a low pitch or frequency) than a long, thin, tense fold, which will produce a higher pitch.

Developmental Changes in the FO of Voice

Until puberty, the larynx is of equal size in males and females. Although both begin to enlarge at puberty, the male larynx outdistances the female, especially in the growth of its anteroposterior dimensions (Aronson, 1990; Weiss, 1950). As a result, the vocal mutation or voice change that takes place as a manifestation of puberty is more dramatic in boys than in girls.

Changes in FO of voice parallel changes in the growth of larynx in persons of different ages. It is well established that the most dramatic changes occur during the period of puberty, and is more marked in boys than in girls. The lower range of voice falls about an octave in boys and by 3 - 4 notes in girls during this period (Weiss, 1950, among others). The voice at puberty begins with a husky quality and an unsteady pitch, oscillating perhaps one to two tones. Although the pitch fluctuates from day to day, the general trend is downward. With time, the high tones become less steady and the low tones more stable (Aronson, 1990). In a majority of persons this change in voice, during puberty, takes place without appreciable breaks in voice, although in some boys, pitch breaks may be observed, particularly in the last six months of puberty (Boone and McFarlane, 2000).

In the 1970s and 80s, the pubertal period ranged between 13 to 15 years in females and 13 to 16 years for males. There is reasonable evidence, although indirect, to say that puberty and associated changes occur much earlier now, say 11 to 14 years in females and 12 to 14 years in males, than before. Better nutrition and the influence of the mass visual media, at least in the urban and semiurban areas, may be the contributing factors for the same.

Statement of the Problem

The purpose of this study was to quantify the changes in FO of voice that occurs during the age of puberty in an Indian population of male and female children. The purpose was also to see if changes in voice during puberty are any different between urban and rural children as the influencing factors on urban and rural children seem to be different as said earlier.

Objectives of the Study

The primary objective of the study was to

- quantify the changes in FO voice during the period of puberty, and secondarily to,
- see if changes in FO of voice during puberty are different in urban and rural children, and
- to note the age, at which changes in FO appears during this period.

Need for the Study

There are not many studies in the Indian context, which have investigated the changes in voice FO during puberty. Studies that have been carried out (Samuel, 1973; Usha, 1978) suffer from a major limitation in their method of study in that the data obtained on changes in FO during puberty, at different ages, have been collapsed across subjects. There might be some boys and girls in a given age group,

in whom there might have been changes in FO of voice and in whom the changes have not taken place. But, the investigators have collapsed the data, for analysis, in each group without taking this into consideration. Therefore, the studies referred to above, do not give information on either extent of change in FO, or the age at which the shift to a lower FO occurs. Therefore, there is a need for a study that will analyze the data segregating the samples, in each age, into those in whom changes in FO have occurred and in whom it has not occurred.

As the most dramatic and obvious changes in voice occur during puberty, it follows that a study of voice during puberty has implications for an understanding of both the physiology of phonation and vocal disturbances. Information about extent of change in FO and the age at which it takes place will help in the therapeutic planning for dysphonics. Hence, this study has been taken up to investigate the FO changes that occur before, during and after puberty in Indian population.

Chapter 2

REVIEW OF LITERATURE

The human voice is one of the highly developed functions of larynx. The voice reflects a wealth of information concerning the speaker to the listener. Every utterance of an individual offers intimate details on everything, including one's gender, race etc., of all the traits voice so freely declares, age is the most obvious. Throughout life, voice continues to change reflecting the individual's culture, personal habits, conditions of health, anatomical growth and age.

Boone (1997) has defined natural voice as a voice that uses ones physical vocal equipment in an easy, efficient manner, and one that achieves a natural balance of breathing, phonation, and resonance. There are three primary parameters of human voice: quality, loudness and pitch (Dworkin & Meleca, 1997). Pitch or frequency is one of the major parameters that establishes a given person's identity and personality (Boone, 1997).

Pitch is the psychological correlate of frequency. Frequency is measured in cycles/sec or Hz, and is directly influenced by alterations in the length, longitudinal tension and cross-sectional mass of the vocal folds (Case, 1996; Titze, 1994). Subglottal pressure also influences frequency in a less significant manner (Case, 1996).

The single most important acoustic variable for voice classification is fundamental frequency (FO). Fundamental frequency refers to the average most natural speed (cycles/sec) of vocal fold vibration during sustained phonation (Dworkin & Meleca, 1997). Titze (1994) has defined fundamental frequency as the lowest frequency in the periodic waveform. The sound energies are concentrated at the level of FO.

Developmental Changes in the Fundamental Frequency of Voice

Physical development plays a large role in determining FO (Titze, 1994). Length, cross-sectional mass and tension interact to account for inter- and intrasubject differences in frequency (Case, 1996). Infant cries show a FO near 500 Hz. Children speak in the 250 to 400 Hz range. The average F0 in conversational speech is between 100 to 150 Hz for males and between 180 to 250 Hz for females (Hollien, Dew and Phillips, 1971).

Sataloff (1991) has reported that life begins with a voice fundamental of 300 to 400 Hz, but continues to decrease after that. As the child grows, mean fundamental frequency of voice drops gradually reaching approximately 275 Hz by 8 years of age. By age 18 years or so, the voice reaches its mature or adult stage where it will remain for several decades. The individual has full control over the dynamic range of the voice and can produce many variations of pitch and voice quality. These vocal abilities reflect the maturation of the anatomical and physiological systems for the support of speech (Kahane, 1982).

Anatomical Differences Between the Male and Female Larynx at Puberty

Until puberty, the larynx is of equal size in both male and female children. Due to this, sex differentiation is not seen in the voice of children. At puberty, hormonal changes take place resulting in physical changes, thereby leading to the emergence of male and female characteristics. Maturation of laryngeal mechanism takes place and a sex differentiation is realized in the nature and degree of many aspects of vocal development.

Kahane (1978) has compared pre-pubertal and pubertal cadaveric larynges and reported the following morphological relationships:

-> Pubertal cartilage and soft tissue measurements were significantly larger than pre-pubertal measurements for both sexes.

-> Sex differences were not present before puberty.

-> Length of vocal folds and weights of laryngeal cartilages were significantly larger in pubertal males than in pubertal females. The extent of increase in vocal fold length in males was 10.87 mm (63%) and 4.16 mm (34%) in females.

-> Thyroid eminence in pubertal males was more prominent than in pubertal females.

The greater structural changes in the male larynx correlate with the greater drop in fundamental frequency of male voice during puberty. Table 2.1 summarizes the dimensions of the larynx with growth.

	Infancy	Puberty	Adult	
			Male	Female
	(in mm)	(in mm)	(in mm)	
Vocal cord length	6-8	12-15	17-23	12.5-17
Membranous portion	3-4	7-8	11.5-16	8-11
Cartilaginous portion	3-4	5-7	5.5-7	4.5-5.5
Glottis: Width at rest	3	5	8	6
Maximum width	6	12	19	13
Infraglottis: Sagittal	5-7	15	25	18
Transverse	5-7	15	24	17

Table 2.1: Dimensions of larynx (Ogura and Mallen, 1977).

By the end of puberty, the larynx has assumed a lower position in the neck, where it rests between C_6 and C_7 of the cervical vertebrae (Morrison et. al, 1994). The laryngeal mucosa loses transparency and becomes stronger. The epiglottis flattens, increases in size, and elevates. In concert with other growth spurts, the larynx of males virtually doubles in size, usually in a short period of a few months. The angle of the thyroid cartilage decreases from 120° to about 90° in the mature male larynx. The membranous portion of the male vocal folds range from 11.5 to

16 mm in length, a 4 mm to 8 mm increase from puberty. The dimensions of the infraglottal sagittal and transverse planes grow in the male to 25 mm and 24 mm, respectively (Ogura and Mallen, 1977). The overall effect is a dramatic drop in the natural FO range of vibration, by at least an octave change.

The growth of the female larynx during puberty is much slower and less dramatic. The angle of the thyroid cartilage does not change significantly and remains approximately 120 degrees. The female membranous vocal folds increase in length to around 8 to 11.5 mm, a 1 to 3.5 mm increase during puberty. The overall pitch and resonance changes are less in females than in the voice of males. Figure 2.1 shows the laryngeal dimensions in the adolescent male and female larynx.

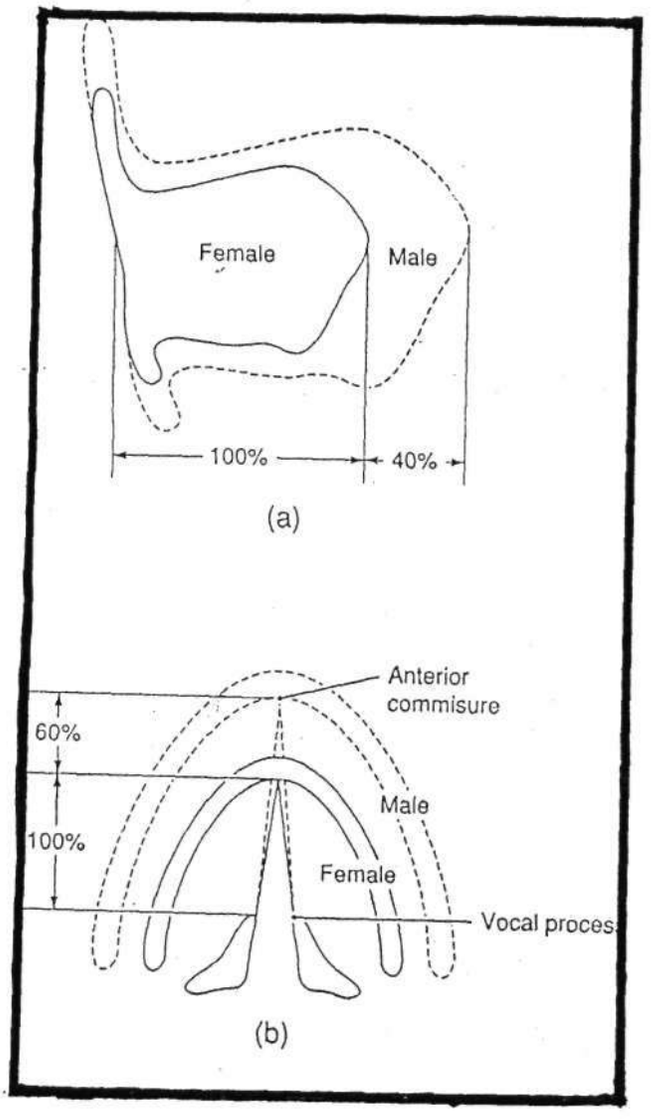

Figure 2.1: Comparison of laryngeal dimensions of males versus females - a) Thyroid cartilage b) Membranous vocal fold length (From Kahane, 1978).

The expansion of the phonatory, resonatory and respiratory anatomy results in voice changes and this parallels the appearance and development of secondary sex characteristics. Frequency or pitch distinction between male and female begins during puberty and continues throughout adolescence. The pitch and quality changes that occur at puberty are much more apparent in males than in females because of the greater magnitude of pitch drop (Aronson, 1990). The change of voice during puberty is termed mutation.

There is considerable data on fundamental frequency, covering ages from birth to death. Table 2.2 summarizes the results of several studies on levels of fundamental frequency at different ages in males and females.

Age (In years)	Sex	FO (In Hz)	Investigators
Infants	Both	413	Case (1996)
7	Males	294	Fairbanks, Willey, and Lassman (1949)
	Females	281	Fairbanks, Willey, and Lassman (1949)
		273	Fairbanks, Herbert, and Hammond (1949)
	Both	Around 275	Case (1996)
8	Males	297	Horii(1983)
	Females	288	Fairbanks, Willey, and Lassman (1949)
		275.8	McGlone and McGlone (1972)
9	Males	237	Andrews (1982)
	Females	236	Andrews (1982)
10	Males	226	Andrews (1982); Hollien and Malcik (1967)
		210	Hollien and Malcik (1962)
	Females	270	Fairbanks, Willey, and Lassman (1949)
		Around 250	Case (1996)
		237	Andrews (1982)
11	Males	Around 250	Case (1996)
		227	Horii (1983)
	Females	269	Curry (1940)
		Around 225	Case (1996)
		238	Horii (1983)
		266	Duffy (1970)
12	Males	225	Andrews (1982)
	Females	236	Andrews (1982)
13	Males	221	Andrews (1982)
	Females	227	Andrews (1982)
14	Males	185	Hollien, Malcik, and Hollien (1965)
		242	Fairbanks, Willey, and Lassman (1949)
		232	Curry (1940)
15	Females	Around 215	Case (1996)
		237	Duffy (1970)
		215	Hollien and Paul (1969)
		207	Michel, Hollien and Moore (1966)

Table 2.2: Mean fundamental frequency of voice across different ages

A study of pitch change by McGlone and Holhen (1963) found that male voice drops approximately one octave during puberty. Female voices were found to drop by 2 to 4 semitones between 11 to 15 years (Greene and Mathieson, 1995). Weiss (1950) has also reported that the lower limit of boy's voices descends a full octave while the upper limit decreases about a sixth during puberty. In girls, the lower limit of frequency has been reported to decrease about 2 tones after puberty and the upper limit has been reported to increase by an equal amount.

Voice breaks or 'stormy' mutation is another phenomenon that might be seen during the pubertal period. This almost always occurs only in males and is rarely seen in females (Aronson, 1990). Aronson refers to 'stormy voice mutation' as the pervasive sudden voice breaks from high to low pitch or the reverse, or excessively husky or hoarse voice associated with adolescent voice change. Luchsinger (1962) has reported that the real voice break or 'stormy' mutation occurring in male adolescence is not the general rule and is encountered only in a minority of boys.

Michel, Hollien and Moore (1966) reported a speaking fundamental frequency of 207.5, 207.3 and 207.8 Hz, respectively in 15, 16 and 17 year old girls. This indicates that F0 is established by 15 years in girls and that mutation is almost complete by then. Figure 2.2 depicts the mutational changes in voice in males and females.

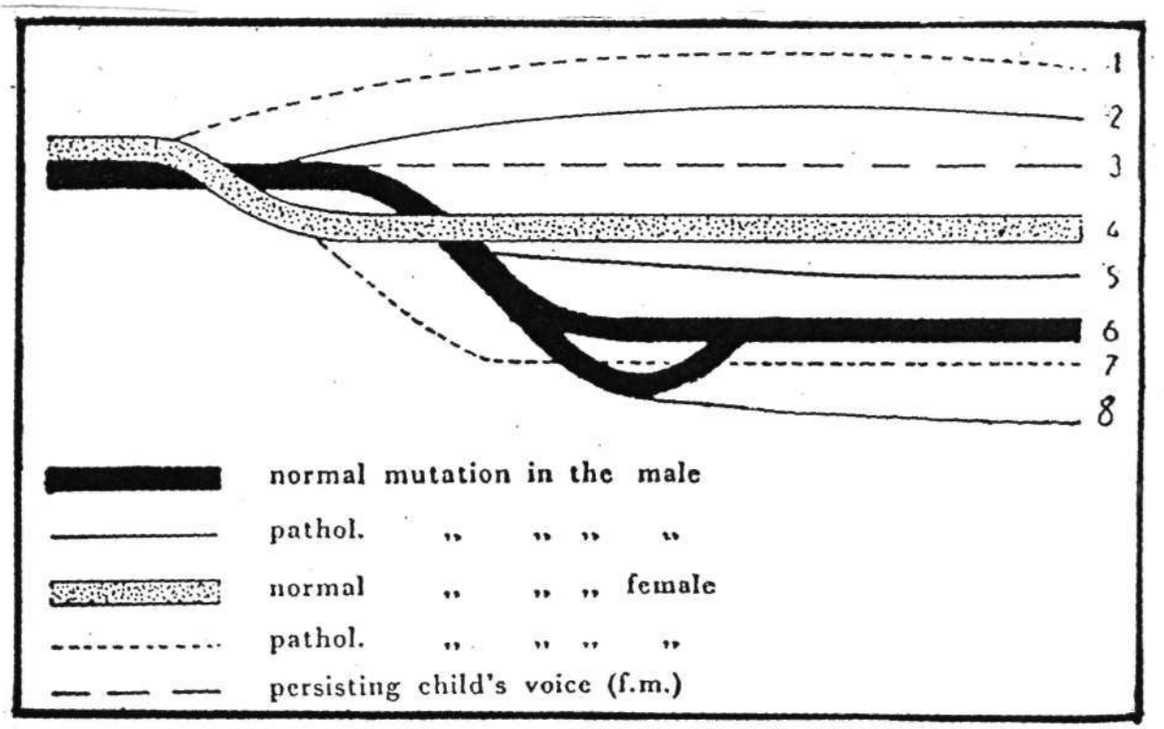

Figure 2.2: Mutational changes in males and females (Weiss, 1950)

There is reasonable evidence to show that, in the Western population, growth changes in girls begin around 9 years and these changes occur over a 4 - 5 year period; whereas in boys, these changes start at 11 years and continue to occur over a 4 - 5 year period (Boone and McFarlane, 2000). By age 17, adolescents of both sexes would have achieved their full adult development (Offer, 1980). There is also a general agreement that the voice F0 drops by an octave in boys during puberty and by 3 to 4 notes in girls during this period.

Studies on Indian Population

There are two studies in the Indian context (Samuel 1973; Usha 1978), although neither investigated the changes in FO of voice with reference to puberty, per se. In a developmental study of the changing fundamental frequency of voice in children in the age group of 7 to 25 years, Samuel (1973) reported a drop in fundamental frequency from 268 Hz in 7 year old male children to 132 Hz in 16 year old adolescents; and from 280 Hz in 7 year old girls to 215 Hz in 15 year old females. Usha (1978) reported vocal mutation to take place between 9 to 12 years in females and between 11 to 14 years in males (results given in Table 2.3).

Age (in years)	FO in Males (in Hz)	F0 in Females (in Hz)
9	266.6	275.5
10	269.7	268.0
11	263.1	258.6
12	231.1	243.6
13	229.5	246.2
14	158.9	239.4
15	168.6	242.1
16	151.2	241.1
17	149.2	240.2
18	141.0	248.8
19	135.8	232.9
20	138.0	248.2

Table 2.3: Change in F0 of voice during puberty (Usha, 1978) and thereafter.

However, as data in Table 2.3 show, there is no valid ground to conclude that mutation starts by 9 years of age and that it is completed by 12 years in females, as Usha (1978) has concluded. In fact, it can be seen that FO is continuously decreasing even by 19 years of age, in the case of females. Similarly, in males, FO has decreased to 158 Hz by 14 years; it increased by as much as 10Hz by 16 years, and then continued to decrease; but, even by 20 years of age, the average FO of voice remains as high as 138 Hz. This variation must be considered significant (though not statistically). It indicates that the FO changes have not stabilized even by 20 years of age, or that there has been some error in sampling. Also it is apparent, in both studies (Samuel, 1973; Usha, 1978), that attempts have not been made to separate children in any age group, into those who are showing voice changes due to puberty and those who are not. The data from all the subjects have been collapsed constituting a serious sampling error.

There is dearth of information in the Indian population on changes in fundamental frequency during puberty. This investigation was taken up to study the fundamental frequency changes occurring in voice during puberty.

Chapter 3

METHOD

The purpose of this study was to quantify the change in vocal FO occurring during puberty. The primary objective of the study was to quantify the changes in vocal FO, in both boys and girls, during the age of puberty.

The secondary objectives were to generative normative data on vocal FO levels in 9 - 16 years old male and female school-going children, and to document and compare the differences, if any, in vocal FO levels between school-going rural and urban children during the age of puberty.

Subjects

Subjects in the age range of 9 - 16 years were selected from schools located in urban and rural areas, in and around the city of Mysore. Table 3.1 summarizes the number of children investigated and their mean age.

Age range (in years)	Urban				Rural			
	Male		Female		Male		Female	
	N	Mean age (in years)	N	Mean age (in years)	N	Mean age (in years)	N	Mean age (in years)
9-10	35	9.5	20	9.8	20	9.8	21	9.4
10- 11	35	10.7	22	10.5	20	10.6	25	10.6
11 - 12	35	11.6	25	11.6	20	11.6	21	11.6
12- 13	35	12.6	25	12.6	29	12.7	23	12.7
13- 14	35	13.7	25	13.7	22	13.7	25	13.6
14-15	35	14.5	24	14.5	20	14.7	21	14.7
15-16	35	15.7	20	15.6	20	15.6	21	15.4
16- 17	35	16.7	23	16.4	20	16.7	20	16.5

Table 3.1 : Sample size (N) and mean age of the children selected for the study.

Selection Criteria

Only those subjects who met the following criteria were included in the study:

> No history of speech, language and hearing disorders.

> No history of E. N.T abnormalities.

> No history of vocally abusive behaviours.

> No history or any complaint of endocrine abnormalities.

Children themselves, class teachers and parents, in many instances, were interviewed to get information that helped to select or exclude children from the study.

Material

Phonation of vowel / a /, a sample of spontaneous speech, and samples of extended phonation of vowel / a / were recorded from each subject.

Procedure

Recording of Data

The subjects were asked to phonate vowel / a / in their natural style and for a duration that was comfortable to them. Later, phonation of extended duration, and a sample of spontaneous speech were also elicited to see if pitch breaks occur. There is some evidence to show that, if pitch breaks occur, they may be observed in the voice of boys during the last six months of puberty when the most rapid and dramatic changes occur in the voice (Boone and McFarlane, 2000). In the case of those boys who may have already been employing a low-pitched voice, attempts were made to see if they could remember and phonate their old high-pitched voice on the premise that the difference in the frequency levels of the two voices could then indicate the drop in F0 of voice at the time of puberty. All recordings were

made on a portable mini disc recorder (Sony Mz - R 30) in as quite surroundings as possible in a school environment.

Acoustic Analysis

The recorded signals were digitized with 12-bit precision at a sampling rate of 16 kHz and stored in the hard disc of the computer. This was done using the record program of the "Utilities module" of VAGHMI Version-3.1 software (Voice and Speech Systems). The signal was then analyzed through the " FOINT" analysis module. Signal from the specified file was read in blocks or frame of 40 msec duration each. Auto correlation technique was used to estimate the average F0 over this block of 40 msec.

The recorded voice samples were analyzed for a number of parameters related to frequency, but only the results on mean F0 are reported here. If pitch breaks were observed in the signal, it was highlighted and the F0 of that segment was measured. If pitch breaks were perceived in the spontaneous speech sample, then that part of the signal was isolated and analyzed in the manner described above.

Statistical Analysis

The obtained data was subjected to appropriate statistical analysis. Separate analysis was made for boys and girls, and for rural and urban children, in different age groups. Finally, the data were analyzed for boys and girls, in each age group, without the distinction between urban and rural origin.

Chapter 4

RESULTS

The aim of the present study was to investigate the changes in vocal FO occurring during the period of puberty. The voice samples of boys and girls in the age range of 9 - 16 years were analyzed and the obtained fundamental frequency was subjected to statistical analysis. The analysis of spontaneous speech samples, particularly for instances of pitch breaks, and extended phonations of vowel / a / were of not much use because of the very number of samples manifesting pitch breaks.

Comparison of FO: Males and Females

Mean FO of voice in boys and girls, of different age groups, are given in Table 4.1. The data of urban and rural children have been combined. The result of the t- test (independent samples) for significance of difference of means are given in Table 4.2. As a large number of statistical tests were used in the present study, a more stringent significance level (0.01) was adopted as a compromise for avoiding Type I and Type II errors. Therefore, only statistical results that did not exceed a chance level of 0.01 were considered to be significant. Mean FO of boys and girls, across different age groups, are pictorially depicted in Figure 4.1.

Age (in years)	Males			Females		
	N	Mean	SD	N	Mean	SD
9	55	253.12	19.97	41	253.72	17.98
10	55	246.37	25.79	47	245.38	16.72
11	55	238.15	23.39	46	237.84	24.12
12	64	231.63	25.10	48	242.57	16.88
13	57	206.80	41.59	50	237.49	17.99
14	55	181.09	42.76	49	234.74	22.41
15	55	150.90	34.63	42	244.60	21.85
16	55	131.51	17.65	43	244.83	14.52

Table 4.1 : Sample size (N), mean and standard deviation (SD) of FO of voice in male and female children of different age groups.

Age (in years)	Males		Females	
	t	**p**	**t**	**p**
9 vs 10	1.54	.13	2.26	.03
10 vs 11	1.75	.08	1.76	.08
11 vs 12	1.46	.15	-1.11	.27
12 vs 13	4.03	.00	1.44	.15
13 vs 14	3.23	.00	0.67	.50
14 vs 15	4.07	.00	-2.12	.03
15 vs 16	3.70	.00	-0.06	.95

Table 4.2 : Results of significance tests for the difference in mean F0 of voice in males and females.

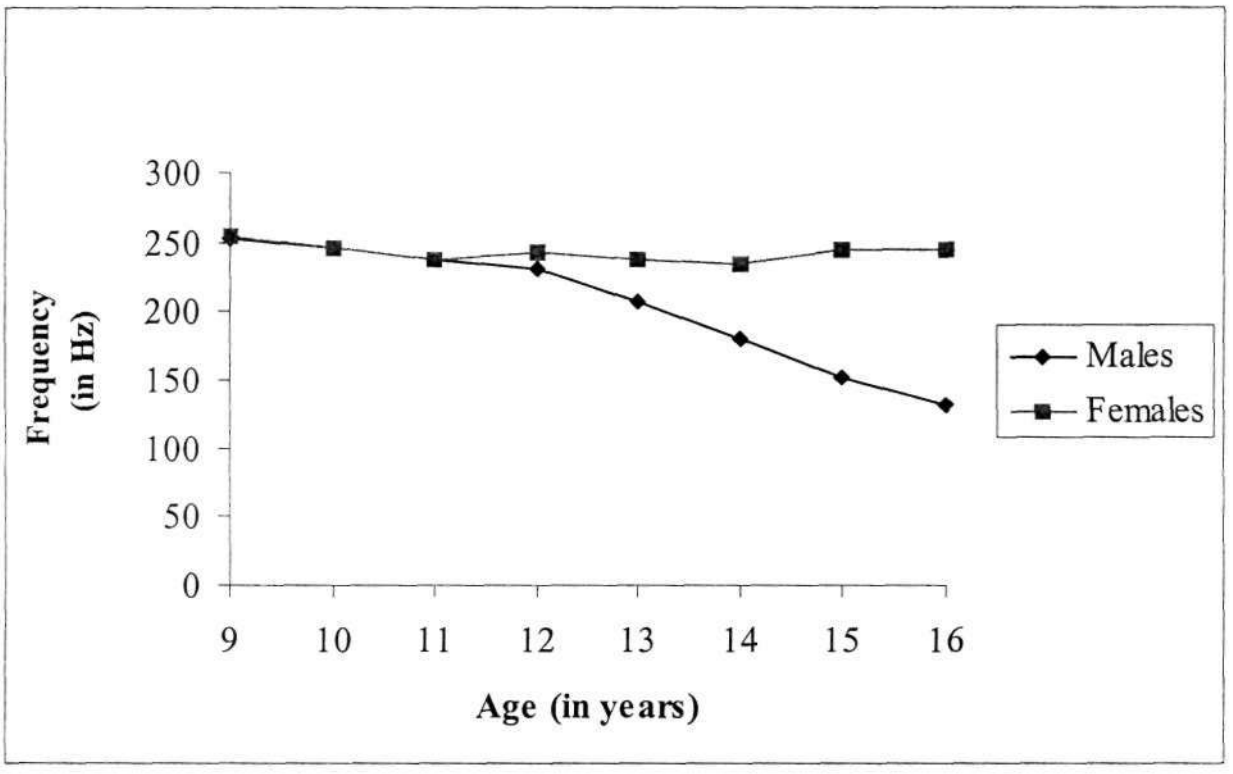

Figure 4.1 : Mean FO of males and females at different ages.

The results indicated a progressive drop in FO in boys from 9 years to 16 years. There was a drop of almost one octave from 9 to 16 years (253.12 Hz to 131.51 Hz). However, the differences in mean were statistically significant between age groups 12 and 13 years, and thereafter. However, in females, neither a steady drop in FO nor a statistically significant difference in means between age groups was seen. In fact, the FO in girls dropped from 253.72 Hz in 9 year olds to only 244.83 Hz in 16 year olds.

Comparison of FO: Urban and Rural Population

A separate analysis of the FO of voice of urban and rural children was carried out. The results of the comparison are shown in Table 4.3 (comparison between urban and rural male children), and Table 4.4 (comparison between urban and rural female children). The results of the tests of significance of difference in means between different age groups are shown in Table 4.5 for urban and rural boys and in Table 4.6 for urban and rural girls.

Age (in years)	Urban Males			Rural Males			t	P
	N	Mean	SD	N	Mean	SD		
9	35	251.88	17.33	20	255.29	24.26	-0.61	.54
10	35	248.92	27.00	20	241.90	23.49	0.97	.34
11	35	235.87	21.47	20	242.14	26.54	-0.96	.34
12	35	226.58	21.90	29	237.73	27.65	-1.80	.07
13	35	204.28	43.23	22	210.81	39.49	-0.57	.57
14	35	166.51	44.48	20	206.61	24.06	-3.72	.00
15	35	143.35	28.73	20	164.12	40.51	-2.21	.00
16	35	136.89	14.94	20	122.10	18.41	3.24	.00

Table 4.3 : Sample size (N), mean, standard deviation (SD) of FO of voice and results of significance tests for differences in mean of F0 of voice between urban and rural male children of different age groups.

Age (in years)	Urban Females			Rural Females			t	P
	N	Mean	SD	N	Mean	SD		
9	20	258.33	16.16	21	249.34	18.34	1.63	0.11
10	22	250.15	15.68	25	241.18	16.77	1.89	0.06
11	25	238.08	24.42	21	237.55	24.35	0.07	0.94
12	25	246.28	16.87	23	238.54	16.29	1.62	0.11
13	25	230.25	16.82	25	244.72	16.39	-3.08	0.00
14	24	234.73	20.78	25	234.76	24.30	-0.01	0.99
15	20	249.05	16.38	22	240.55	25.55	1.27	0.21
16	23	249.66	14.79	20	239.28	12.34	2.48	0.02

Table 4.4 : Sample size (N), mean, standard deviation (SD) of F0 of voice and results of significance tests for differences in mean of F0 of voice between urban and rural female children of different age groups.

The results of significance test showed that the mean FO of voice was significantly different between urban and rural boys at 14 years and thereafter (Table 4.3). The mean FO was significantly different between urban and rural females (Table 4.4) at 13 years of age. None of the other differences in mean FO was statically significant.

As said above, the difference in mean FO of the voice of urban and rural children, within each group, but across the age groups, was analyzed. The results of significance tests are given in Table 4.5 for urban and rural males and in Table 4.6 for urban and rural females. The results showed that the mean FO of the voice of urban males were significant between ages 12 and 13, and thereafter till 14 and 15 years. The mean FO of voice was not significantly different between 15 and 16 year olds. FO of voice dropped from 226.58 Hz at 12 years to 204.28 Hz at age 13, and then to 166.51 Hz at age 14 and to 143.35 Hz at age 15. Similarly, in rural boys, FO of voice was different between 12 and 13 years, between 14 and 15 years, and between 15 and 16 years, but not between 13 and 14 years (Table 4.5).

The difference in mean FO of voice of urban females between 12 and 13 years, and between 14 and 15 years was statically significant (Table 4.6). None of the other differences reached statistically significant levels. The mean FO of the voice of rural females dropped from 246.28 Hz to 230.25 Hz between 12 and 13 years, but increased from 234.73 Hz to 249.05 Hz between 14 and 15 years.

Age (in years)	Urban Males		Rural Males	
	t	p	t	p
9Vs1O	0.55	0.58	1.77	0.08
10 Vs 11	2.24	0.03	-0.03	0.98
11 Vs 12	1.79	0.08	0.56	0.58
12 Vs 13	2.72	0.00	2.86	0.00
13 Vs 14	3.60	0.00	0.41	0.68
14 Vs 15	2.59	0.01	4.03	0.00
15 Vs 16	1.18	0.24	4.22	0.00

Table 4.5 : Results of significance tests for the difference in mean F0 of voice between urban and rural males.

Age (in years)	Urban Females		Rural Females	
	t	p	t	p
9 Vs l0	1.66	0.10	1.55	0.13
10 Vs 11	1.99	0.06	0.59	0.55
11 Vs 12	-1.38	0.17	-0.15	0.87
12 Vs 13	3.37	0.00	-1.31	0.19
13 Vs l4	-0.83	0.41	1.69	0.09
14 Vs 15	-2.50	0.01	-0.79	0.43
15 Vs 16	-.128	0.89	0.20	0.84

Table 4.6: Results of significance tests for the difference in mean F0 of voice between urban and rural females.

Differential Analysis of FO of Voice in Boys

The results in Tables 4.1 and 4.2, and the raw data of male children show that, in each age group after 12 years, there are boys in whom a significant shift in FO of voice has taken place and boys in whom the change has not occurred. Therefore, collapsing the data across all boys would be wrong. An attempt was made to separate boys in whom FO of voice has significantly changed from those in whom the FO of voice has not shifted, in each group. The mean FO of voice was adopted as the criterion to make this separation from age 12 years and above. The mean FO of voice of all children falling above the mean for a given age, and those falling below this level are shown in Table 4.7 and plotted in Figure 4.2. The difference in means, above and below the mean FO of voice in a given age group, were all statistically significant. As the difference in FO was not statistically significant between any age group for female children, the female data were not subjected to further analysis.

The results showed that there was a significant shift in FO starting at the age of 12 years in the case of male children. By age 16 years, the difference in FO between the two categories seemed to have considerably narrowed down to say that all children have achieved a drop in FO of voice by the time they were 16 years old. Further drop in FO of voice can be expected in children who belong to the upper line of the curve in Figure 4.2, thereafter.

Age (in years)	N	Mean	SD	t	P
9	55	253.12	19.97		
10	55	246.37	25.79		
11	55	238.15	23.39		
12 (below Mean)	30	212.36	17.55	-8.33	.00
12 (above Mean)	34	248.64	17.22		
13 (below Mean)	25	169.83	33.23	-9.64	.00
13 (above Mean)	32	235.68	17.50		
14 (below Mean)	26	140.41	21.26	- 15.87	.00
14 (above Mean)	29	217.56	14.47		
15 (below Mean)	39	131.57	12.89	- 13.46	.00
15 (above Mean)	16	198.02	23.58		
16 (below Mean)	27	117.39	8.93	-9.47	.00
16 (above Mean)	28	145.12	12.44		

Table 4.7 : Sample size (N), Mean, standard deviation (SD) and results of significance tests for difference in means of FO of voice of males after categorizing the age groups

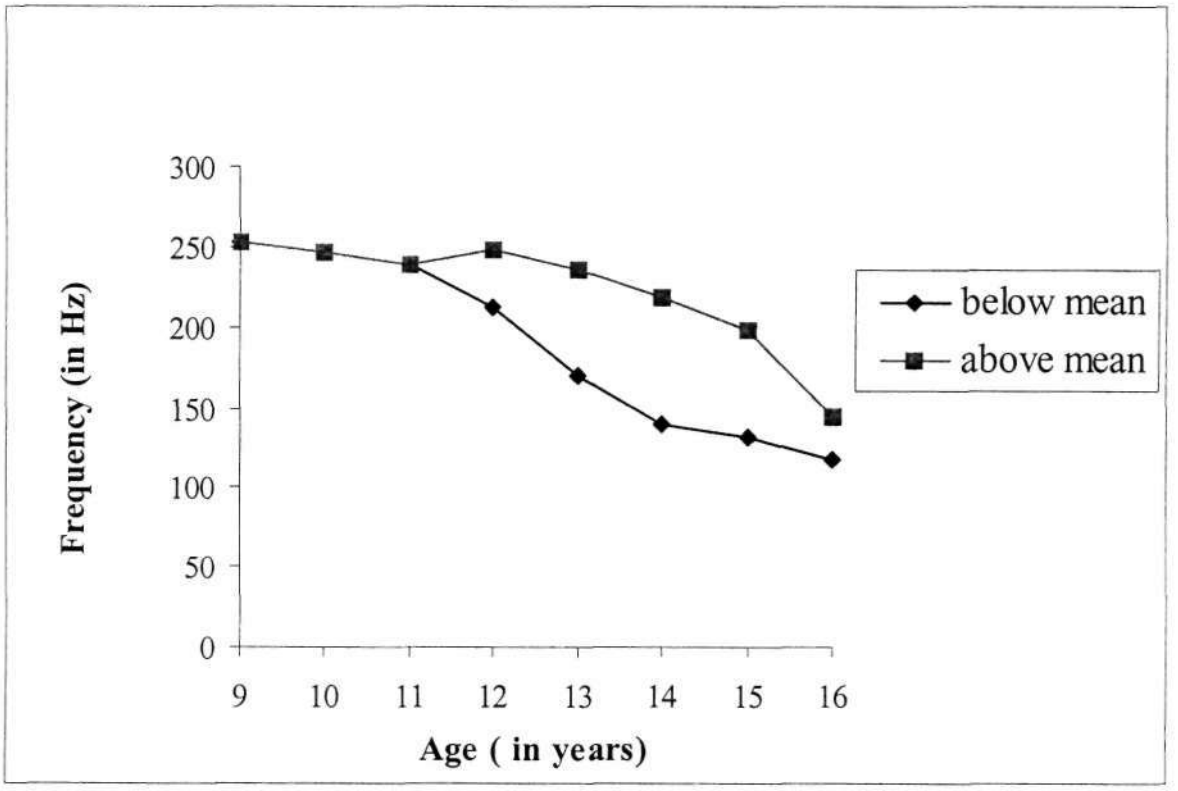

Figure 4.2 : Mean FO of male children after categorizing them on the basis of mean FO of voice

Chapter 5

DISCUSSION

In the present study, the voice sample of boys and girls in the age range of 9 to 16 years were analyzed to investigate the changes in FO occurring during puberty.

Comparison of FO : Males and Females

In the case of male children, the FO of voice dropped from 253.12 Hz at 9 years of age to 131.51 Hz at 16 years of age. Though a difference was noted between each age group, statistically significant differences were noted only from 12 years to 16 years of age. From this, it can be inferred that the maximum change during the pubertal age occurs at 12 years of age and continues till 16 years of age. There is no evidence to say whether the change in FO of voice has stabilized, or continues beyond 16 years of age. Usha (1978) reported a sudden decrease in the mean fundamental frequency at the age of 11 years. But, no significant difference in mean FO was observed beyond 14 years of age. Changes after 14 years were reported to be more gradual. Samuel (1973) has also reported a definite lowering of the FO in males after 10 years of age. But, he reported that the lowering in FO was gradual across all ages and that there was no significant difference between successive age groups. The results of the present study do not support the findings

of Usha (1978). The statistically significant changes in FO of voice occurred at the age of 12 years in males, and changes in FO of voice, in females, were very significant. However, any comparison of the results of the present study with those of Samuel (1973) and Usha (1978) has to take into consideration that difference in the way the data were analyzed in these studies, as has been explained in the last section of this chapter.

In the case of females, the FO dropped from 253.72 Hz at 9 years to 244.83 Hz at 16 years of age. Though there was a drop, it was very small (around 9Hz), besides being inconsistent between successive age groups.

In summary, it can be said that FO of voice starts to shift downward in voice from age 9 (the lowest age group considered in this study) to reach almost adult voice by 16 years in males. However, the most significant changes in FO of voice starts at 12 years and thereafter, in males. The drop in FO during puberty appears to be approximately an octave in males. The shift in FO of voice in female children is not consistent, and the reported drop of 2 to 4 semitones in Western population (Greene and Mathieson, 1995) was not seen in this study. The minor and inconsistent variations in FO, seen in female children in the present study, may be because of sampling errors.

Comparison of FO of Voice : Within Urban and Rural Children across age groups, and between Urban and Rural Children in each age group

The mean FO of voice was significantly different between urban and rural male children at 14 years and thereafter. However, the difference in mean FO of voice, between age groups were significant after 12 years of age in both urban and rural children. This implies that FO of voice starts showing a downward shift at the same age in both urban and rural male children, but that there was a greater shift between 13 and 14 years in urban male children, while the greater shift in FO was seen between 14 and 15 years in the case of rural male children. The greatest shift in FO of voice (204.28 Hz to 166.51Hz from 13 to 14 years: urban males, and 206.61Hz to 164.12 Hz from 14 to 15 years: rural males) suggests that shift in FO of voice occurs in urban male children at or after 13 years, while it occurs in rural males at or after 14 years. Thus changes in FO during puberty occurs earlier in urban males than in rural males. This may be due to social influences as hypothesized in Chapter 1 (better nutrition, greater exposure to mass media, particularly electronic, in urban areas). There may be other reasons for this difference that needs to be investigated.

On the other hand, none of the differences in mean FO of voice was statistically significant either between urban and rural female children, or within urban and rural females in any age group. An exception was the significant

difference seen in the mean FO of voice of urban females between 14 and 15 years. In fact, the FO of voice increased from 234.73 Hz to 249.05 Hz during this period. This inconsistent observation could be due to some sampling errors. An examination of the raw data also holds support to this.

Differential Analysis

Arriving at 'norms' for a given population is done based on several criteria. For example, age related norms is arrived at testing subjects of several ages for a given variable and then computing its mean and variation around the mean, for each group. Age related norms for height, weight, etc., can be arrived at in this manner. Norms for FO of voice for different age groups can also be arrived in this manner for most of the age groups. However, such a strategy will be wrong for children in the puberty period because it is well recognized that FO of voice will be changing during this period, and that changes are unequal. Some children in the age group of 10 years and after would have undergone changes in FO of voice and some would not have, and combining them for arriving at FO norms would constitute serious sampling errors and result in erroneous data. Therefore, an analysis was done in this study to separate out boys in whom changes in FO have taken place from those in whom it has not taken place. This analysis was carried out only in the case of boys because the changes in FO of voice during puberty are more prominent in them. Tables 4.1 and 4.2 show that

FO of voice was significantly different in boys after 12 years. Therefore, starting from age 12 years, children were separated into two groups, those who have FO above the mean, and those who have FO below the mean. The men FO of voice of these groups was computed and plotted (Figure 4.2). Children in the groups of 9-11 years were not included in this analysis as the FO of voice was not statistically different across ages in this range.

The purport of the graph in Figure 4.2 is that the changes in FO of voice start taking place after 12 years. In some children the changes are more rapid than the rest. But, by age 16 years, all children would have achieved almost the same levels of FO of voice. FO of voice drops almost an octave (from 253.12 Hz to 131.51 Hz) from 9-16 years, at which point changes in FO may be complete in some children while it may continue in others. However, considering that FO of voice was not significantly different between 9 to 11 years in boys, it would be prudent to quantify the changes from 12 years. Therefore, it can be said that FO of voice drops from 248.64 Hz at 12 years to 145.12 Hz at 16 years in some boys, while in some others, it drops from 212.36 Hz at 12 years to 117.39 Hz at 16 years, on an average. In either instant the drop in FO of voice is around 100 Hz. This result is different from the norms reported for the Western Population.

Chapter 6

SUMMARY AND CONCLUSION

Voice is one of our primary means of expression. Throughout life, voice continues to change, reflecting the individual's culture, personal habits, conditions of health, anatomical growth, and age. Until puberty, the larynx is of equal size in both male and female children. Approaching puberty, both begin to enlarge, but the male larynx outdistances the females, especially in the anteroposterior dimension. This results in sex differentiation of voice at puberty.

The purpose of this study was to quantify the changes in vocal FO occurring during puberty. Also, attempts were made to generate normative data on vocal FO levels in 9 - 16 year old male and female school going children and to document and compare the differences in vocal FO levels between school going urban and rural children during the age of puberty.

Samples of phonation of vowel / a / were recorded from 816 subjects, who were divided into four groups viz., urban male, urban female, rural male and rural female, in the age range of 9-16 years old each. Only those subjects with no history of any speech, language and hearing disorders, ENT, endocrine abnormalities, or vocally abusive behaviours were taken for the study. The recorded samples were analyzed using VAGHMI version 3.1 software (Voice and Speech Systems \ and the mean FO and range of FO were obtained. The data were subjected to statistical

analysis separately for boys and girls, for rural and urban children, and in different age groups. Also, the data was analyzed for boys and girls, in each age group, without the distinction between urban and rural Origin.

The following conclusions, tentative though, are in order

--> Significant changes in FO of voice during puberty, occurs at 12 years of age in boys and continues till 16 years of age. Change in FO of voice may continue even beyond 16 years of age.

--> The changes in FO of voice in females are not as marked as in the case of males. A drop of only around 9Hz is noted in females during puberty, but the changes were inconsistent across age.

--> Significant differences are noted between rural and urban population; especially in males. The changes in FO of voice start to occur at 12 years in both urban and rural males. But the greatest shift in FO was noted to occur at 13 years in urban males and at 14 years in rural males.

--> Among male children in the pubertal age (12 years and after), there are children in whom the shift in FO of voice is gradual, but faster. There are also children in this age group who show gradual, but slower changes in FO of voice. However, both the groups have almost

the same levels of FO of voice at 16 years. The drop in FO of voice, during puberty (12 to 16 years) was around 100 Hz in boys.

--> Any analysis of voice of children for FO of voice during puberty must take into considerations the back ground (urban or rural), particularly in the case of boys.

Suggestions for further research

--> A similar study, but investigating an extended age range (say upto 20 years) can be carried out for more definite information on the age at which FO of voice stabilizes following pubertal changes.

--> A similar study, but following a longitudinal approach would be much better to generate information on changes of FO of voice.

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