A COMPARISON OF TWO METHODS OF MEASUREMENT OF FUNDAMENTAL FREQUENCY AND INTENSITY VARIATIONS IN NORMALS AND DYSPHONICS

Reg. NO. M. 9002

Dissertation submitted as part fulfilment for the second year

M.Sc. (Speech and Hearing) to the University of Mysore

All India Institute of Speech and Hearing
MYSORE - 570 006

1992

To MY MOTHER

________You mean the "WORLD" to me

to Mr.VENKATESH.C.S.

_______for all that he has taught me

CERTIFICATE

This is to certify that the Dissertation entitled "A COMPARISON OF TWO METHODS OF MEASUREMENT OF FUNDAMENTAL FREQUENCY AND INTENSITY VARIATIONS IN NORMALS AND DYSPHONICS" *is a bonafide work, done in part fulfilment for the Second Year M.Sc. (Speech and Hearing) of the student with* **Reg.No.M9002.**

DR(MISS).S.NIKAM
DIRECTOR
AH India Institute of
Speech and Hearing
MYSORE - 6

MYSORE
1992

CERTIFICATE

This is to certify that the Dissertation entitled: "A COMPARISON OF **TWO METHODS OF MEASUREMENT OF FUNDAMENTAL FREQUENCY AND INTENSITY VARIATIONS IN NORMALS AND DYSPHONICS"** ***has been*** *prepared under my supervision and guidance.*

MYSORE
1992

Mr.C.S.VENKATESH
(GUIDE)
Lecturer,
Dept. of Speech Sciences,
AIISH, MYSORE

DECLARATION

This dissertation entitled **"A COMPARISON OF TWO METHODS OF MEASUREMENT OF FUNDAMENTAL FREQUENCY AND INTENSITY VARIATIONS IN NORMALS AND DYSPHONICS"** *is the result of my own study under the guidance of* **Mr.C.S.VENKATESH,** *Lecturer, Department of Speech Sciences, All India institute of Speech and Hearing, Mysore and has not heen submitted earlier at any other University for any other Diploma or Degree*

MYSORE **Reg.No. M.9002**
1992

ACKNOWLEDGEMENTS

At the outset, I would like to extend my sincere thanks to my teacher and guide **Mr.C.S.VENKATESH,** Lecturer Dept. of Speech Sciences, AIISH, Mysore, for rendering me with invaluable guidance and unfailing support, for being a "PSYCHOLOGICAL BOOST" during the low ebbs in the course of this scientific work I will always be indebted to you for sowing the seeds of patience and perseverance in me and leaving no stone unturned to complete this study

To **Dr.(Miss).S.NIKAM,** Director, AIISH, Mysore, for permitting me to carry out this study.

My sincere thanks to **Dr.N.P.NATARAJA,** Professor and HOD of Speech Sciences, AIISH, Mysore, for permitting me avail the facilities of Speech Sciences Instrumentations.

I WOULD ALSO LIKE TO EXTEND MY THANKS TO:

RAGHU, for sharing his Bank of knowledge, for his helping hands showering its own warmthness on every step of my work.

GANESH & **BALA** for being wonderful friends offering me all support with affection, kindness and encouragement.

JENY, SATYA for their morale support and timely help throughout the course of this study.

SUNITA, BHUVANA,C.S. & SHANTHI for their extended encouragement showered on me.

THARMAR, SOWMYA.N., HARI MAMMA, RAVANAN, RAJKUMAR, SANTOSH, KANNAN, MANOJ, MOHAN, BD, BIRU & NANDU, for their morale support and help

BATRU, MAHADEVA & PANDEY, for providing me with nutritious food during the period of my stay.

My ANNAS, AKKAS, ANNIS, ANAND & KUTTI ANAND, for their silent prayers, blessing, love and financial support for success in all my endeavours.

Mr.RAVISHANKAR, for his patient and Creative programming of this work.

C O N T E N T S

LIST OF TABLES

LIST OF GRAPHS

INTRODUCTION

"Voice is the laryngeal modulation of pulmonary air stream which is further modified by the configuration of vocal tract" (Michael and Wendahl, 1971).

Voice plays an important role in speech communication. The production of voice involves a complex and precise control by the central nervous system of a series of synchronous events in the peripheral phonatory organs namely respiration, phonation and resonation.

Hence, the anatomical and physiological deviation in any of these systems would lead to a voice disorder (dysphonia). The incidence of voice disorder is 0.6% of general population. Nearly 9.8% of cases, who visited the AIISH had voice disorder during 90-91 (AIISH Annual report 90-91). So the clinician should be equipped with an appropriate diagnostic tool which enables him/her to asses and detect the voice disorders as early as possible. The treatment of patients suffering from dysphonia depends upon the ability to assess the type and degree of voice disorder and also to monitor the patient's progress through the treatment.

There have been many attempts over the years to find different voice parameters and objective methods that aid in early detection, diagnosis and treatment of voice disorders. They are acoustic, aerodynamic and perceptual parameters, of which acoustic evaluation ha3 a promising future as a diagnostic tool and in management of voice disorders. Healthy voices have nearly constant pitch, loudness and quality during phonation. On the contrary subjects with the laryngeal dysfunction exhibit variations in frequency and intensity during phonation. Fundamental frequency and intensity measurements are very sensitive to the presence of laryngeal disorders.

Acoustic analysis of the voice signal may be one of the most attractive methods for assessing phonatory function or laryngeal pathology as it is non-invasive, objective and quantitative. Many acoustic parameters derived by various methods have been reported to be useful in differentiating between the pathological voice and normal voice. [Crystal and Jackson (1970), VonLeden and Koike (1970), Koike (1973), Nataraja (1986) and Pinto & Titze (1990)].

Small variations in frequency and intensity ie., cycle to cycle variation in fundamental frequency (pitch perturbation or jitter) and cycle to cycle variation in intensity (amplitude perturbation or shimmer) are shown to be natural ingredients in normal voice (Lieberman 1961). In-fact such perturbations are important for the natural quality of voice. These variation in pitch and amplitude are probably due to the neuro muscular, phonatory control system.

However large perturbation reflect alteration in the normal vibratory pattern of the vocal fold (Von Leden, Moore and Timicke,, 1960) and are often associated with laryngeal dysfunction (Hecker & Kreul 1971). A survey of literature reveals different methods for quantifying waveform perturbation [Lieberman, (1961, 1963), Koike (1973), Kitajima and Gould (1976), Horii (1979), Hurry and Doherty (1980), Askenfelt and Hammeberg (1986) and Higgins & Saxman (1989)].

Several studies have compared pitch and amplitude perturbation measurements between the vowels /a/, /i/ and /u/. These studies have provided contradictory results. Some studies [Zemlin (1962), Johnson and Michal (1969), Wilcox (1978), Sorensen and Horii (1983, 1984) and Linville & Korabic (1987)] have reported difference between vowels in terms of pitch and amplitude perturbation and the studies by Heiberger & Horii (1980) and Horii, (1982) have reported that there is no difference between vowels in terms of pitch and amplitude perturbation.

There are two types of measurements of fundamental frequency and intensity variations.

A) Gross measures

(1) Extent of fluctuation in fundamental frequency (Ex.F.Fo)

(2) Speed of fluctuation in fundamental frequency (Sp.F.Fo)

(3) Extent of fluctuation in intensity (Ex.F.I)

(4) Speed of fluctuation in intensity (Sp.F.I)

B) Fine measures

There are several measures in pitch and amplitude perturbation the few of them mentioned here are:

1) Jitter ratio (JR),
2) Relative Average Perburation (RAP),
3) Shimmer in dB (SHM)
4) Amplitude Perburation Quotient (APQ).

No study is available in literature which have reported the comparisons between these two types of measurementa. However there are few studies which have made an attempt to compare different pitch and amplitude perturbation measures (Hurry and Doherty,1980; Askenfelt and Hammerberg 1986; Higgins and Saxman 1989; and Venkatesh, Sathya & Jeny 1992). Nataraja (1986) has compared the extent and speed of fluctuation in frequency and intensity measures.

There is no uniformity and no standardization in the analysis procedures in the different research reports. Although there is high activity in this field, there is also considerable disparities in the clinical procedure and normative data. These disparities prevent a fair comparison of different perturbation measures to say which of them are identical or superior to each other. Also the studies have used small number of subjects, hence it is difficult to accept the validity and reliability of the normative data provided by them. Hence this study was aimed at developing normative data for the eight different measures of fundamental frequency and intensity variations. They are (a) Gross measures, Ex.F.Fo., Sp.F.Fo., Ex.F.I. and Sp.F.I. (b) fine measures, JR, RAP, SHM and APQ. This study also aimed at comparing the gross and fine measures of fundamental frequency and intensity variations and to find the highly weighted measures to discriminate normals and dysphonics.

The objectives of the present study were:

1) To establish normative data for the following measurements of fundamental frequency and intensity variations.

(i) Measurement of fine variation in fundamental frequency and intensity:

a) Jitter Ratio (JR)

b) Relative Average pitch perturbation (RAP)

c) dB shimmer (SUM)

d) Amplitude Perturbation Quotient (APQ)

(ii) Measurement of Gross variations in fundamental frequency and intensity:

a) Extent of fluctuation in fundamental frequency (Ex.F.Fo)

b) Speed of fluctuation in fundamental frequency (Sp.F.Fo)

c) Extent of fluctuation in intensity (Ex.F.I.)

d) Speed of fluctuation in intensity (Sp.F.I)

2) To identify the significant differences between the three consecutive trials of phonation of /a/, /i/ and /u/ in terms of fundamental frequency and intensity variation measures.

3) To identify the significant differences between the vowels /a/, /i/ and /u/ in terms of fundamental frequency and intensity variation measures.

4) To identify the significant differences between
   (a) Normal males and normal females.
   (b) Normals and Dysphonics.

5) To identify the highly weighted and efficient fundamental frequency and intensity variation measures to differentiate Normals and Dysphonics.

6) To identify the highly weighted and efficient measures between gross and fine fundamental frequency and intensity variation measurements.

REVIEW OF LITERATURE

"Speech is complex motor act brought about by sophisticated and fine movements of the components of the vocal tract and their complex interaction with one another. This result is due to the fine organization, coordination and modulation between the respiratory, phonatory, articulatory and resonatory systems" (Newman, 1963). In other words, the acoustic output that results is marked with the components to speech, namely language, voice, articulation, fluency and prosody. Effective communication is eventually achieved due to a conglomeration of these factors along with the cognitive, psychological and environmental aspects among and between individuals.

Voice is an important component of speech, because it is the carrier of speech wave, which acts like basel note. Michel and Wendahl (1971) define voice as "the larnyngeal modulation of the pulmonary air stream, which is further modified by the configuration of the vocal tract".

The production of voice depends on the synchrony between the respiratory, the phonatory and the resonatory systems. Any anatomical and physiological deviation in any of these systems would lead to a voice disorder. Such a disorder may cause soical, economic and psychological problems to the individual. Therefore, voice problems must be identified a an early stage and treated as early as possible.

"The treatment of patients suffering from dysphonia depends upon the ability to identify early, assessment and diagnosis, and also to monitor the patients subsequent progress throughout the treatment (Kelman, 1981). With regard to diagnosis of voice disorder mainly two methods have been used by many clinicians and researchers. The methods are:

I. Psychoacoustical evaluation (Subjective evaluation)

II. Physioacoustical evaluation (Instrumental evaluation).

I. Psychoacoustical evaluation (Subjective evaluation)

It is the assessment of voice samples through listening by the clinician. It relies on the identification and discrimination capabilities of varying sound complexes by the clinician. Well trained voice clinicians are able to determine the causative pathologies on the basis of psychoacoustical impression of abnormal voices (Takahashi, 1974; Hirano, 1975). Though this method of evaluation is relatively time saving and inexpensive, but, it is subjective. Hence, the inter and intra clinician variabilities are more, which may lead to erroneous diagnostic formulations. It is difficult to measure the degree of disorder and prognosis using this methods.

II. Physioacoustical evaluation (Instrumental evaluation):

This method of evaluation uses various measuring techniques using instruments and procedures which may be invasive or non-invasive, for the measurement of various parameters of voice. It gives an accurate, precise and quantitative account of the voice. In other words, quantitative interpretation regarding the mode of vibration of vocal folds can be obtained. It has an added advantage of uniformity in the diagnostic formulation with respect to the different clinicians and clinical settings. But this method of evaluation may be time consuming and is not an economical method.

The instrumental evaluations describe the voice based on measurements of following parameters:

I) AERODYNAMIC PARAMETERS:

a) Vital capacity

b) Mean air flow rate

c) Phonation quotient

d) Vocal velocity index

e) Maximum phonation duration

f) s/z ratio.

II. ACOUSTIC PARAMETERS:

Acoustic parameters can be divided into fundamental frequency measurements, intensity measurements and spectral measurements.

A. Fundamental frequency related measurements.

1) Fundamental frequency in phonation.

2) Fundamental frequency in speech.

3) Fundamental frequency in reading.

4) Frequency range in phonation.
5) Frequency range in speech.
6) Jitter (Pitch perturbation)
7) Extent of fluctuation in fundamental frequency in phonation.
8) Speed of fluctuation in fundamental frequency.
9) Pitch sigma

B. Intensity related measurement?:

1) Intensity range in phonation.
2) Intensity range in speech.
3) Shimmer (amplitude perturbation).
4) Extent of fluctuation in intensity.
5) Speed of fluctuation in intensity.

C. Spectral Parameters:

1) Alpha ratio: Ratio of intensities between 0-lKhz and above l-5Khz.
2) Beta Ratio: Ratio of intensities of harmonics and the noise in 2-3 KHz.
3) Frequency of first formant.

Hanson, Gerratt and Ward (1983), suggested that majority of phonatory dysfunctions are associated with abnormal and irregular vibrations of the vocal folds. These irregular vibrations leads to the generation of random acoustic energy ie., noise, fundamental frequency and intensity variations. This random energy and aperiodicity of fundamental frequency is percerived by the human ears as hoarseness. The aerodynamic parameters measure the respiratory airflow. They do not provide adequate information regarding the voice and its production. Where as spectral parameters, intensity parameters and fundamental frequency parameters are more appropriate in quantifying the phonatory functions. However, spectral measurements are complex to obtain and the instruementation is highly sophisticated and expensive. Hence, for clinical purposes these measurements are not desirable. Although intensity related measurements are useful in describing the phonatory function and are relatively easy to measure, the values are highly variable. So they have reduced reliability. Among the various intensity related measurement, the measurements of intensity variation are very useful in early identification and assessment of severity of voice disorders. They are:

1) Amplitude perturbation (Shimmer).
2) Extent of fluctuation in intensity.
3) Speed of fluctuation in intensity.

However, the extent and speed of fluctuation in intensity has been found to be a gross measure. Kitajima and Gould (1976), Venkatesh, et.al., (1992) have reported significance of shimmer in the evaluation of voice disorders and also stated that it was technically simpler to measure and calculate.

The fundamental frequency related measurements are the most rugged and sensitive in detecting anatomical and physiological changes in the larynx.

Among the fundamental frequency related measurements, the measurements of fundamental frequency variation are very useful in early identification, assessment of severity and differential diagnosis of dysphonics. They are:

1) Pitch perturbation (Jitter)
2) Extent of fluctuation in fundamental frequency.
3) Speed of fluctuation in fundamental frequency
4) Pitch sigma.

Cycle to cycle variation in fundamental frequency is called pitch perturbation or jitter and cycle to cycle variation in amplitude is called as intensity perturbation or shimmer. Presence of small amount of perturbation in normal voice has been known (Moore and VonLeden, 1958; VonLeden,et.al., 1960). A periodic laryngeal vibratory pattern have been related to the abnormal voice (Carhart, 1938, 1941, Bowler, 1964). Relatively few attempts have been made to note the perturbation in fundamental frequency and intensity, although such a measure may have value in describing the stability of laryngeal control (Liberman, 1963).

Baer (1980) explains vocal jitter as inherent to the method of muscle excitation, based on the neuromuscular model of fundamental frequency and muscle physiology. He has tested his model using EMG from cricothyroid muscle and voice signals, and claims neuromuscular activities as the major contributor for the occurrence of perturbation.

Wyke (1969) Sorenson, Horii and Leonard (1980) have reported the possible role of laryngeal mucosal reflex mechanism in fundamental frequency perturbation. This view of possible role of laryngeal mucosal reflex findings gets support from the studies, where the deprivation or reduction of afferent information from the larynx occured by anesthesizing the laryngeal muscles. This may have reduced the laryngeal mucosal reflex (Wyke, 1967, 1969) and in turn increased the jitter size in sustained phonation (Corenson, et.al., 1970).

According to Heiberger and Horii, (1982) also the mucosal receptors in the larynx are important in maintaining the laryngeal tension, particularly in sustaining high frequency tones. Heiberger and Horii (1981) state that "Physiological intepretation of jitter in sustained phonation should probably include both physical and structural variations and myoneurological variations during phonation. A number of high speed laryngoscopic motion pictures revealed that the laryngeal structures (the vocal folds) were not totally symmertric. Different amounts of mucous accumulates on the surface of the vocal folds during vibration. In addition turbulent airflow at the glottis also causes some perturbations. Limitations of laryngeal servo mechanism through the articular myotitic and mucosal reflex systems (Gould and Okamura 1974, Wyke , 1967) may also introduce small perturbations in the laryngeal muscle tones. Even without the consideration of the reflex mechanisms, the laryngeal muscle tones have inherent perturbation due to the time-staggered activities of motor units, which exists in any voluntary muscle contractions.

VonLeden et.al., (i960) reported that the most frequent observation in pathological conditions is that there is a strong tendency for frequent and rapid changes in the regularity of the vibratory pattern. The variations in the vibratory pattern are accompanied by transient pressure changes across the glottis which are reflected acoustically in disturbance of the fundamental frequency and amplitude patterns. Hence, pitch perturbation and amplitude perturbation values are greater in pathological conditions.

Wilcox (1978); Wilcox and Horii (1980) reported that a greater magnitude of jitter occurs with advancing age and this they atributed to the reduced sensory contributions from the laryngeal mechanoreceptors. However, these changes in voice with age may also be due to physical changes associated with respiratory and articulatory mechanism.

This perturbations in pitch and amplitude can be measured using several parameters. There are different algorithms for the measurements of pitch and amplitude perturbation. Each algorithm has its own advantages and disadvantages. Out of several algorithms a few of them are given below:

I Pitch perturbation measurements:

1) Jitter Ratio (JR) =
(Horii, 1979)

$$\frac{1/(n-1)\left[\sum_{i=1}^{n-1} |p_i - p_{i+1}|\right]}{1/n \sum_{i=1}^{n} p_i} \times 1000$$

2) Jitter Factor (JF) =
(Doherty, Hollien, & Michel, 1973)

$$\frac{1/(n-1) \sum_{i=1}^{n-1} \left[\,|F_i - F_{i+1}|\,\right]}{1/n \sum_{i=1}^{n} F_i} \times 100$$

3) Period variability index (PVI)
(Deal & Emanuel, 1978)

$$= \frac{1/n \left[\sum_{i=1}^{n} (P_i - \overline{P})^2\right]}{\overline{P}^2} \times 1000$$

4) Relative average perturbation (3 point) (Koike, 1973)

$$\text{RAP (3 point)} = \frac{1/(n-2) \left(\left[\sum_{i=2}^{n-1} \left| \frac{p_{i-1} + p_i + P_{i+1}}{3} - p_i \right|\right]\right)}{1/n \sum_{i=1}^{n} p_i}$$

5) Relative average perturbation (5 point) (Koike, 1973)

$$\text{RAP (5 point)} = \frac{\frac{1}{n-2} \sum_{i=2}^{n-1} \left| \frac{p_{i-2}+p_{i-1}+p_i+p_{i+1}+p_{i+2}}{5} - p_i \right|}{1/n \sum_{i=1}^{n} P_i}$$

6) Deviation from linear trend (DLT)
(Ludlow, Coulter and Qentges, 1983)

$$DLT = \frac{\sum_{i=3}^{n-2} \left[\frac{pi+2+pi-2}{2} \right] - pi}{n-4}$$

7) Pitch sigma (PS)

$$P = \sqrt{\sum_{i=1}^{n} (\bar{p}-pi)^2/N}$$

8) Directional perturbation factor (DPF) (Hecker and Kreul, 1971)

It is defined as the percentage of the total number of differences in pitch" period for which there is a change in algebraic sign.

II) Amplitude perturbation measurements:

1) Shimmer (In d B) =
(Horii, 1980)

$$\sum_{i=1}^{n-1} \frac{|20\log (Ai/Ai+1)|}{n-1}$$

2) Amplitude variability index (AVI):
(Deal and Emanuel, 1978)

$$AVI = \frac{\text{Log}10 \quad 1/n\sum_{i=1}^{n}[(Ai-\bar{A})^2]}{\bar{A}^2} \times 1000$$

3) Amplitude perturbation quotient (APQ) (Koike, 1973)

$$APQ = \frac{\frac{1}{n-1} \sum_{i=6}^{n-5} \left| \frac{Ai-5+Ai-4 \;...+Ai+..Ai+4+Ai+5)}{11} - Ai \right|}{1/n \sum_{i=1}^{n} Ai}$$

4) Directional Perturbation Factor for Amplitude (DPF)
(Hecker and Kreul, 1971):

It is defined as the percentage of the total number of differences in amplitude for which there is a change in algebraic sign.

Lieberman, (1963) found that pitch perturbations in normal voice never exceeded 5msecs in the steady state portion of sustained vowels. Similar variations in fundamental periodicity of the acoustic waveform have been measured by Fairbanks (1940).

Iwata and VonLeden (1970) reported that the 95% confidence limits of pitch perturbations in normal subjects ranged from -0.19 to +0.2 msec.

Several factors have been found to effect the values of jitter such as age, sex, vowel produced, frequency and intensities.

Wilcox (1978), Wilcox and Horii (1980) compared the jitters of sustained /a/, /i/ and /u/ produced by young and older adult males. The results showed a significantly greater amount of jitter in sustained phonations of the older adults (0.75%), than was seen in the younger subjects (0.57%). This was attributed to the reduced sensory contributions from the laryngeal mechanoreceptors.

Linville (1988) has reported that the jitter values were larger in old womens than in young children. They also found that the intra subject variability with in one recording session was high for some female speakers.

Higgins and Saxman (1989) reported higher values of frequency perturbation in males than females. Gender difference may exist not only in magnitude, but also in the variability of frequency perturbation.

Sorensen and Horii, (1983) reported that normal female speakers have more jitter than normal male speakers. This result is contradicting the findings of Higgins and Saxman, (1989).

Robert and Baken, (1984) reported higher jitter values in males than females. They attributed this difference to fundamental frequency. When the fundamental frequency increases the percentage of jitter values decreases.

Zemlin, (1962) has reported a significantly greater jitter for /a/ than /i/, and /u/ had lowest value. This result is supportd by the studies of Wilcox (1978) and Linville & Korabic (1987).

Johnson and Michel, (1969) reported greater jitter value for high vowels than low vowels in 12 English vowels.

Wilcox and Horii, (1980) reported that /u/ was associated with significantly smaller jitter (0.55%) than /a/ and /i/ (0.68% and 0.69% respectively).

Sorensen and Horii, (1983) studied the vocal jitter during sustained phonation of /a/, /i/ and /u/ vowels. The result showed that jitter values were low for /a/ with 0.71% high for /i/ with 0.96% and intermediate for /u/ with 0.86%.

Sorensen and Horii, (1984) reported that directional jitter factor values were highest for /u/ and /a/ had lowest and /i/ was intermediate.

Heiberger and Horii, (1980) & Horii, (1982) reported that there is no significant difference between the eight English vowels.

Linville and Korabic, (1987) have found that intra speaker variability tend to be greatest on the low vowel /a/, with less variability on high vowels /i/ and /u/.

The values of the measures of jitter are dependent upon the vowels produced during sustained phonation and also the frequency and intensity level of the phonatory sample and also the type of phonatory initiation and termination.

Horii, (1979) has studied fundamental frequency perturbation in sustained phonation. Subjects were 6 male adults and the middle segment of sustained phonation of /i/ was produced at fundamental frequency ranging from 98 to 298Hz. The results showed that between 98Hz and 210Hz, mean jitter size decreased as the fundamental frequency increased, where as the corresponding jitter ratios remained relatively constant. Above 210Hz, mean jitter remained relatively constant and consequently, the jitter ratio increased as fundamental frequency increased.

Jocob, (1968) found a median jitter of about 0.6% for phonation produced at a comfortable intensity level and he added that jitter magnitudes were dependent on the intensity level and frequency of the particular phonatory sample. The greatest amount of jitter was observed during a sustained /a/ at a low intensity level and a low frequency. This findings was supported by Koike, 1973; Hollien et.al., 1973).

Ramig, (1980) postualated that jitter values should increase when subjects were asked to phonate at a specific intensity, and/or as long as possible.

Several investigators have studied the measures of pitch perturbation in normals and pathological groups. The proposed measurement and their obtained data on pitch perturbation have been summarised in Table-IA & B.

Shimmer in any given voice is dependent at least upon the modal frequency level, the total frequency range and the SPL relative to each individual voice (Michel and Wendahl, 1971) and Ramig, 1980) postulated that shimmer values should increase when subjects are asked to phonate at a specific intensity and/or as long as possible.

Kitajima and Gould, (1976) studied the vocal shimmer during sustained phonation in normal subjects and patients with laryngeal polyps. They found the value of vocal shimmer ranging from 0.04 dB to 0.21 dB in normals and from 0.08 dB

FITCH FERTCRBATION MEASUREMENTS

Investigators	Year	Method	Portia	Horaative Data Males	Feaales	Pathological
-Lieberman VonLeden Moore 4 Ti<ke	1961 1963 1960	Pitch Pertur- bation factors	The Integral of frequency distribu- tion of t>0.5msec.	Ho. 6		Larger than normal speakers at similar pitch level
-Hecker 4 Rreul	1971	Directional Perturbation factors	% of total no. of difference for which there is a change in algebraic sign.	Ho. 5 Phonation		Directional pertur- bation factor was sensitive enough to distinguish between normals & cancer patients.
-Sorensen & Horll		-do-	-do-	/a/ 46.21 /u/ 19.26 /i/ 16.37	18.79 52.77 52.1	
-Horll	1979	Jitter Ratio		Ho. 6 Fo JR 98 5.3 to to 298 7.6		

PITCH PERTURBATION MEASUREMENTS

Investigator:	Year	Method	Formula	Nortmative Data Males	Females	Pathological
Hollien, Michael & Doherty	1973	Jitter factor		No. 1 Phonation .... Fo JE. 102 .18 112 .76 198 .85 276 2.67		
-Hurry & Doherty	1980	-do-		No. 5 115.3 .99		
-Deal & Emanuel	1978	Period Variability index		Ho. 20 7 sec. phonation /u/ .4471 /i/ .4898 /^/ .4196 // .4412 x .4951		
-Koike	1973	Relative Average Perturbation		Mo. 7 Fo RAP. 108.1 .0057	2 Fo RAf 206 .0061	
Takahashi Hoike	1975	Frequency Perturbation quotient				
-Ludlow	1983	Deviation from Linear trend		Mo. 4 sus-tained /a/ 38.4	6 21.71	
Sorensen & Horil	1983	Jitter value		No.		/a/ .71% /i/ .96% /u/ .86% Overall .84%
Robert & Baken	1989	-do-		Mo. 6 Mean value 6.9%	6 2.4%	

Wilcox	1978	-do-	Phonation old & young overall /a/ 7% Jitter /i/ .6% values /u/ .5% overall old .75% young .57%	
Wilcox 4 Horli	1980	-do-	Phonation /a/ .68% /i/ .69% /u/ .55%	
Kane & Wellen	1985	-do-	No. 10	
			Children	Jitter value 0.0023-0.0472msecc
Sridhara	1986	-do-	Mo. 30 30 /a/ .065 .58 (asec) /i/ 11 .03 /u/ .067 .048	
Zyshi, Bull McDonalds Johns	1984	RAP	Ho. 20 RAP 0.0010 -0.0036	52 laryngeal 0.016 to 0.1190
Smith Weinberg Feth & Horii	1978	Jitter ratio Jitter	Ho. 9	mean JR 95.47 range 39.53- 148.88 range 0.65-5.13msec
Robbins	1984	Jitter ratio	Ho. 15 S.D. 0 1 4 01	15 S.D. 0.7 & 0.6
Zajac & Linville	1989	Jitter	No. 5 children 1.20%	VPI 1.61%

Table 1b: Frequency Perturbation for Normal & Disordered Voices

Disorder	Measure	Sex	No.of Subj.	Age Mean	Age S.D.or Range	Normal Mean	Normal S.D.or Range	Disorder Mean	Disorder S.D.or Range
Hoarse	PVI	M	20+20	Adult		0.4807	0.1216	0.8295	0.4783
Tumor	DPF	M	5	63.8	55-71	58.5%	45.8-65.3		
	DPF	M	5	65.2	61.69			64.5%	55.4-76.7
	DPF	M	5	63.2	42.75	33.3%	4.2		
	JF	M	5	63.8	55.71	0.55%	0.76-1.49		
	JF	M	5	65.2	61-69			3.79%	0.77-9.71
	RAP	M	7	27.7		0.0057	0.00134		
	RAP	M	1	50				0.00687	
	RAP	F	2	29.5		0.0061	0.00056		
	RAP	F	1	61				0.2022%	
	RAP	M/F	15	Adult				0.0176	
Paralysis	RAP	M/F	15	Adult				0.0125	
	RAP	M	2	49.5				0.0452	0.0537
Nodules	RAP	M/F	10	10	8.5	6.1-11 .5		0.0123	.0023-.4372
	RAP	M	2	54.5				0.0084	0.00049
	JR	M/F	10	45.3	16-72	5.00 (us)	1.78	9.26 (us)	3.83
	DLT	M/F	10	45.3	16-72	21.71 (us)	11.99	35.76 (us)	12.55
Inflamed	RAP	F	2	36				0.0074	0.00064
Esophageal	PF	M	22	58	36-81			41.1%	8.9-66.8
	JR	M	9	50				95.47	

to 3.23 dB in the case of vocal polyps. Although, some overlap between the two groups was observed they noted that the measured value may be a useful index in screening for laryngal disorder or for diagnosis of such disorders and differentiation between the two groups.

Vowel produced and sex are the two factors effecting shimmer values. These factors have been reported in the literature.

Sorensen and Horii, (1983) reported that normal female speakers have less shimmer than normal male speakers.

Wilcox and Horii, (1980) reported that shimmer values are different for different vowels.

Sorensen and Horii (1983) studied the vocal shimmer during sustained phonation of /a/, /i/ and /u/ vowels. The results showed that shimmer values was lowest for /u/ with 0.19 dB, highest for /a/ with 0.33 dB and intermediate for /i/ with 0.23 dB. This result is supported by Horii (1980).

Sorensen and Horii, (1984) reported that directional shimmer factor values for men was high for /i/ and intermediate for /a/ and for women, /a/ had the highest value and /i/ was intermidiate.

Heiberger and Horii, (1980) and Horii, (1982) reported that there is no significant difference between the eight English vowels.

Several investigators have studied the measures of amplitude perturbation in normal and pathological groups. The proposed measurement and their obtained data on amplitude perturbation have been summarized below in Table-2.

The extent & speed of fluctuation in Frequency & intensity are also one of the fundamental frequency and intensity variation measurements. The fluctuations in frequency and intensity in phonatlon sample may indicate the physiological (neuromuscular) or pathological changes in the vocal mechanism.

Kim, Kakita and Hirano, (1982) have analyzed tempanese /u/, /o/, /e/ /a/ and /i/ vowels. This was earlier analyzed by Imaizumi, (1980) using the spectrography in 10 voices of patients with recurrent laryngeal nerve paralysis and 10 normals to obtain the following acoustic parameters.

The acoustic parameters obtained from the spectrographs were:

Extent of fluctuation in fundamental frequency:

The extent of fluctuation was defined as the percent score of the ratio of the peak to peak value of fluctuation (ΔFo) to the mean fundamental frequency (Fo).

2) Speed of fluctuation in fundamental frequency:

This has been defined as the number of positive peaks within isec.

3) Extent of fluctuation in intensity:

This has been defiend as the peak to peak value in decibels measured on an average amplitude display.

TABLE 2. SHIMMER MEASURSMENIS

Investi-gators	Year	Method	formula	Normative Data Males	females	Pathological
-Hecker & Kreul	1971	Directional Perturba-tion factor				
-Sorensen & Horii	1984	-do-		No. 20 Age. 25-19 years /a/ 59.46 /u/ 58.91 /i/ 61.63	20 63.13 59.76 61.71	
-Deal & Emaneul	1978	Amplitude variability index		No. 20 /u/ -.1287 /i/ -.1330 /^/ -.0389 // -.0619 // -.216 overall-.0768		20 males with hoarse voice .4142 .5707 .5977 .2163 .5876 .3908
-Horii	1980b	Shimmer in dB		No. 31 /a/ -17 /i/ .37 /u/ .33 overall .39	20 .33 .23 .19 .25	
-Takahashi & Koike & Calcaterra	1975 1977	Amplitude perturbation quotient		No. 7 Fo. APQ 108.140.3	2 Fo. APQ 206 32.9x10.9	
-Davis	1976 1979 1981	-do- window size five		No. 8 120 5.97	2 206 6.81	
Sridhara	1986	Shimmer		No. 30 in dB /a/ 0.033 /i/ 0.066 /u/0.15	30 0.7 0.37 0.44	
Zyski Bull McDonald & Johns	1984	-do-		No. 20 0.89 to 11.84		
Zajac & Linville	1989	-do-		No. 5 1.66%		VPI 2.27%

4) Speed of fluctuation in intensity:

This was defined as the number of positive peaks on an amplitude display within 1 sec. Peaks of 3dB or greater from adjacent throughs have been counted.

The results of this study have indicated that among the acoustic parameters studied, significant difference were found between the control and the diseased groups in terms of fluctuation of fundamental frequency.

Yoon, Kakita and Hirano, (1984) have studied the voice of paients with glottic carcinomas, using the same procedure and the parameters as described by Kim et al., (1982). They have concluded that significant differences were found between the normals and patients with advanced carcinomas in terms of extent of fluctuation in fundamental frequency, speed of fluctuation in fundamental frequency, extent of amplitude fluctuation and speed of amplitude fluctuation. Rashmi, (1985) has concluded that,

The fluctuations in frequency of the initial and final segments of phonation of /a/, /i/ and /u/ showed a decreasing trend with age in males.

The 14 to 15 year old group showed an increase in the range of fluctuations for all the vowels.

In females, there was a decrease in the extent of fluctuations in frequency of the initial and final segments upto the age of nine years, an increase in the extent of fluctuations in the nine to eleven year old females, which again drops down till the age of 15 years.

The medial segment of phonation, both males and females was quite steady, and the extent of fluctuation as a function of age did not show much difference.

No difference in the extent of fluctuation in frequency between males and females was observed in the younger age groups.

The males consistently showed greater fluctuations in frequency in the phonation of /a/, /i/ and /u/ than the females of 14 to 15 year old group.

The fluctuations in the initial and final segments of phonation for all the three vowels was greater than the fluctuations in the medial segment for both males and females.

The fluctuations in intensity did not show any systematic trend for any vowels both in males and females. However the initial segment of phonation showed a significantly longer fluctuations in intensity in the above 12 year groups, in the case of males, for all three vowels.

Vanaja, (1986); Tharmar (1991) and Suresh (1991) have reported that as the age increased there was increase in fluctuations in frequency and intensity of phonation and this difference was more marked in females.

Nataraja (1986) has found that speed of fluctuation in fundamental frequency and extent of fluctuation in intensity parameters were sufficient to differentiate the dysphonics from the normals. He has given definitions for extent and speed of fluctuation in fundamental frequency and intensity. They are mentioned below.

The extent of fluctuation in frequency was defined as the means of fluctuation in fundamental frequecy in phonation of one second.

Fluctuation in frequency was defined as variations +. 3H2 and beyond in fundamental frequency.

The speed of fluctuation in frequency was defined as the number of fluctuations in fundamental frequency in a phonation of one second.

The extent of fluctuation in intensity was defined as the means of fluctuations in intensity in a phonation of one second.

Fluctuation in intensity was defined as variations ± 3dB and beyond in intensity.

The speed of fluctuation in intensity was defined as the number of fluctuations in intensity in phonation of one second.

Nataraja, (1986) has given normative data for extent and speed of fluctuation in frequency and intensity in normal males, normal females and dysphonics.

Table-3: Normative data for extent & 3peed of fluctuation in frequency & intensity

Measures	Normal males	Normal females	Disphonics males	Disphonics females
	/a/	/a/	/a/	
Ex.F.Fo.	3.89 (1.69)	3.56 (1.70)	28.90 (17.85)	24.79 (17.34)
Sp.F.Fo.	6.2 (4.53)	6.19 (4.1)	47.59 (24.60)	48.31 (26.58)
Ex.F.I.	2.45 (1.82)	1.59 (170)	3.27 (144)	4.24 (2.91)
Sp.F.I.	1.4 (1.4)	1.0 (1.15)	6.88 (5.68)	6.54 (5.01)

An attempt has been made to determine the most effective way of calculating jitter and shimmer perturbations among the various measures of pitch and amplitude perturbation. Such studies have been mentioned below:

Lieberman, (1961, 1967) has shown that pathological voices generally have large perturbation factors than normal voices with comparable fundamental frequency and that this factor is sensitive to size and location of growths in larynx. Pitch perturbation factor was defined as the relative frequqency of occurence of perturbation larger than 0.5msec.

Hecker and Kreul, (1971) found that directional perturbational factor was a more effective parameter than magnitude perturbation factor in differntiating normals from pathological groups.

Kitajima and Gould, (1976) have found that vocal shimmer is a useful parameter for the differentiation of normals and vocal cord polyp groups.

Hurry and Doherty, (1980) found that directional perturbation factor was the single most effective parameter for separating two groups of five normals and five laryngeal cancer patients and discriminant function analysis showed that jitter measures, magnitude perturbation deviation, standard deviation for fundamental frequency and mean fundamental frequency where the 2nd, 3rd and 4th respectively to discriminate between groups.

Askenfelt and Hammerberg, (1986) combined seven acoustic measures of cycle to cycle variation in speech from 41 voice cases before and after voice therapy. Standard deviation of distribution of relative frequency difference (DFo) was suggested as the most useful acoustic measure of waveform perturbation for clinical application.

Higgins and Saxman (1989) investigated with in subject variation of 3 vocal frequency perturbation indices over multiple sessions for 15 female and 5 male normal young adults (pitch perturbation quolient and directional perturbation factor). Co-efficient of variation for pitch perturbation quotient and directional perturbation factor were considered indicative of termporal stability of these measures. While jitter factor and pitch perturbation quotient provided redundant information about laryngeal behaviour Also jitter factor and pitch perturbation quotient varies considerably with in the individual across sessions, while directional perturbations factor was a more termporally stable measures.

Venkatesh, et.al, (1992) reported jitter ratio (JR), relative average perturbation. 3 point (RAP3), deviation from linear trend (DLT), shimmer in dB (SHM) and amplitude perturbation quotient (APQ) to be most effective parameters in differentiating between normal males, normals females and dysphonic groups. They added that in the clinical application shimmer in dB is most effective and can act like a quick screening device and in pitch perturbation measures like jitter ratio (JR), relative average perturbation (3 point) and deviation from linear trend (DLT) are most useful in differentiating laryngeal disorders. This was based on discriminant function analyses of 12 parameters of pitch and amplitude perturbation.

Based on the review of studies it can be inferred that pitch and amplitude perturbation measurements and extent and speed of fluctuation in frequency and intensity can effectively be used in detecting and differentiating laryngeal pathologies and also differentiating normal males, normal females and pathological groups. However there are no experimental studies which have compared Pitch and Amplitude perturbation measurements with Extent and Speed of fluctuation in frequency and intensity measurements. Hence, present study aims to compare the measures of Pitch & Amplitude perturbation and Extent & Speed of fluctuation in frequency and intensity and to identify the most effective and useful of the groups.

METHODOLOGY

SUBJECTS:

Thirty normal adult males and thirty adult females ranging from 17 to 35 years, served as subjects. None of the subjects had any speech and hearing problem and all were free from cold or sinus problem at the time of the experiment. Twenty male dysphonics and ten female dysphonics with age range 16 to 62 years constituted the pathological group. Laryngological examinations of the 30 dysphonics was performed using fibreoptic laryngoscope by a laryngologist. The diagnosis represented in the voice sample showed organic disorder for a majority of patients. The patients not exhibiting organic disorders (4 cases) had functional dysphonia. Details of the diagnosis are provided in Table-4.

Table-4: Subject details.

No.	Laryngeal Disorder	Males	Females	Total
1	Vocal nodule	1	3	4
2	Vocal polyp	8	3	11
3	Glottic chink	4	1	5
4	V.C. paralysis	2	-	2
5	Laryngitis	1	3	4
6	Over hanging epiglottis	1	-	1
7	Ventricular dysphonia	2	-	2
8	Diplophonia	1	-	1
	Total	20	10	30

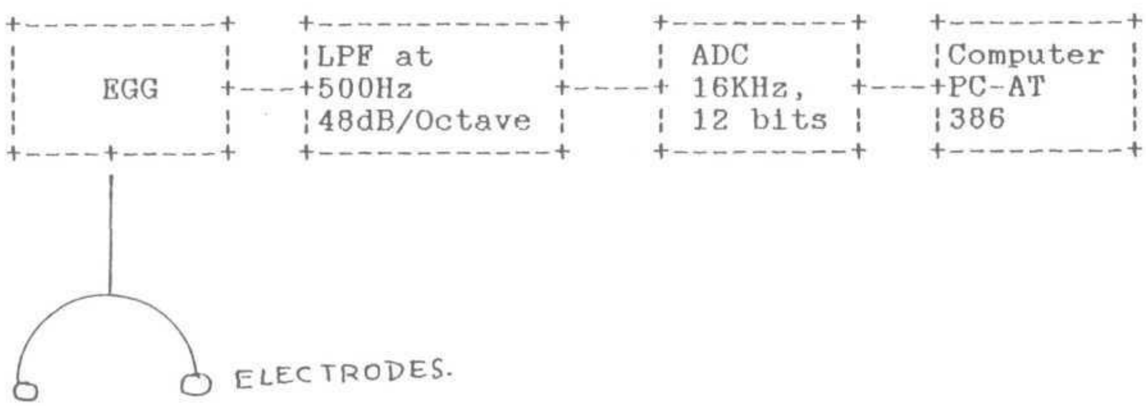
MATERIAL FOR VOICE SAMPLE

The subjects were instructed to phonate vowels /a/, /i/ and /u/ with in 55-60 dB SPL for 5 seconds. It was emphasized that the subject keep his voice as steady as possible at a comfortable and constant pitch and intensity.

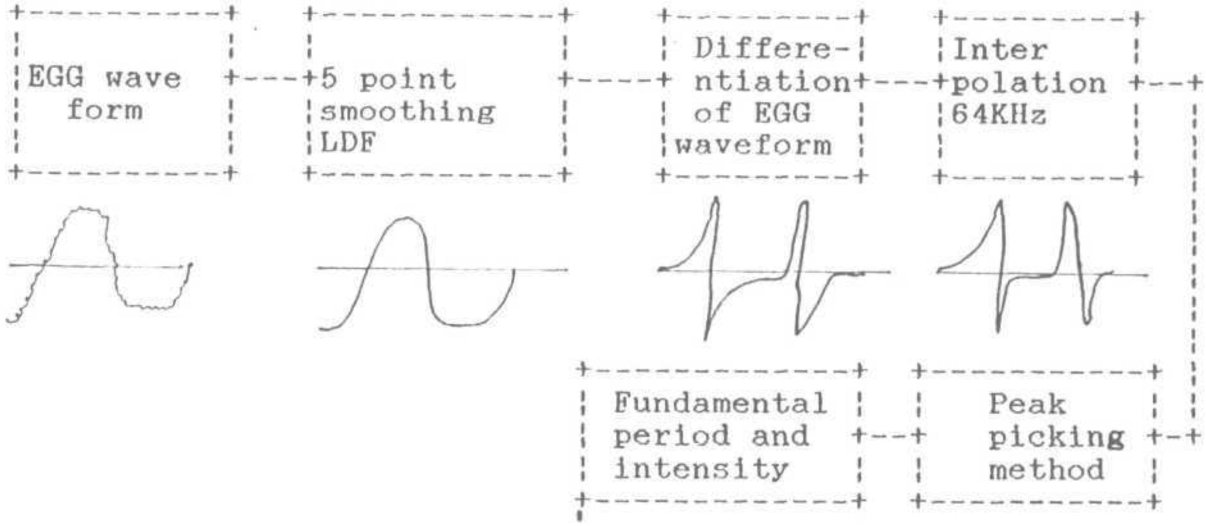
Three trials of phonation of each vowel, that is, totally nine phonations of 5 seconds each were taken for the measurment of fundamental frequency and intensity variation.

RECORDING

The subjects were seated comfortably and the voice source recording was done using the electroglottography (EGG-Kay Laryngograph 80138). The electrodes of the EGG wave placed on the thyroid lamina of the subjects and they were asked to phonate vowels /a/, /i/ and /u/ for 5 secs. Three trials of phonation at each vowel was obtained. Prior instructions were given to the subjects as to not to move their head or neck during phonation. The Kay laryngograph was used to obtain the EGG waveform during phonation. Digitization of the EGG waveforms was done with a sampling frequency of 16 KHz using a 12 bit ADC card. The digitized EGG wave forms of phonation were stored in a PC-AT 386 and were used for the fundamental frequency and intensity variation analysis.



BLOCK DIAGRAM OF INSTRUMENTAL SET UP



EXTRACTION OF FUNDAMENTAL PERIOD AND INTENSITY

FUNDAMENTAL FREQUENCY AND INTENSITY VARIATION ANALYSIS:

This analysis was carried out with the help of a computer programme called "JTSHM" developed by Voice and Speech Systems, Bangalore. Middle three seconds of the digitized EGG wave forms were used for extraction of fundamental frequency using digital PC-AT 386. The EGG wave forms were initially passed through a low pass digital filter having a cut off frequency of 500Hz. The filtered waveforms were then differentiated and then interpolated to 64KHz. Peak picking method was used to extract cycle to cycle fundamental period from these differentiated, interpolated waveforms.

The following algorithms were used to obtain fundamental frequency and intensity variation values from the fundamental period data with help of digital computer PC-AT-386.

Fundamental frequency variations:

a) Fine measures:

1) Jitter Ratio (JR) = (Horii, 1979)

$$JR = \frac{1/(n-1)\left[\sum_{i=1}^{n-1} |pi - pi+1|\right]}{1/n \sum_{i=1}^{n} pi} \times 1000$$

2) Relative average perturbation (3 points): (Koike 1973)

RAP (3 points)

$$\frac{1/(n-2)\left(\left[\sum_{i=2}^{n-1}\left|\frac{pi-1 + pi+Pi+1}{3} - pi\right|\right]\right)}{1/n \sum_{i=1}^{n} pi}$$

b) Gross measures:

3) Extent of fluctuation in fundamental frequency:

It was defined as the mean of fluctuation in fundamental frequency in a phonation of one second. It was also defined as variations j_ 3Hz and beyond in fundamental frequency.

4) Speed of fluctuation in fundamental frequency:

It was defined as the number of fluctuation in fundamental frequency in a phonation of one second.

Amplitude variation measurements:

a) Fine measures:

1) Shimmer (In dB) = (Horii, 1980)

$$\sum_{i=1}^{n-1} \frac{|20\log(Ai/Ai+1)|}{n-1}$$

2) Amplitude perturbation quotient (APQ) (Koike 1973)

$$APQ = \frac{\frac{1}{n-10}\sum_{i=6}^{n-5}\left|\frac{Ai-5+Ai-4 \ldots +Ai+ \ldots Ai+4+Ai+5)}{11} - Ai\right|}{1/n \sum_{i=1}^{n} Ai}$$

b) Gross measures:

3) Extent of fluctuation in amplitude:

It was defined as the mean fluctuations in intensity in phonation of one second. It was also defined as variations ±. 3 dB and beyond in intensity.

4) Speed of fluctuation in amplitude:

It was defined as the number of fluctuations in intensity in a phonation of one second.

STATISTICAL ANALYSIS

The eight acoustic fundamental frequency and intensity variation measures described above ware compared for each of the thirty normal adult males, thirty normal adult females and thirty dysphonic patients, using the following statistical measures:

a) Descriptive statistics

b) T-test

c) Analysis of variance (ANOVA).

d) The ability of fundamental frequency and intensity variation measures to discriminate between normal males, normal females and pathological voice quality was estimated using a linear discriminant function analysis.

RESULTS AND DISCUSSION

The objectives of the present study were:

1) To establish normative data for the following measurements of fundamental frequency and intensity variations.

(i) Measurement of fine variations in fundamental frequency and intensity:

a) Jitter Ratio (JR)
b) Relative Average pitch perturbation (RAP)
c) dB shimmer (SHM)
d) Amplitude Perturbation Quotient (APQ)

(ii) Measurement of Gross variations in fundamental frequency and intensity:

a) Extent of fluctuation in fundamental frequency (Ex.F.Fo.)
b) Speed of fluctuation in fundamental frequency - (Sp. F.Fo.)
c) Extent of fluctuation in intensity (Ex.F.I.)
d) Speed of fluctuation in intensity (Sp.F.I)

2) To identify the significant differences between the three consecutive trails of phonation of /a/, /i/ and /u/ in terms of fundamental frequency and intensity variation measures.

3) To identify the significant differences between the vowels /a/, /i/ and /u/ in terms of fundamental frequency and intensity variation measures.

4) To identify the significant differences between

(a) Normal males and normal females.
(b) Normals and Dysphonics.

5) To identify the highly weighted and efficient fundamental frequency and intensity variation measures to differentiate Normals and Dysphonics.

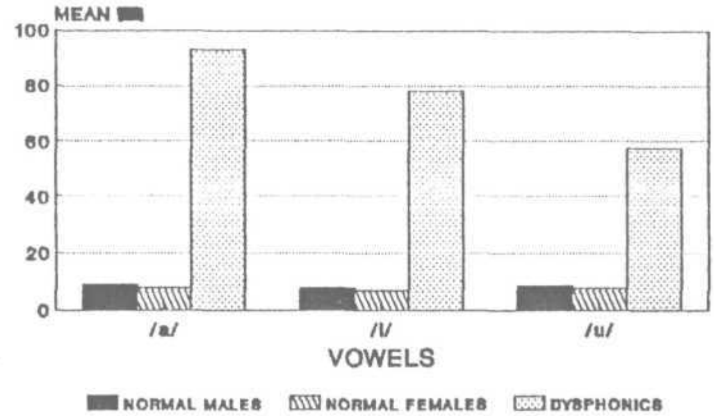
6) To identify the highly weighted and efficient measures between gross and fine fundamental frequency and intensity variation measurements.

OBJECTIVE-1

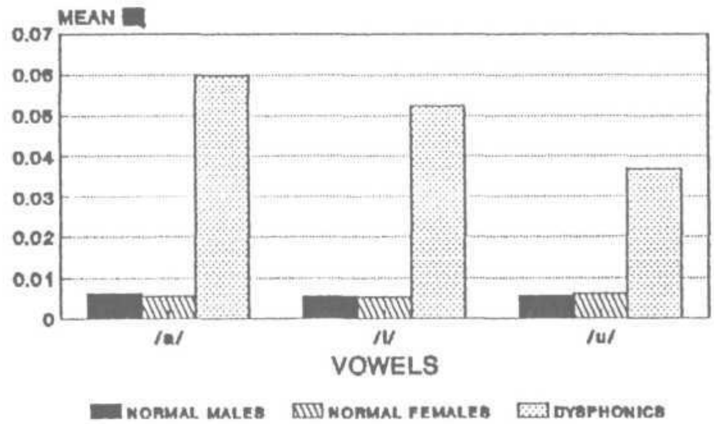
The normative data in terms of the mean and SD for each of the three groups (i.e., males, females and dysphonics) and each of the eight fundamental frequency and intensity variation measurements are presented in Table-5,6 & 7. The Graphs-1 to g depicts the mean values of each of the fundamental frequency and intensity variation measurements across vowels (/a/, /i/ and /u/) and subjects (normal males, normal females and dysphonics). These values and graphs show that the fundamental frequency and intensity variation measure were higher in dysphonics than the normals. The variation in these measures was also higher (indicated by S.D.) in dysphonics. This indicates that these fundamental frequency and intensity variation measures are different in normals and dysphonics.

The normative data provided by the present study was in good agreement with the study by Venkatesh et al., (1992) for the fine measures of fundamental frequency and intensity variations. Similarly, the normative data, for the gross measures of fundamental frequency and intensity variations, correlates well with the normative data provided by Nataraja, (1986).

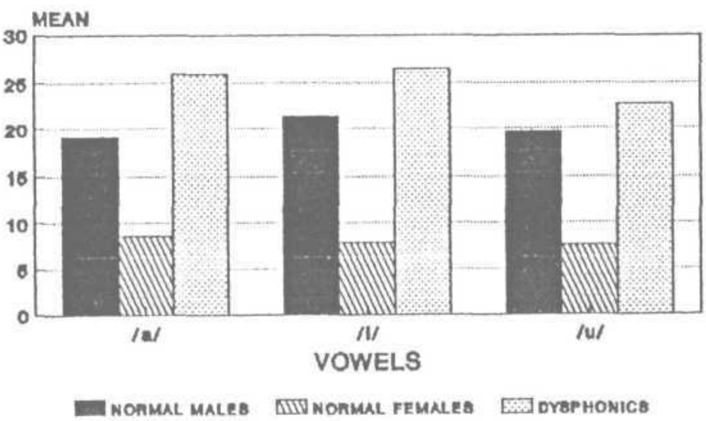
GRAPH-1: MEAN VALUES OF JITTER RATIO FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



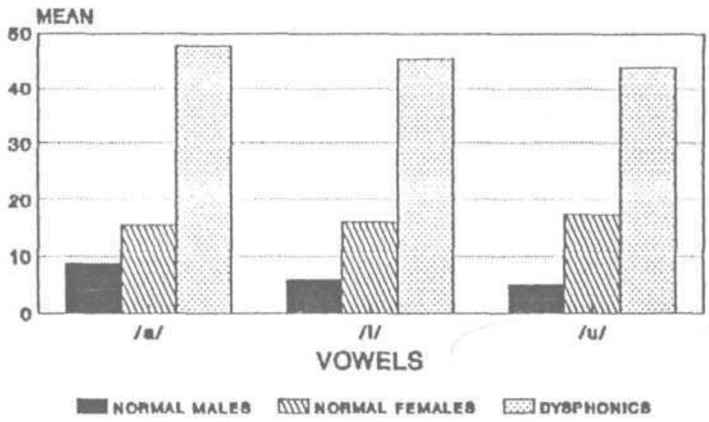
GRAPH-2: MEAN VALUES OF RAP FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



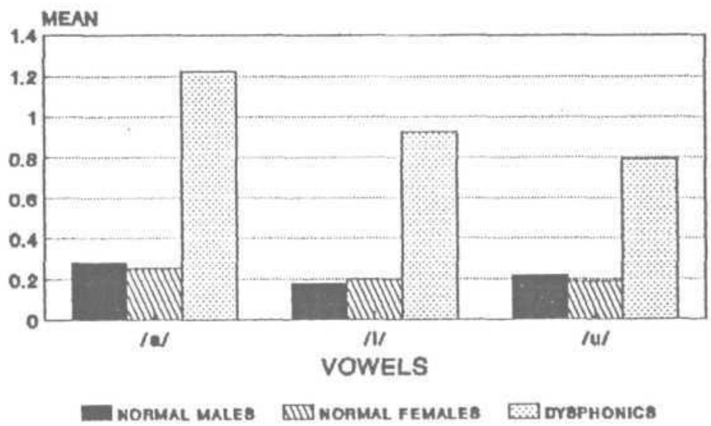
GRAPH-3: MEAN VALUES OF EX.F.Fo. FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



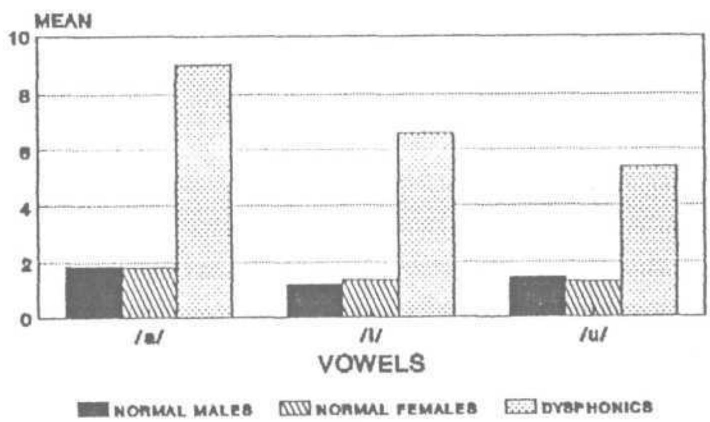
GRAPH-4: MEAN VALUES OF Sp.F.Fo. FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



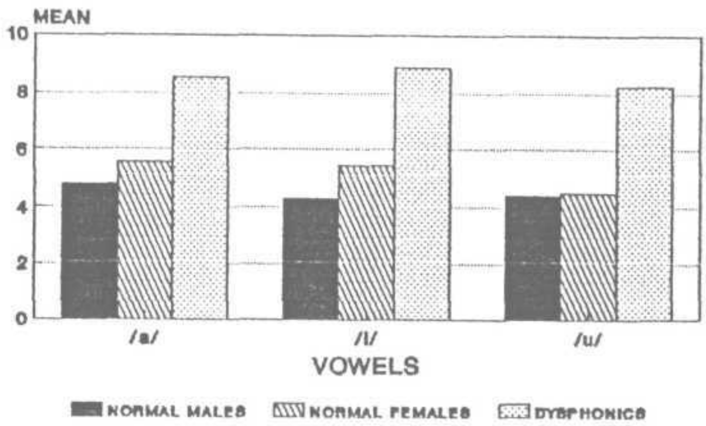
GRAPH-5: MEAN VALUES OF SHM FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



GRAPH-6 MEAN VALUES OF APQ FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



GRAPH-7: MEAN VALUES OF Ex.F.I. FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/



GRAPH-8: MEAN VALUES OF Sp.F.I. FOR NORMAL MALES, NORMAL FEMALES AND DYSPHONICS ACROSS VOWELS /a/, /i/ & /u/

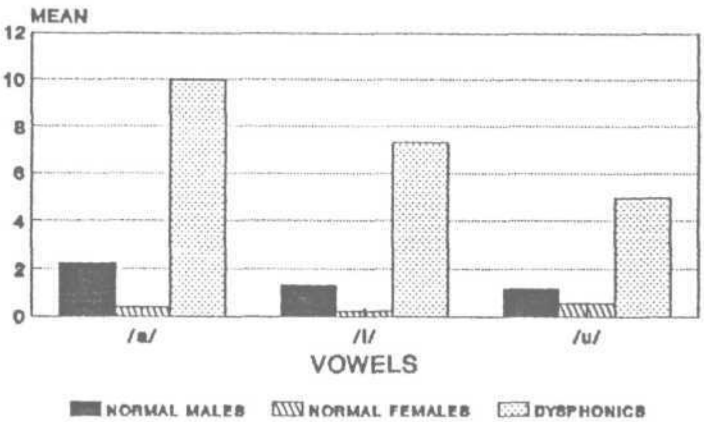


TABLE-5 Mean & SD for eight measures of fundamental frequency and intensity variations in normal male3

Measures	Normal males /a/	/i/	/u/
1. Fo	122.12 (12.46)	128.52 (13.45)	131.69 (14.06)
2. JR	9.172 (4.28)	7.823 (2.322)	8.5005 (5.265)
3. RAP	0.0062 (0.003)	0.0054 (0.001)	0.0058 (0.003)
4. Ex.F.Fo	19.13 (14.97)	21.28 (15.99)	19.62 (12.07)
5. Sp.F.Fo.	8.73 (15.06)	5.85 (13.32)	4.99 (1o.6o)
6. SHM	0.28 (0.262)	0.1747 (0.074)	0.215 (0.179)
7. APQ	1.873 (1.794)	1.1703 (0.528)	1.427 (1.077)
8. Ex.F.I.	4.812 (2.93)	4.28 (4.28)	4725 (3.905)
9. Sp. F.I.	2.23 (6.053)	1.28 (6.55)	1.112 (3.265)

TABLE-6 Mean & SD for eight measures of fundamental frequency and intensity variations in normal females

Measures	Normal females /a/	/i/	/u/
1. Fo	231.31 (20.56)	239.43 (20.24)	244.77 (23.69)
2. JR	8.0597 (1.69)	7.149 (1.84)	7.81 (1.98)
3. RAP	0.0058 (0.000)	0.0053 (0.001)	0.0061 (0.006)
4. Ex.F.Fo	8.5508 (4.59)	7.769 (4.171)	7.475 (2.306)
5. Sp.F.Fo.	15.42 (6.69)	16.071 (11.95)	17.299 (9.21)
6. SHM	0.253 (0.113)	0.1977 (0.090)	0.1848 (0.094)
7. APQ	1.799 (0.839)	1.367 (0.625)	1.295 (0.658)
8. Ex. F.I.	5.58 (5.82)	5.429 (7.95)	4.5392 (6.332)
9. Sp. F.I.	0.309 (0.488)	0.2312 (0.306)	0.5392 (2.944)

TABLE-7 Mean & SD for eight measures of fundamental frequency and intensity variations in dysphonics.

Measures	Dysphonics /a/	/i/	/u/
1. Fo	162.81 (43.36)	172.19 (48.74)	170.91 (48.99)
2. JR	93.38 (112.45)	78.07 (120.36)	57.69 (94.68)
3. RAP	0.0595 (0.07)	0.0522 (0.08)	0.037 (0.059)
4. Ex.F.Fo	25.94 (27.78)	26.59 (30.64)	22.77 (28.35)
5. Sp.F.Fo.	47.51 (31.19)	45.22 (33.22)	43.54 (29.7)
6. SHM	1.2204 (1.221)	0.9235 (0.776)	0.7928 (0.693)
7. APQ	9.044 (11.75)	6.598 (6.468)	5.362 (4.929)
8. Ex. F.I.	8.812	8.89 1. 017)	6.27 (7.22)
9. Sp. F.I.	9.977 (13.76)	7.335 (10.83)	4.96 (8.27)

OBJECTIVE-2

Eight one-way ANOVA tests were conducted to determine the significant differences between the means of three trials of phonation of /a/, /i/ and /u/ vowels. The obtained F-value is shown in Table-8.

TABLE-8: F-values and their significance of the measures of fundamental frequency and intensity variations across three trials for vowel /a/, /i/ and /u/

Measures	/a/ F-values		/i/ F-values		/u/ F-values	
JR	1.23	N.S	2.04	N.S	1.14	N.S
RAP	0.76	N.S	1.49	N.S	1.08	N.S
SHM	1.78	N.S	1.23	N.S	1.45	N.S
APQ	2.01	N.S	1.53	N.S	1.76	N.S
EX.F.Fo	2.12	N.S	2.10	N.S	1.98	N.S
SP.F.Fo	0.85	N.S	0.95	N.S	1.06	N.S
EX.F.I.	1.96	N.S	1.78	N.S	1.83	N.S
SP.F.I	0.96	N.S	0.81	N.S	0.78	N.S

S = Significant, NS = Not significant at 0.05 level

Further, individual T-tests were conducted to determine the significant differences, across the trials for each measures of fundamental frequency and intensity variation and for each vowels.

The F-values indicate that there was no significant difference between trails in terms of the means of fundamental frequency and intensity variation measures. Hence, the scores on each trials were added. The sample size was increased to 90 from 30. This study agrees with the findings of Venkatesh et al., (1992).

It can be concluded that during the diagnostic formulation, it is not necessary to have more number of trials for the measurement of fundamental frequency and intensity variation. Because, the reliable and valid measurements can be obtained from the analysis of single trial only.

OBJECTIVE-3

The significance of mean difference between vowels (/a/, /i/ and /u/) in terms of the fundamental frequency and intensity variation measures were determined by using two-way ANOVA. The Table-9 depicts the F-values for each measure of fundamental frequency and intensity variation.

TABLE-9: F-value and significance of the measures of fundamental frequency and intensity variation across the vowel /a/, /i/ and /u/

Measures	F-value	Probability	
JR	2.50	0.0826	NS
RAP	2.34	0.0975	NS
SHM	8.83	0.0002	S
APQ	7.56	0.0006	S
Ex.F.Fo.	0.73	0.4814	NS
Sp.F.Fo.	0.67	0.5110	NS
Ex. F.I.	2.07	0.1274	NS
Sp.F.I.	5.20	0.0057	S

S = Significant; NS = Not significant

The F values in Table-9, indicates that there was significant difference between the vowel (/a/, /i/ and /u/) only for (1) SHM (2) APQ and (3) Sp.F.I.

For rest of the measures, namely (1) JR, (2)RAP, (3)Ex.F.Fo, (4) Sp.F.Fo and (5) Ex.F.I., there was no significant mean difference between vowels. Individual T-test also indicated that there was no significant mean difference between vowels for the measures of fundamental frequency variations.

Zemlin, (1962), Johnson and Michel,(1969), Sorensen and Horii, (1983) and Horii, (1986) reported significantly different pitch and amplitude perturbation values between the vowels /a/, /i/ and /u/. Sorensen and Horii, (1984) reported the same finding for directional perturbation factor. However, Heiberger and Horii, (1980) and Horii, (1982) found no significant difference between eight English vowels for the measures of pitch and amplitude perturbation.

In the present study only measures of intensity variation reflected a significant difference between vowels. This can be attributed to the lip radiation. Which is more for /a/ than /i/ and /u/ and also it is an established fact that lip radiation contributes to intensity of signal, hence, varying vowel intensity for different vowels. At the same time each vowels have different intra-oral breath pressure, vowel /a/ having less intra oral breath pressure, whereas vowel /u/ has high intra oral breath pressure. Thus varying intra-oral breath pressure alters the sub-glottal breath pressure, which in turn leads to change in vowel intensity.

OBJECTIVE-4(a):

In order to find the significance of mean difference between normal males and normal females, the data was subjected to one-way ANOVA. The Table-10 depicts the F-values for each measure of fundamental frequency and intensity variations across normal males and normal females.

Table-10: F-values, Probability and significance of the measures of fundamental frequency and intensity variation across normal males and females.

Measures	F-value	Probability	
JR	8.80	0.0030	S
RAP	0.05	0.8162	NS
SHM	0.77	0.3790	NS
APQ	0.00	0.9698	NS
Ex.F.Fo.	176.98	0.0000	S
Sp.F.Fo.	96.87	0.0000	S
Ex. F.I.	14.45	0.0001	S
Sp. F.I.	10.84	0.0010	S

N = Significant; NS = Not significant

The F-values indicate that there was a significant mean difference between normal males and normal females for the gross measures of fundamental frequency and intensity variations (Ex.F.Fo., Sp.F.Fo, Ex.F.I, Sp.F.I.) and Jitter Ratio. Majority of the fine measures of fundamental frequency and intensity variations (RAP, SHM and APQ) did not show any significant difference between the means.

The difference can be attributed to the procedural difference in calculating gross and fine measures of fundamental frequency and intensity variations. In fine measures of fundamental frequency and intensity variations the perturbation values were normalized by dividing them by the mean fundamental frequency and mean intensity. This normalization process neutralizes the effect of large variation in fundamental frequency and intensity.

Whereas in gross measures of fundamental frequency and intensity variations, this normalization process was not present. Hence there was significant difference between males and females in terms of Ex.F.Fo., Sp.F.Fo, Ex.F.I and Sp.F.I.

The present study is in agreement with the studies of Robert and Baken, (1984), Higgins and Saxman, (1989). They reported higher values of frequency perturbation in males than females. However, Sorensen and Horii, (1983) reported that normal females have more jitter than normal males. This result was not in agreement with the studies of Robert and

Baken, (1989), Higgins and Saxman, (1989). The result of the present study shows higher shimmer values in males than females. These results are in consonance with the results of Sorensen and Horii, (1983), Horii, (1980) and Takahashi & Koike, (1975).

OBJECTIVE 4(b)

To find the significance of mean difference between normals and dysphonics the data was subjected to Two-way ANOVA and the table-11 depicts the F values for each measures of fundamental frequency and intensity variations across normals and dysphonics.

TABLE-11: F value, probability and significance of the measures of fundamental frequency and intensity variation across normals and dysphonics

Measures	F-value	Probability	
JR	207.08	0.000	S
RAP	204.17	0.000	S
SHM	336.27	0.000	S
APQ	227.70	0.000	S
Ex.F.Fo	59.23	0.000	S
Sp.F.Fo	484.04	0.000	S
Ex.F.I.	13.87	0.001	S
Sp.F.I.	139.25	0.000	S

S = Significant

The fundamental frequency and intensity variations were very high in dysphonics when compared to normals. The difference between normals and dysphonics were highly significant as shown in the Table-11.

This finding of significantly higher fundamental frequency and intensity variations in this study is in accordance with VonLeden et al., (1960), Lieberman, (1961, 1963), Hecker and Kreul, (1971), Kitajima and Gould, (1976) Deal and Emaneul, (1978), Murry and Doherty, (1980), Askenfelt and Hammerberg, (1986), Nataraja, (1986), Higgins and Saxman, (1989) and Venkatesh et al., (1992).

This higher level of fundamental frequency and intensity variations in dysphonics may be due to

a) Lack of neural control over vocal cord (Wilcox 1978; Baer, 1980; Wilcox and Horii, 1980).

b) Irregular laryngo mucosal reflex (Wyke, 1967, 1969; Gould and Diammara, 1974; Sorensen et al, 1980; and Heiberger and Horii, 1982).

c) Turbulent airflow through glottis (Vonleden et al, 1960; Heiberger and Horii, 1981).

OBJECTIVE-5

To achieve this objective, the data was subjected to a linear discriminant function analysis. The results are provided in Tables-12, 13 and 14.

TABLE-12: Classification matrix of normals and dysphonics based on eight measures of fundamental frequency and intensity variations.

	Predicated (Total)	Predicated (Normals)	Predicated (Dysphonics)
Actual (Total)	810	611	199
Actual (Normals)	540	511	29
Actual (Dysphonics)	270	100	170
Percent reduction in classification error due to X's			68.1

TABLE-13: Linear discriminant function of Normals and dysphonics across eight measures of fundamental frequency and intensity variations

Measures	Normals	Dysphonics
JR	-0.010169	-0.017017
RAP	-11.12345	10.42011
SHM	1.167268	3.272565
APQ	-0.034393	-.1160864
Ex.F.Fo	0.061692	0.053157
Ex.F.I.	0.1092674	0.072334
Sp.F.Fo	0.037225	0.095928
Sp.F.I.	-0.086461	-.1059293

TABLE-14: Variable selection report of the linear discriminant function analysis across eight measures of fundamental frequency and intensity variations.

Variable	F-Val	F-Prob
Sp.F.Fo	97.8	0.0000
SHM	38.9	0.0000
Ex.F.I	6.9	0.0088
APQ	4.6	0.0319
RAP	2.5	0.1124
Ex.F.Fo	1.3	0.2588
Sp.F.I	1.2	0.2757
JR	0.6	0.4267
Overall Wilk's Lambda	0.5757	

From the Table-12 it can be inferred that the eight fundamental frequency and intensity variation measures can classify 68.1% of population correctly as normals and dysphonics. However, the discriminant function has 31.9% of erroneous classification, having majority of false positives (i.e., classifying a dysphonics as normals).

The Table-14 provides the ranking of fundamental frequency and intensity variation measures based on F-values.

According to this analysis Sp.F.Fo has highest weightage, next to that is SHM and JR has lowest weightage. Hence it can be considered that the Sp.F.Fo., SHM, Ex.F.I. and APQ are the powerful measures to discriminate the normals from dysphonics.

Nataraja, (1986) reported that Sp.F.Fo and Ex.F.I. were effective measures to differentiate between normals from dysphonics. Kitajima and Gould, (1976), reported that dB shimmer was effective measure in differentiating normals from dysphonics. Venkatesh et al., (1992) reported that dB shimmer and APQ were effective in discriminating normals and dysphonics. The present study was in agreement with these findings.

OBJECTIVE-6

To achieve this objective, the data obtained for (a)Gross measures fundamental frequency and intensity variations and (b) Fine measures fundamental frequency and intensity variations were subjected to linear discriminant function analysis. The results are provided in Tables.15,16, 17, 18, 19 and 20.

Table-15: Classification matrix of normals and dysphonics based on four Gross measures of fundamental frequency and intensity variations.

	Predicated (Total)	Predicated (Normals)	Predicated (Dysphonics)
Actual Total	810	609	201
Actual Normals	540	504	36
Actual Dysphonics	270	105	165
Percent reduction in classification error due to X's			65.2

Table-16: Linear discriminent functions of normals and dysphonics across four Gross measures of fundamental frequency and intensity variations.

Measures	Normals	Dysphonics
Ex.F.Fo	0.025127	0.029380
Ex.F.I.	0.1221077	0.086423
Sp.F.Fo	0.259762	0.1004722
Sp.F.I.	-0.035427	-.018345

Table-17: Variable selection report and linear discriminant function analysis across four gross measures of fundamental frequency and intensity variations.

Variable	F-Value	Probability
Ex.F.I.	240.5	0.0000
Sp.F.Fo	7.2	0.0072
Sp.F.I.	1.3	0.2491
Ex.F.Fo	0.7	0.4147
Overall Wilk's Lambda	0.6199	

Table-18: Classification matrix of normals and dysphonics based on four fine measures of fundamental frequency and intensity variations.

	Predicated (Total)	Predicated (Normals)	Predicated (Dysphonics)
Actual (Total)	810	647	163
Actual (Normals)	540	535	5
Actual (Dysphonics)	270	112	158
Percent reduction in classification error due to X's			71.1

Table-19: Linear discriminant functions of normals and dysphonics across four fine measures of fundamental frequency and intensity variations.

Measures	Normals	Dysphonics
JR	-0.011173	-0.017755
RAP	17.88747	46.58682
SHM	0.8296675	3.297458
APQ	-0.013637	-0.061176

Table-20: Variable selection report and linear discriminant function analysis across four fine measures of fundamental frequency and intensity variations.

Variable	F-value	Probability
SHM	70.5	0.0000
RAP	5.6	0.0185
APQ	1.8	0.1766
JR	0.7	0.4102
Overall Milk's Lambda	0.6508	

From the Tables-15, 16, 17, 18, 19 and 20, it can be inferred that the gross fundamental frequency and intensity variation can classify 65.2% of the population correctly, as normals and dysphonics. Whereas the Fine fundamental frequency and intensity variations can classify 71.1% of the population correctly. However, both measurements had 38.9% and 41.5% of false positive classification respectively (i.e., classifying the dysphonics as normals).

From the above linear discriminant function analysis, it can be concluded that the Fine measures of fundamental frequency and intensity variations were more effective and efficient classification parameters between normals and dysphonics, These measures classified 71.1% of the population correctly which is approximately 6% higher than the classification capability of gross measures of fundamental frequency and intensity variation. This may be due to the higher sensitivity of the Fine measures of fundamental frequency and intensity variations. Whereas the gross measures of FF and I variation does not consider the small variations i.e., the variations below 3 Hz and 3dB. There was no study available to compare this data and findings.

SUMMARY AND CONCLUSION

The present study was aimed at developing normative data for the eight different measures of fundamental frequency and intensity variations. They are (a) Gross measures, Ex.F.Fo, Sp.F.Fo, Ex.F.I and Sp.F.I. (b) fine measures, JR, RAP, SHM and APQ. This study also aimed at comparing the gross and fine measures of fundamental frequency and intensity variations and to find the highly weighted measures to discriminate normals and dysphonics.

Thirty normal adult males, thirty normal adult females and thirty dysphonics served as subjects. The age range of normal subjects varied from 17 to 35 years. Where as the age range of dysphonic groups varied from 16 to 62 years. Three trials of EGG recording and for each of the vowels /a/, /i/ and /u/ were obtained using Kay laryngograph. The EGG recordings were digitized at 16KHz sampling frequency using 12 bits analog digital converter. Digitized data was stored on hard disk of PC-AT 386. The digitized EGG wave forms were smoothened, differentiated and peak picking method was used to extract the fundamental period and intensity. The obtained cycle to cycle fundamental period data and intensity were subjected to further analysis using PC-AT 386, to obtain JR, RAP, SHM, APQ, EX.F.Fo., Sp.F.Fo., Ex.F.I. and Sp.F.I.

The measured FF and I variations data were subjected to analysis of variance (ANOVA), linear discriminant function analysis. The following conclusions were drawn:

1) There was no significant difference between the trials for all the eight measures of fundamental frequency and intensity variations. Hence it is not really necessary to take more number of trial of the same vowel for the purpose of measurement of fundamental frequency and intensity variations. Even a single trial of recording can give same amount of information.

2) There was significant difference between the vowels /a/, /i/ and /u/ for SHM, APQ and Sp.F.I measures, i.e., measures of intensity variation. Whereas rest of the measures JR, RAP EXF.I., EX.F.Fo. and Sp.F.Fo. i.e., mainly the measures of fundamental frequency variations did not have any significant difference across vowels. This may idicate that fundamental frequency variations measures are constant across vowels, where as Intensity variation measures vary across vowels. This may be due to different intra-oral breath pressure and different amount of lip radiation between vowels. Hence measurement of fundamental frequency and intensity variations across the vowels enhances the reliability of the data.

3) There was no significant difference between males and females for fine measures of fundamental frequency and intensity variation (JR, RAP, SHM and APQ). Whereas the significant difference was present between males and females for gross measures of fundamental frequency and intensity variations. The presence of significant difference in gross measures of fundamental frequency and intensity variation

were due to the absence of normalization in the measurement procedure of gross measures of fundamental frequency and intensity variation (Ex.F.Fo., Sp.F.Fo., Ex.F.I. and Sp.F.I.)

4) There was very high significant difference between normals and dysphonics across all the eight measures of fundamental frequency and intensity variations. Higher values of fundamental frequency and intensity variation among dysphonics is due to the abnormal and deviant vibration of vocal folds.

5) According to linear discriminant function analysis the Sp.F.Fo, SHM, EX.F.I and APQ were highly weighted measure of fundamental frequency and intensity variations.

6) The same linear discriminant function analysis indicated that the fine measures of fundamental frequency and intensity variations were highly weighted between gross and fine measures of fundamental frequency and intensity variations. The fine measures of fundamental frequency and Intensity variation could classify 71.1% population correctly where as the gross measures could classify only 65.2% of the population.

7) The classification of normals and dysphonics using these measures had high degree of false positive classification. This is the major disadvantage of using fundamental frequency and intensity variation measures as screening and classification procedures. This aspect has to be further investigated.

However, the finer measures of fundamental frequency and intensity variation are powerful and reliable measures to discriminate between normals and dysphonics. It is also suggested to investigate the classification capability of these measures within the dysphonic groups.

BIBLIOGRAPHY

AIISH Annual Report (1990-1991). Published in All India Institute of Speech and Hearing. Mysore.

Askenfelt, A. & Hammerberg, B. (1986): Speech waveform perturbation analysis. A perceptual acoustical comparison of seven measures. J.S.H.R., 29, 50-64.

Baer, T. (1980): Vocal jitter - A neuromuscular explanation Trasncripts of the eighth symposium of the care of the professional voice. Voice Foundation - New York, 19-22.

Baggs, T.W. & Pine, S.J. (1983): Acoustic characteristics. TEP speech J. Comm, Dis., 16, 299-307.

Baken, R.J. (1987): Vocal fundamental frequency.Ch.5, in clinical measurement of speech and voice". College Hill Press, A division of little, Brown and Company (Inc), Boston, Massa Chusetts.

Biswas, A.K. (1991): A few objective measurements of quality of voice in cleft palate individuals. Unpublished Master's Dissertation. Univer, of Mysore.

Blood, G.W. (1984): Fundamental frequency and intensity measurement in laryngeal and alaryngeal speakers. J.comm, Dis., 17, 319-324.

Bowler, N.W. (1964): A fundamental frequency analysis of harsh vocal quality. Speech Monograph, 31, 128-134.

Carhart.R. (1938). Intra glottal resonance and a cushion Pipe. Speech monograph, 5, 65-90.

Carhart,R. (1941): The spectra of model larynx tones. Speech Monograph, 8,76-84.

Cavallo,S.A., Baken, R.J. & Shaiman,S (1984): Frequency perturbation characteristics of pulse register phonation. J.Comm.Dis., 17, 231-243.

Childers.D.G., Hicks, D.M., Moore, Q.P., Eskenaze and Lalnvani A.L. (1990): Electroglottography and vocal fold physiology. J.S.H.R., 33, 245-254.

Crystal (1970): Jitter and Shimmer in sustained phonation speech and hearing. Edited by Lass N.J. (1982) Speech and Lang, Basic advances in research and practice, N.J. Academic Press, 1, 271-335.

Davis,S.B. (1976): Computer evaluation of laryngeal pathology based on inverse filtering of speech. SCRL monograph No.13, Santa Barbara CA: Speech Communications Research Lab.

Davis,S.B. (1979): Acoustic characteristics of normal and pathological voices, Edited by Lass N.J. (1982) Speech and Lang, Basic advances in research and practice, N.J. Academic Press, 1, 271-335.

Davis,S.B. (1981): Acoustical characteristics of normal and pathological voices. A.S.H.A. Reports., 11, 97-115.

Deal,R. and Emanuel, F. (1978): Some waveform and spectral features of vowel roughness. J.S.H.R, 21, 250-264.

Fairbanks,G. (I960): Voice and articulation drill book. New York. Harper and Row Publishers.

Fairbanks,G. (1970): Recent experimental investigations of vocal pitch in speech. J.A.S.A, 11, 4547-466.

Gould,W.J. (1975): Quantitative assessment of voice function in microlaryngology. Folia Phoniat. 27, 190-200.

Gould,W.J. and Okamura,H. (1974): Static lung volumes in singers. Annl of Oto. Rhinol and Laryngol. 82, 89-94.

Haji.T., Horigudu,S. Baer,T. and Gould,W.J. (1986): Frequency and amplitude perturbation analysis of EGG during sustained phonation. J.A.S.A. 80, 58-62.

Hanson,D.G., Gerrat, B.R. and Ward,H.P. (1983): Glottographic measurement of vocal dysfunction - A preliminary report. Annl-of Otorhinol-Laryngol. 92(5), 413-419.

Hartman, E. and Von Craman.D. (1984): Acoustical measurement of vocal cord quality in central dysphonia. J.Comm.Dis., 17, 425-440.

Hecker.M.A. and Kruel,E.J. (1971): Descriptions of the speech of patients with cancer of the Vocalfolds. JASA. 49, 1275-1282.

Heiberger, V.L. and Horii.Y. (1980): Jitter and Shimmer in sustained phonation" Edited by Lass N.J. (1982). Speech and Language advance in Basic research and practice. Academic Press, New York, 7, 299-330.

Heiberger.V.L and Horii.Y. (1982): Jitter and Shimmer in sustained phonation" Edited by Lass N.J. (1982). Speech and Language advance in Basic research and practice. Academic Press, New York, 7, 299-330.

Hillen Brand,J. (1987): A methodological study of perturbation and additive noise in synthetically generated voice signals. J.S.H.R, 30, 448-461.

Higgins, B.M. and Saxman, H.J. (1989): A comparison of intrasubject variation across sessions of three vowel frequency perturbation indices. J A.S.A., 86(3), 911-916.

Hirano,M. (1975): Phonosurgery basic and clinical investigations otologia (Fukuoka) 27, 239-440.

Hollien.H., Michel,J. and Doherty,E.T. (1973): A method for analysing vocal jitter in sustained phonation. J. of Phonetics, 1, 85-91.

Horii.Y (1979): Fundamental frequency perturbation observed in sustained phonation. J.S.H.R, 22, 5-19.

Horli.Y (1980): Vocal shimmer in sustained phonation. J.S.H.R, 23, 202-209.

Horii.Y (1982): Jitter and Shimmer differences among sustained vowel phonation. J.S.H.R, 25, 12-14.

Imaizumi,S., Hiki.S., Hirano, M. and Masushita, H. (1980): Analysis of pathological voice with a sound spectrograph. J.Acoustic Soc, Jpn, 36, 9-16.

Iwata,S. (1972): Periodicities of pitch perturbations in normals & pathologic larynges. Laryngoscope. 82, 87-95.

Iwata,S. and VonLeden,H. (1970): Pitch perturbation in normal and pathologic voices. Folia Phoniat, 22, 413-424.

Jacob,L. (1968): A normative study of laryngeal jitter. Unpublished master's thesis. Univer. of Kansas.

Johnson,W. and Michal.J.F. (1969): The effect of selected vowels on laryngeal jitter. ASHA, 11, 96-109.

Kane.M. and Wellan.C.J. (1985): Acoustical measurements and clinical judgements of vocal quality in children with vocal nodules. Folia Phoniat. 37, 53-57.

Kelman.A.W. (1981): Vibratory pattern of the vocal folds. Folia. Phoniat, 33, 73-99.

Kim,K.M., Kakita,V. and Hirano, M. (1982): Sound spectrographic analysis of the voice of patients with recurrent laryngeal nerve paralysis. Folia Phoniat. 34, 124-133.

Kitajima.K and Gould, W.J. (1976): Vocal shimmer in sustained phonation of normal and pathologic voice. Annl. of Otolo-Rhinol and Laryngol. 85, 377-381.

Klimgholz, F and Martin, F (1985): Quantitative spectral evaluation of shimmer and Jitter. J.S.H.R, 28, 169-174.

Koike, Y (1969): Vowel amplitude modulations in patients in laryngeal diseases. J.A.S.A, 45, 839-844.

Koike, Y (1973): Application of some acoustic measures for the evaluation of laryngeal dysfunction. Studies Phonologica. 7, 17-23.

Koike, Y. Takahashi H. and Calcaterra T. (1977): Acoustic measures for detecting laryngeal pathology. Acta. Otalaryngo Logica., 84, 105-117.

Lieberman, P. (1961): Perturbation in vocal pitch. J.A.S.A., 33, 597-605.

Lieberman, P. (1963): Some measures of the fundamental periodicity of normal and pathological larynges. J.A.S.A, 35, 344-353.

Linville, S.E. (1988): Intraspeaker variability in fundamental frequency stability. An use related phenomenon. J.A.S.A. 83, 741-745.

Linville, S.E. and Korabic, E.W. (1987): Fundamental frequency stability characteristics of elderly women's voices. J.A.S.A, 81, 1196-1199.

Ludlow, C.L., Bassich.C.J., Lee, Y.J., Ganner N.P. and Caulter D.C. (1984): The validity using phonatory jitter and to detect laryngeal pathology. J.A.S.A, 75(suppl). 558.

Ludlow,C. Coulter, P and Cardane, C. (1979): Application of pitch perturbation measures to the assessment of hoarseness in Parkinson's disease. J.A.S.A, 66, 64.

Ludlow,L., Coulter,D and Gentges,F. (1983): The differential sensitivity of measures of fundamental frequency perturbation to laryngeal neoplasms in neuropathologies. In Bless, D.M. and Abbs, J.H. (Edrs). Vocal fold physiology contemporary research and clinical Issues, San 'Diego College Hill, 1983, Ch.3, 381-392.

Michel,J.F. and Wendahl,R. (1971): Correlates of voice production in Travis,L.E. (ed). Handbook of Speech pathology and Audiology, Prentice - Hall, Inc., Englewood Cliffs, N.J. 465-480.

Moore,G.P. and Thompson,C. (1965): Comments on physiology of hoarseness. Achieves of Oto. 81, 97-102.

Moore,G.P. and VonLeden, H. (1968): Dynamic variations of the vibratory pattern in the normal larynx. Folia Phoniat. 10, 205-238.

Murry.J. and Doherty, E.T. (1973): Frequency perturbation and durational characteristics of pathological and normal speakers. J.A.S.A, 62-65.

Murry, J. and Doherty, E.T. (1980): Selected acoustic characteristics of pathological and normal speakers. J.S.H.R, 23, 361-369.

Murry, J. and Singh, S. (1980): Multidimensional analysis of males and females voices., J.A.S.A, 68(5), 1294-1300.

Nataraja.N.P. (1986): Differential diagnosis of dysphonia. Doctoral Thesis, Univer. of Mysore, Mysore.

Newman,J.B. (1963): The categorization of disorders of speech, language and communication. J.S.H.D., 3, 287-289.

Pinto,N.B. and Titze, I.R. (1990): Unification of perturbation measures in speech signals. J.A.S.A, 87, 1278-1289.

Ramig,L. (1980): Acoustic characteristics of voice and selected measures of body physiology. Unpublished doctoral dissertation, Purdue University.

Rashmi.M. (1985): Acoustic aspects of speech of children. Unpublished master's dissertation, Univer.of Mysore.

Robbins.J. (1984): Acoustic differentiations of Laryngeal, Esophageal, TEP speech. J.S.H.R, 27, 577-585.

Robert,R. and Baken, R.J. (1989): The effect of the heartbeat on vocal Fo frequency perturbation. J.S.H.R, 32, 576-582.

Sorensen.D. and Horii,Y. (1983): Frequency and amplitude perturbation in the voices of female speakers. J. Comm. Dis. 16, 57-61.

Sorensen, D. and Horii,Y. (1984): Directional perturbation factors for Jitter and Shimmere. J.Comm, Dis. 17, 143-151.

Sorensen,D. and Horii, Y. (1984a): Frequency characteristics of males and female speakers in pulse register. J.Comm, Dis. 17, 65-73.

Sorensen, D., Horii, Y and Leonard, R. (1980): Effects of laryngeal topical anesthesia on voice fundamental frequency perturbation. J.S.H.R, 23, 274-284.

Smith,B.E. Weinberg.B, Feth.L.F. and Horii,Y (1978): Vocal roughness and Jitter characteristics of vowels produced by esophageal speakers. J.S.H.R, 21, 240-249.

Suresh,T. (1991): Acoustic analysis of voice in geriatric population. Unpublished master's dissertation, Univer. of Mysore, Mysore.

Takahashi.H. (1974): Significance of perceptual study of pathological voices, Prart, Otol. (Kyoto) 67, 949-953.

Takahashi,H. and Koike,Y. (1975): Some perceptual dimensions and acoustical correlates of pathological voices. Acta Otoloryngol. Suppl. 338, P.1-24.

Tharmar,S.(1991): Acoustic analysis of voice in children and adults. Unpublished Master's dissertation. Univer. of Mysore, Mysore.

Titze.I.R. Horii,Y, and Scheres.R.C. (1987): Some technical considerations in voice perturbation measurements. J.S.H.R, 30, 252-260.

Vanaja,C.S. (1986): Acoustic parameters of normal voice. Unpublished Master's dissertation. Univer. of Mysore, Mysore.

Venkatesh.C.S., Satya, K. and Jeny, E.P. (1992): Normative data on pitch and amplitude perturbation measurements in normals and discriminant function analysis of pitch and amplitude perturbation measurements in dysphpnics. Presented at XXIV National Conference of ISHA.

VonLeden,H. and Koike,Y. (1970): Detection of laryngeal disease by computer techniques Arch, of Otol. 91, 3-10.

VonLeden,H., Moore, G.P. and Timicke.R. (1960): Laryngeal vibration measurement of the glottal wave, part III, the pathologic larynx. Arch, of Otol. 71, 16-35.

Weng,D. Ito, MR. and Tize,I.R. (1986): A hybrid model of vocal fold vibration illustraling perturbation. J.A.S.A, 79(A), 582.

Wilcox, K. (1978): Age and Vowel differences in vocal jitter. Unpublished master's thesis. Purdue University.

Wilcox, K and Horii,Y (1980): Age and changes in vocal jitter. J. of Geronotogy, 35, 194-198.

Wyke, B.D. (1967): Recent advances in the neurology of phonation. Phonatory reflex mecanisms in the larynx. The British. J.of Dis. of Comm. 2, 2-14

Wyke,B.D. (1969): An analysis of the laryngeal reflex mechanisms of speech. The British. J.of Comm.Dis. 4, 3-25.

Yashiyaki,H. and Borrbara, F. (1990): Selected acoustic characteristics of voices before intubation and after exterbation. J.S.H.R, 33, 505-510.

Yoon,M.K., Kakita.Y. and Hirano.M. (1984): Sound spectrographic analysis of the voice patients with glottic carcinomas. Folia Phoniat 36, 24-30.

Zajac.D.J. and Linville,R. (1989): Voice perturbation of children with perceived nasality and hoarseness. CPJ. 26(3), 226-231.

Zemlin.W.R. (1962): A comparison of the periodic function of vocal fold vibration in multiple sclerosis and normal population. Unpublished doctoral dissertation, University of Minsnesota.

Zyski, B.J. Bull.G.L., Me Donald, W.E. and Johns M.C. (1984): Perturbation analysis of normal and pathologic larynges. Folia Phoniat. 36, 190-198.