CLOSED QUOTIENT AS A GLOTTAL EFFICIENCY INDICATOR

M.N. Balakrisha
Register No. M 9101

A Dissertation submitted as part fulfillment for
Final Year M.Sc, (Speech and Hearing)
to the University of Mysore.

ALL INDIA INSTITUTE OF SPEECH AND HEARING
MYSORE - 570 006
MAY - 1993

Dedicated

To

AJJI,AMMA & APPA

CERTIFICATE

This is to certify that the dissertation entitled "CLOSED QUOTIENT AS A GLOTTAL EFFICIENCY INDICATOR" is the bonafide work in part fulfillment for the degree of Master of Science (Speech and Hearing) of the student with Register No. M 9101.

Mysore
May 1993

Director
All India Institute of Speech & Hearing
Mysore - 570 006.

CERTIFICATE

This is to certify that the dissertation entitled "CLOSED QUOTIENT AS A GLOTTAL EFFICIENCY INDICATOR" has been prepared under my supervision and guidance.

Mysore
May 1993

DR. N.P. NATARAJA
Guide
19/5/93

DECLARATION

This dissertation is the result of my own study undertaken under the guidance of Dr. N.P. Nataraja Prof, and HOD Speech Science, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any University for any other Diploma or Degree.

MYSORE
MAY 1993

Reg. No. M. 9101

ACKNOWLEDGMENTS

"Gurubrahma Guruvishnuhu
Gurudevo Maheshwaraha
Gurushakshat Parabrahma
Tasmai Shree Guruve Namaha"

First and foremost I extend my heartfelt gratitudes to my teacher and guide **Dr. N.P. Nataraja, Prof. and Head, Dept. of Speech Sciences,** All India Speech and Hearing, Mysore, for his excellent guidance and help.

I am thankful to **Dr. (Miss.) S. Nikam, Director** AIISH, for allowing me to undertake this study.

I also thank -

Mr. C.S. Venkatesh, Lecturer in Speech Sciences, AIISH for his valueable suggestions, criticisms and constant help. Sir, I can never thank you enough for all that you have done for me.

Mrs. Sujatha, Mrs. Sreedevi, Miss. Rohini and **Miss. Lalitha** for making my work enjoyable by their friendly touch.

Ramesh, Venkatesh, Padmaja, Asha, Atte, Raghu and **Latha** for their constant inspiration.

Anitha for being so caring about me, easing my tension and worries and for her invaluable help at every phase of this work.

My better three-fourths, **Thangamani**, **Raghu** and **Gokul** whose motherly affection, fatherly . love, sisterly inspiration, brotherly touch, husband like understanding, wife like shelter and opponently criticism together has been with me always to keep me in track.

Bhuvaneshwari, C.S. for constantly pulling me towards my work whenever I deviated from it.

Zaver, **Sanyu**, **Sunil** and **Shabeer** for their love, concern and timely help.

Anu, K.T., **Mareena**, **Mohan**, **Manoj**, **Ajay**, **Abhay**, **Vikram**, **Rahul**, **Binu** and **Shantala** for coming forward and helping me wholeheartedly in completing this work.

Hema, **Priya**, **Sunil**, **Nanda**, **Vijaya**, **Kiran** and other **I MSc's** for their motivation and help.

Ravanan, **Rajkumar**, **Santosh**, **Patro**, **Patakji** and all my classmates for their cooperation.

All **I BSc's**, **II BSc's** and **Final BSc's** for their cooperation.

The **library staff** for allowing me to peep into the ocean of AIISH literature.

Last but not the least I thank **KEYBOARD COMPUTER SYSTEMS AND REPROGRAPHICS** for converting my scientific literature into a beautiful dissertation.

CONTENTS

LIST OF TABLES

LIST OF GRAPHS

INTRODUCTION

Voice is the result of breath under pressure from lungs causing the approximated vocal cords to perform the rhythmic excursions of separation and closure.

- Greene 1980,

phonation is the specialized activity of the larymn correct voice production requires co-ordination between respiratory and phonatory systems.

Voice may be defined as a laryngeal tone which can be heard or measured.

"The normal voice should possess certain characteristics of pitch, loudness and quality, which make meaning clear, arouse the proper emotional response or ensure a pleasant tonal effect upon the hearer".

- Berry and Eisenson - 1962

Normal voice is related to physical determinants such as age, sex, size of the speech organs and cultural determinants like socio economic conditions etc. (Van Riper).

To understand the physiology of voice one needs proper measurement techniques. Abnormal vibratory movements of vocal folds are known to manifest in the form of phonatory disorders. Hence study of vibratory movements is of greater importance.

Many researchers have attempted to study the vibratory patterns of vocal-folds using various techniques. Electrolaryngraphy is one of the methods used extensively to quantify the glottal waveform.

"The laryngograph is a practical instrument which has designed to allow vocal fold closure to be monitored most notably giving a basis for the measurement of aspects of vocal fold vibration which occurs during voiced sounds".

(Fourcin and Abberton, 1971)

Details of vocal fold vibration can be related to a typical Lx cycle for normal modal voice. Generally four main features can be seen in any normal Lx waveform.

1) A steep rising edge 2) A maximum peak 3) A shallow falling edge 4) A trough essentially constant with time. These correspond to the vocal fold.

1) closing phase 2) closed phase 3) opening phase 4) open phase (Lectuse - 1977).

Many studies have been reported regarding parameters like speed quotient, open quotient, speed-index, 's' ratio, jitter and shimmer etc.

It is evident from the review of literature that not much study has been done to relate the parameters with voice quality of an individual. Also, most of the studies have used a small sample (10 cycles) to study the glottal parameters. The reason for this is that these studies used the manual method where the analysis of a greater sample was not feasible as it is time consuming. Hence the present study was proposed. The main aims of the study were a) to validate the newly developed automatic extraction programme would provide sample more waveforms in a relatively shorter time h) to relate the parameters thus obtained to the perceived voice quality.

30 normal subjects (15 males and 15 females) in the age range of 18 to 31 years and 6 trained singers (3 males and 3 females) in the age range of 22 to 38 years were studied using electro laryngograph and computer (PC/AT) necessary software for analysis.

Purpose of the study:

The purpose of the present study was to validate the newly developed automatic method of extraction of glottal parameters and to relate these parameters to the perceived voice quality.

The following parameters were studied in phonation of /a/ using 10 consecutive cycles in the normal method and 10 and 100 consecutive cycles in the automatic extraction method, keeping the frequency and intensity of sustained phonation constant for all the subjects.

1. Closed quotient
2. Fundamental frequency
3. Open quotient
4. Speed quotient
5. Speed index.

Main hypothesis

I. There is no significant difference between manual and automatic extraction method for the extraction of the glottal parameters.

II. There is no relationship between closed quotient and glottal efficiency.

III. There is no relationship between fundamental frequency and glottal efficiency.

IV. There is no relationship between open quotient and glottal efficiency.

V. There is no relationship between speed quotient and glottal efficiency.

VI. There is no relationship between speed index and glottal efficiency.

Auxiliary hypothesis

la. There is no significant difference between manual and automatic method of extraction of the parameter closed quotient.

Ib. There is no significant difference between manual and automatic method of extraction of the parameter fundamental frequency.

Ic. There is no significant difference between manual and automatic method of extraction of the parameter open quotient.

Id. There is no significant difference between manual and automatic method of extraction of the parameter speed quotient.

Ie. There is no significant difference between manual and automatic method of extraction of the parameter speed index.

If. There is no significant difference in the values of the parameters for 10 and 100 cycles of analysis by automatic extraction method.

IIa. There is no effect of sex on the closed quotient of non singers.

lIb. There is no relationship between fundamental frequency and closed quotient of non singers.

lIe. There is no effect of sex on the closed quotient of singers.

IIIa. There is no effect of sex on the fundamental frequency of non singers.

IIIb. There is no relationship between fundamental frequency and perceived voice quality.

IIIc. There is no effect of sex on the fundamental frequency of singers.

IVa. There is no effect of sex on open quotient of non singers.

IVb. There is no relationship between the fundamental frequency and open quotient of non singers.

IVc. There is no effect of sex on the open quotient of singers.

IVd. There is no relationship between fundamental frequency and open quotient of singers.

Va. There is no effect of sex on the speed quotient of non singers.

Vb. There is no relationship between speed quotient and fundamental frequency of non singers.

Vc. There is no effect of sex on speed quotient of singers.

Via. There is no effect of sex on the speed index of non singers.

VIb. There is no relationship between fundamental frequency and speed index of non singers.

VIc. There is no relationship between speed index and perceived voice quality of non singers.

VId. There is no effect of sex on the speed index of singers.

VIe. There is no relationship between speed index and fundamental frequency of singers.

Implications of the study:

1. It provides information regarding the normal vibration of vocal folds.

2. It provides an opportunity for studying vocal fold vibration in terms of different parameters.

3. A new parameter Cq is used for the normative data and its relationship with perceived voice quality is provided.

4. The results of the study can be used as norms for evaluating voice disorders.

5. The results may be used to evaluate the progress made by cases during and after therapy.

6. It may be used to make comparison with other studies.

7. It provokes more research on this line.

Definitions:

The following definitions have been used in the present study.

1. **Closed quotient** $= \dfrac{\text{closed phase}}{\text{total period}} \times 100$

$$\frac{\text{closing time + closed time + opening time}}{\text{total period}} \times 100$$

2. **Fundamental frequency**

$$= \frac{1}{\text{time difference between two successive +ve going zero crossing}}$$

3. **Open quotient** $= \dfrac{\text{open phase}}{\text{total period}} \times 100 \dfrac{\text{open time}}{\text{total period}} \times 100$

4. **speed quotient** $= \dfrac{\text{opening time}}{\text{closing time}}$

5. **Speed index** $= \dfrac{\text{speed quotient - 1}}{\text{speed quotient + 1}}$

6. **Total period** = The time required to achieve a cycle of the Lx wave.

7. **Manual extraction method:** In this method the various points are plotted by the investigation for each cycle based on which the computer calculates the values of different parameters.

8. **Automatic extraction method:** In this method the computer automatically plots various points and calculates the values of different parameters.

9. EGG = Electroglottogram, same as electrolaryngograph.

10. **Glottal waveform or laryngeal waveform** = The graph obtained by EGG.

11. **Trained singers** = Individuals who had a minimum of 3 to 4 years of training in singing.

Limitations of the study:

1. The number of normal subjects were restricted to 30 males and 15 females).

2. The number of trained singers studied was 6 (3 males and 3 females).

3. Only one trial of phonation has been studied.

4. Only on vowel (a) was studied.

5. Only five parameters have been considered in the present study.

REVIEW OF LITERATURE

"Speech is the way of life for man. No normal person is without this faculty and no other species is known to possess it" (Punt, 1952).

Once acquired, speech becomes a constant companion to man. It becomes a property of the individual, at the same time it is the bond which established the society.

Speech is produced without observable effort by the human being. The range of speech variation is immense, and considered normal.

Only a small part of the information conveyed by speech, less than 1%, is used for linguistic purposes, as such the rest gives other kinds of information, about the specific character of the vocal tract of the speaker, which enables us to recognize his voice, his physical well being, his emotional state and his attitudes towards the entire context in which the speech event occurs. It can also carry other information about the speaker, with reference to the convention of social class, occasion and style.

The primary mode of communication is speech and voice is the vehicle of speech. Voice has been defined differently by different workers. The one commonly accepted definition is given by Michel and Wendahl (1971). According to them voice is the "Laryngeal modulation of the pulmonary air stream, which is then further modified by the configuration of the vocal tract". This voice is not only used as a vehicle for speech but also for singing and theatrical performances.

Humans can produce vocal sounds at a wide range of fundamental frequencies with great varieties of tonal qualities, using only a single pair of vocal folds. This is in contrast to many other musical instruments which have multiple strings in order to cover fundamental frequencies and/or tonal qualities. That is to say that the vocal folds can become vibrators with many different properties (Hirano, 1977).

According to Wilson (1956) the characteristics of a good voice are:

a. pleasing voice quality.
b. proper balance of oral and nasal resonance.
c. appropriate loudness.
d. a-modal frequency level (habitual pitch level) suitable for his age and sex and
e. an appropriate voice inflection involving pitch and loudness.

The production of voice is a complex process. It requires precise control by the central nervous system of a series of events in the peripheral phonatory organs.

The crucial event essential for voice production is vibration of the vocal folds. The vibration of the vocal folds convert D.C. air-stream into A.C. air-stream.

There is controversy regarding the mechanism of vocal cord vibration. There are mainly two theories to explain this:

1. The myoelastic aerodynamic theory proposed by Muller (1849) and later modified by Tonndorf (1925) and Smith (1954). However the salient feature of Muller's version have remained unchanged which postulate that the vocal folds are set into vibration by the air stream from the lungs and the fundamental frequency of vibration is dependent upon the effective mass, length and stiffness of vocal folds. These vibrations are regulated in all fine details by the sustained innervation of interval and external laryngeal muscles and associated resonators (Vander Berg, 1958).

2. The Neurochronaxic Theory: It was proposed by Hussan (1950). This states that each new vibratory cycle is initiated by a nerve impulse transmitted from the brain to the vocalis muscle by the way of recurrent branch of vagus nerve. The frequency of the vocal fold vibration is dependent upon the rate of impulses delivered to the laryngeal muscles. Various studies have been conducted. The result of some of them support and some of them

contradict both the theories. But according to Fant (1960), the most commonly accepted one is the myoelastic theory.

Voice serves both linguistic and non-linguistic functions in any language, though the degree and extent to which they serve, vary from language to language. Some of these functions are:

1. Variations in voice in terms of pitch and loudness provide the required rhythm to speech.

2. Voicing (i.e., the presence of voice) has been found to be a major distinctive feature as in most of the language, wherein its absence as function in the voice of any individual leads to a speech disorder.

3. Speech prosody is a function of vocal pitch, loudness and phonetic duration and variations/modulations in these bring about a change in the meaning. Thus voice also plays a semantic role.

4. Voice can reveal the speaker's identity in terms of age, sex, height and weight of the speakers (Perkins, 1971). It is also possible to identify the speaker in terms of race, socio-economic status and racial features (Lass, Brong, Ciccolena, Walters & Maxuell, 1980).

5. Several investigators contend that the voice reflects the personality of an individual (Starkweather, 1981; Rousey and Mariarty, 1965).

Studies by Fairbanks (1942, 1966) and Huttar (1967) have found that voice reflects emotional status of the individuals.

6. Voice has been considered to reflect the physiological state of an individual. Eg. A weak voice may indicate ill health of a person; denasal voice may indicate the speaker having common cold, etc.

More specifically, voice reflects the anatomical and physiological conditions of the respiratory, phonatory and resonatory system; deviations in which may lead to voice disorders.

7. In recent times, it has been found by many investigators, that it is possible to identify abnormalities in neonates by analyzing their cry.

Thus, voice serves numerous and varied functions, of this, it plays a major role in speech and hence in communication. Therefore voice needs to be constantly monitored and in the event of abnormal functioning of voice, an immediate assessment should be undertaken. This assessment will lead to the diagnosis which not only identifies the voice disorders but also acts as an indicator for the treatment and management to be followed.

The ultimate aim of studies on normality and abnormality of voice and assessment and diagnosis of the voice disorders is to enforce a procedure which will eventually bring back the voice of an individual to normal or optimum level is the main aim or objective of treatment.

The management of voice problem is through either medical, surgical or therapeutic intervention in the order. Hence always medical line comes first and then surgical. After the primary pathology, if any, is treated the therapeutic intervention is done if voice problem persists or to correct the undesirable habits in producing voice. Again based on the nature, extent and severity of the voice disorder, and or a combination of the intervention strategies is considered. Eg. A vocal nodule may require all the three, while puberphonia with pitch breaks requires only voice therapy.

As effective managements required, it becomes necessary to device and use a wide battery of tests or assessment strategies in order to arrive at an effective diagnosis.

There are various means of analysing voice, developed by different workers, to note the factors which are responsible for creating an impression of a particular "voice" (Hirano, 1981; Nataraja & Jayaram, 1979; Rashmi, 1985).

There are various methods of direct or indirect assessment, observation and/or measurement of the parameters involved in the process of production of voice. Some of those which are directly related to voice are:

Electromyography (EMG):

Which can be used to demonstrate the muscular activity of the laryngeal muscles that regulate the vibratory pattern of vocal cords at the physiological level.

The acoustic analysis of voice:

Hirano (1981) states that ".. this may be one of the most attractive method for assessing phonatory function or laryngeal pathology because it is non-invasive and provides objectives and quantitative data".

Many acoustic parameters, derived by various methods, have been reported to be useful in differentiating between the pathological voice and normal voice. But Hanson et al (1983) reported that the acoustical measurements do not necessarily have a direct physiological correspondence to abnormal glottal activity.

The aerodynamic aspect of phonation is characterized by four parameters mainly subglottal pressure, supraglottal pressure, glottal impedance and volume velocity of the air flow at the glottis (Hirano, 1981). These measures have also been reported to be related to listeners rating of deviant voice dimensions (Hanson et al., 1983).

The psycho-acoustic evaluation of voice

The human ear has a remarkable capacity to identify and discriminate varying sound complex. One can identify the speakers simply by listening the voice. Well trained voice clinicians are frequently able to determine the causative pathologies on the basis of phycho-acoustic impression of voice (Takhashi, 1974; Takhashi et al 1974; Hirano, 1975).

Examination of Phonatory Ability

The term phonatory ability refers to the measurements of maximum duration of sustained phonation (Lass & Michel, 1969; Placek and Sander, 1963; Van Riper, 1954; Fairbanks, 1960; Laden et al., 1968). Maximum frequency range (Hillen and Michel, 1968), dynamic range of vocal intensity, glottal efficiency and others.

Measurements that can be reflected to the normal physiology and pathophysiology of abnormal behaviour are highly desirable. Since phonatory dysfunction, usually manifests as a result of abnormal oscillatory movements, the measurement and analysis of the vibratory pattern of vocal folds has the potential to provide detailed information on the pathophysiology of the vocal folds during phonation (Hanson et al., 1983).

The study of vibratory movements has drawn a lot of researchers recently. Several methods have been developed with the objective of visualizing the rapid movements of the vocal folds.

Methods of studying vocal fold vibration

The vocal cords vibrate in the frequency range 100-300 hz during normal conversation and even at higher levels during singing. Observation of such vibrations require special methods. The following are some of the methods used to study vocal fold vibration.

1. Stroboscopy.
2. Ultra-sound glottography/Echoglottography.
3. Ultra-high speed photography.
4. Inverse filtering.
5. Photo-electric glottography (PGG).
6. Electroglottography (EGG).

Stroboscopy

Schonhari (1960) was the first one to make extensive and pioneering studies with the use of a modern laryngo-stroboscopy. In this technique the light source of the stroboscope emits intermittent light flashes, which can be synchronized with vibratory cycles when the flashes are emitted at the same frequency as that of the vocal fold vibration, a sharp and clear still image of the vocal-folds is observed. When the flashes are emitted at frequencies slightly less than the frequency of the vocal fold vibration, giving rise to a systematic phase delay of the consecutive light flashes, a slow motion effect is produced (Hirano, 1981). Stroboscopy does not give any objective recording but is entirely depended on the investigators subjective impression of slow motion.

Ultrasonic glottography:

First described by Hensch (1964), makes use of short ultrasound pulses generated by electrically excited ultrasound transducer with a repetition frequency of about 10 MHz (Homer et al, 1973). The transducer probe placed on the thyroid lamina, and the reflected ultra-sound pulse will be picked by a transducer, visualized as a curve on a cathode ray oscilloscope.

Ultra high speed photography:

The technique involves photographing the vibratory movements of vocal cords by a special camera at a speed of about 4300 frames per second (Hallin et al, 1977).

The larynx can be viewed directly in a small mirror suitably positioned far back in the mouth. By illuminating the vocal cords with a high intensity light beam. Fransworth

(1940) was able to make movies of vocal cord motion at 4000 frames/sec.

This method is invasive and hence requires a great deal of cooperation from the subject. It is not only expensive but also consumes a lot of space and time.

Anatomical abnormalities of pharynx and larynx may cause problem. But the advantage with this method is that it facilitates frame by frame analysis of various parameters of the vibration of vocal cords.

Inverse filtering method:

It is an acoustic procedure in which the inverse of the lip radiation and vocal tract spectral contributions are used to remove the acoustic effects of supraglottal vocal tract leaving the glottal volume flow. The more abnormal the voice, the more direct to choose inverse filter parameters. This method was first described by Miller (1959), Sondhi (1975). But for a signal having large Jitter value, the inverse will be the poorest choice of techniques.

Photo-electric glottography (PGG):

This is a technique (Sonesson, 1959 and 1960) in which light, being transmitted through the skin of the neck, is allowed to pass through the glottis and is picked up by light-conductive rod introduced into the mouth. When the vocal folds vibrate, the glottis is alternately varies corresponding to the actual glottal area. The light conducting rod is connected to a multiplier phone tube, and on to a cathode ray oscilloscope. A curve is then obtained which corresponds to the vibration of vocal cords.

This method is better than stroboscopy because graphical display is possible and better than ultra-high speed photography because it is economical.

This method does not allow conclusions concerning the vibratory movements of one vocal-fold according to Homer et al, 1973.

Photo-electric glottography, unlike electroglottography gives more information during the open portion of the glottal cycle (Hanson et al, 1983).

Electro glottography (EGG):

The principle is based on the fact that human tissue conducts electric current (Colton et al, 1983). The electroglottography registers the contact between the vocal cords as a time varying signal (Childers and Krishnamurthy, 1985). When the two gold-plated guarding electrodes are placed on either side of the neck, at the level of the vocal folds.

This technique makes use of motion induced variation in the electrical impedance between two electrodes placed on the skin covering the thyroid laminae. A week, high frequency signal (0.5 - 10 MHz) is applied to one electrode. The other electrode picks up the electrical current passing through the larynx. The transverse electrical impedance varies with the opening and closing of the glottis, and results in a variation of electrical current in phase with the vibratory phase of the vocal folds.

This technique was first developed by Fabre (1957). Improvements in the apparatus and application of the technique to clinical investigation have been extensively performed by several investigators (Fourcin and Abberton, 1972: Fourcin , 1981). The relation between the impedance of the electroglottogram and the underlying physiology of the vocal folds has been well documented by several investigators (Pederson 1977, Childers, Smith and Moore 1984, Gilbert, Lecluse, Broacaer and Verschure, 1975).

Lecluse and his co-workers (1975, 1977) recorded EGG simultaneously with stroboscopic images, and related the EGG recording to the glottal images.

Fourcin (1979) made simultaneous recordings of EGGs and airflow velocity curves for different modes of phonation and described the method to interpret the electroglottograms. He also emphasized that fundamental period of the vocal fold vibration could be determined quite accurately using EGG.

In contrast to PGG whose output signal reflects the size of the glottal area during the open phase, the output signal of EGG convey information regarding the contact area of the vocal folds (Koster and Smith, 1970). So EGG could be useful for investigating the glottal condition during the closed phase.

The EGG, however, appears to be considerably affected by artifacts, including variations in the impedance between the electrodes and the skin, vertical displacement of the larynx in relation to the electrodes, conditions of cervical structures other than glottis, and so on. It is difficult to determine the extent to which the contact area of the vocal fold contributes to the output signal of EGG.

Discussing the various parameters of voice, Michel and Wendhal states that "glottal waveform cannot be easily defined as some of the other parameters. Basically, however, an index of glottal waveform may be obtained by calculating (a) the opening time of the vocal folds, (b) the closing time of the vocal folds (c) the open time, (d) the closed time, all during a single vibratory cycle".

Different workers give different description of the glottal waveforms. For example Hirano (1981) divides one vibratory cycle into two major phases, the open phase and the closed phase. Open phase is further divided into opening and closing phase.

Moore and Thompson (1965) state that the following two conditions are present for normal phonation.

(l) All the tnree phases of the vibratory cycle viz. opening pnase, closing phase, ana closea pnase.

(2) Tne motion of the two cords tena to be relatively synchronous and equal in amplitude.

the information obtained througn tne electrogiortography can be summarised as follows:

(l) It proviaes far more information about the closea phase of the groutal cycle than about the open pnase ana in particular, it provides some level 01 insight about vertical contact changes.

(2) It is nut possible to deterime the exact. insight of opening or closing of the vocal words (Roster anu Smith, l970). It is clear, however that a minimum resistance peas represents Closure, while the opposite peak snows a point in tne open phase,. Tne slupes between tne peaks currespunu, at reast grossly, to opening ana closing pnases. onset or closure is usually signrea by a rapid rail of resistance, witn a knee" in the closing portion 0r trie wave childrens, Naik, Larar, Krishnamurtny ana moore, 1983; Childers, Smitn and moore, 1905;.

(o) qualification or phases or tne vocal fold cycle on the basis of Lx is or questionable validity, although quantitative measures of Lx may be relevant to evaluation of voice disorder.

(4) Lx may permit qualitative description of laryngeal actions especially when used in conjunction with other types of measures (Hirano, 1981; Valiancies, Gatherson, Pasternak, Guisez, Placy, 1971; Titze and Talkin, 1981; Kitzing, 1982, Baer, Titze, Yoshika, 1983).

The following have been listed regarding various aspects of measurements of E.G.G.

(1) Electrode placement - Lecluse, Brocarr and Vershcure (1975) have reported that signal to noise ratio is optimized when the electrodes are positioned at the level of the vocal folds.

(2) Skin - electrode resistance - there is some impedance introduction at the electrode - skin interface. If the electrode impedance remains constant it constitutes no problem. Slow drift will be filtered out by the high-pass characteristics of the Lx mode, but will alter the Gx trace. Relatively fast changes of electrode resistance, however, will introduce artifacts into the data. Consequently, electrodes must be clean and firmly fixed at properly prepared site.

(3) Fat tissue is a very poor conductor. A substantial fatty layer under the skin can degrade the Lx signal

badly. The presence of significant fat may explain why electroglottography has not been particularly successful with very young children, although other factors may also be responsible (Holm, 1971).

(4) Vertical larynx height changes for different, articulations and phonational qualities, especially for Fo (Ewan and Krones, 1974, Shipp; 1975, 1979; Shipp & Izdebski, 1975). This results in a change in the relationship of the electrodes to the vocal folds and thereby influences the electroglottographic waveform. If phonations at different pitches are to be compared, caution in interpretation is advisable.

(5) Head movement alters the relationship of neck structures and may compromise the data output. The high-pass filtering of Lx will eliminate much of the baseline shift, but some artifacts may still remain. It is important that the subjects head be stabilized with a head rest.

Various quotient and index can be calculated using the measurements of duration of different phases of the vibratory cycle in order to study the glottal wave forms.

On the basis of analysis of a great many cases, Vonleden, Moore, (1961), Yangihara (1967) have drawn the following conclusions:

(1) Benign lesions do not prevent vibration of the vocal fold on which they are located. Both folds vibrate at the same frequency.

(2) In general, abnormal vibration patterns are typical of disease, with the possible exception of very small lesions.

(3) The most common symptom of disease is frequent and rapid changes in vibratory rate.

(4) Damping of vocal fold vibration is caused by all but the very small lesions.

(5) Great increases in excursion are often associated with paralysis.

(6) There is almost always asynchronism of vibration of the two folds. That is, they will move out of phase.

(a) The phase shift may be constant during the cycle, or it may change.

(b) If the phase shift affects the closed phase the approximated edges of the vocal folds will deviate from the mid line.

(7) It is common for either the normal or the diseased vocal fold to cross the midline during part of the glottal cycle.

(8) Projecting soft tumours tend to follow the motions of the opposing healthy vocal fold but firm tumours do not.

(9) The period of closure is prolonged at the site of a projecting tumour. The projection however, prevents any approximation in adjoining areas.

(10) The open quotient is often increased.

Hirano, Gould, Lombiase and Kakita (1981) - have confirmed many of these findings in cases of unilateral vocal fold polyps, cycle-to-cycle wave form variability is considerable in many cases of laryngeal pathology. Rapid changes in the glottal wave form contribute significantly to the perception of vocal roughness (Coleman, 1971).

E.G.G. is normally employed to investigate the vibratory pattern of the vocal folds by analysing the impedance variations registered during the vibratory cycle. Regarding pathological conditions (Van Michal, 1967), studying glottic wave morphology in subjects with nodules of the vocal folds, observed a notch in the portion responding to the adductory phase of the vibratory cycle. However in recent time the investigators have sought to know the existence of pathgonomic traces for functional or organic pathologies responsible for dysphonic and the modifications of the traces themselves after adequate treatment (Motta, Cesari Iengo, Motta Jr. 1990).

Some of the investigations have indicated the possibility of using E.G.G. in clinical assessment and treatment of voice disorders.

Dejankere and Lebacq (1985) state that abnormal E.G.G. findings can be considered in five different ways.

(1) Pitch characteristics (too high or low).

(2) Vibrational irregularities (Jitter & Shimmer) demonstrated by Fo histograms (Kitzing 1982, Fourcin, 1981).

(3) Special features of the signal in the case of diplophonica (Dejonckers & Lebacq, 1983).

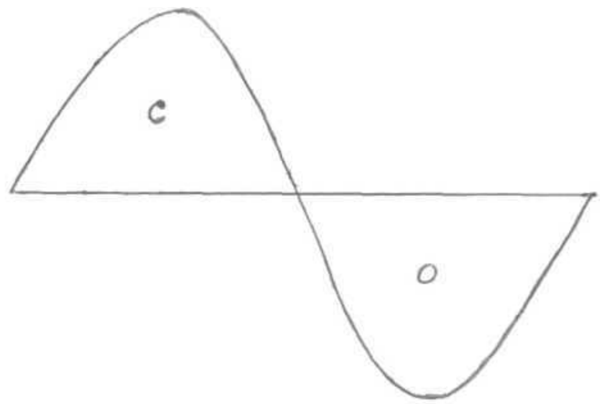
(4) Qualitative waveform of the modified wave form (Wescheler 1977, Fourcin, 1981)

(5) Spectral analysis of the waveforms (Kelman 1981).

Dejoncker & Lebac (1985) made an attempt to quantify the shape of E.G.G. signal. The purpose of their work was to provide an answer to the following question.

Can a single E.G.G. parameter be easily and systematically qualified in order to show a possible difference between subjects with a characteristics pathology such as vocal nodules and normals?

In order to answer the question, they measured the quotient "S" for each curve. The ratio is the ratio between the upper half of the cycle i.e. closed half and the lower half of the cycle i.e. open half.



$$SR = \frac{\text{CLOSED HALF}}{\text{OPEN HALF}} = \frac{C}{O}$$

They concluded saying that in case of pathological subjects the "S" ratio is much lower compared to the normal (Pathological subject 0.4073 and normal 0.65669).

They also showed that mean value of "S" ratio was significantly different and high among normals than vocal nodule cases. That is to say, the contact area is reduced in case of vocal nodules and this reduced vocal fold contact is an etiologic factor of vocal nodules.

Soron (1967) has developed sound synchronized high speed cinematography equipment with which he has produced data. He has found that positive air pressure peak within the glottal cycle varies with the proportion of time that the cords are closed, with the cords closed about 50% of the glottal period, the acoustic peak appears during early opening time of the glottis. As the proportion of closure time decreases, the position of the acoustic peak means to a later point in the glottal area where peak coincides when the glottis does not close. The acoustic peak occurs during the closing phase.

Ohala (1966) on the other hand, has used a glottograph with which he has found peak of pressure during the closing phase of the glottal cycles in which cord-closure time was relatively longer, contradicting Soron's study (1967).

Kitzing and Sonnesson (1974) studied 20 young females during normal phonation using E.G.G. and found the values for open Quotient, Speed Quotient and Rate Quotient. For low pitch the values were 0.63, 1.1, 2.3 and for high pitch 0.77, 1.1, 1.7 respectively. For weak intensity the values were . 0.83, 1.1, 1.5 and for strong intensity they were 0.7, 1.1, and 2.1 respectively.

The concluded that:

* OQ increases as pitch increases and intensity decreases.
* SQ increases as intensity increases but is not influenced by pitch.

* RQ increases as intensity and pitch decreases.

Kitzing and Loquist (1979) used PGG and EGG for evaluation of voice therapy. One of the subjects, a 45 years old woman, showed changes in Fo, OQ & SQ after the removal of oedema and subsequent voice therapy.

Hanson (1983) compared three cases with vocal pathologies with a normal subject using PGG. He calculated different quotients for comparison and chief among them was OQ which was 0-44 for normal and 0.84, 0.42 and 0.55 for pathological cases. SQ which was 1.13 for normal and 5.2, 2.66 and 1.90 for pathological subjects.

Fourcin (1981) states that for vigorous breathy voice the contact phase of Lx wave form is distinguished by the presence of small, well defined, positive closure phase. The contact phase is more rapid and the open phase is relatively longer.

In case of orally voice the laryngeal wave form typically shows pairs of vocal contact separation sequence in which a small peak proceeds a large peak, both occurring with considerable temporal irregularities. The small peak has a relatively slower onset than longer and the width of larger peak indicates a very long closure duration.

Fourcin (1981), using Fx histograms, was able to differentiate between laryngitis and normals. He has studied the possible affects of smoking using Fx histograms on different age groups. He has also studied pathological subjects like recurrent laryngeal nerve palsy, laryngeal . . . . . . and vocal polyp. While discussing the use of laryngographic studies, he states that studying of the Lx wave form is useful not only for the assessment of phonatory function but also helpful in therapy.

Kitzing et al (1982) in their aerodynamic and glottographic study of the glottal cycle of voice with hard attack and breathy attack state that in both cases about five cycles are required for the glottis to reach a stable mode of vibration.

Kelman (1981) obtained the following results for vowel /u/ 12 cycle (154 Hz) by a male and vowel /i/ 14 cycle (204 Hz) produced by a female. He did not find consistent differences in the results obtained for different vowels. In his study the majority of phonations required between 7 to 16 cycles for the amplitude to become steady. His data showed that the male subjects took significantly longer time than the female subjects to attain steady amplitude. These probably reflect higher fundamental frequency for females and also greater mass and inertia of male vocal folds.

Childers et al (1984) reported, unusual change in the rising slope of the Lx wave forms in individuals with vocal nodules and extensive cancer. They also observed double periodicity of Lx wave forms in a patient with unilateral paralysis of vocal cords. However, they also reported that EGG wave forms of certain individuals with vocal cord paralysis appeared normal and Lx wave forms of some normals appeared abnormal.

Fourcin et al (1972) also reported that Lx wave forms in cases of different laryngeal pathologies like vocal polyp, unilateral vocal cord paralysis, vocal nodules, vary from that of normal Lx waveforms. But they also observed that Lx wave forms are not necessarily impaired uniformly in laryngeal pathologies and one part of the utterance may be normal while others are very disturbed.

Motta et al (1990) observed 432 patients and divided them as follows: 50 subjects not affected by any kind of dysphonia, 66 presenting a functional hyperkinetic dysphonia, 92, having nodules involving one or both vocal folds, 86 with mono or bilateral polyps of the vocal folds, and 53 affected by mono or bilateral Rainke's oedema.

They found different types of EGG patterns:

(a) In normal subjects the glottic wave was characterized by a curved peak and a more or less uniform inclination of the ascending and descending portions.

(b) The glottic wave showed a particularly sharp peak and a reduced amplitude in 93% of cases, the remaining 7% did not give any significant alterations.

(c) A plateau like glottis wave observed in 95% of cases, in the remaining 5% such alterations could not clearly be confirmed.

(d) A single notch in the portion corresponding to the adductory phase occurred in 72% of cases, the remaining 28% gave a nearly normal trace.

(e) A single notch (25% of cases) or a double notch (68%) were noticed in 93% of cases with vocal polyps along the portion corresponding to the adductory phase, the remaining 7% gave a glottic trace not far from normals.

(f) A single notch (24%) or a double notch (72%) recurred in Reinke's Oedema's. While in the remaining 4% of cases an irregular wave was noticed, which did not allow the identification of the ascending and the descending phase.

Table I. Showing the summary of the Morphology of the EGG curve in different types of dysphonia.

Types	Morphology
Normal	Curved peak, uniform ascending and descending portions. Normal amplitude.
Functional Dysphonia:	
Hypokinetic dysphonia	Particular sharp peak, reduced amplitude.
Hyperkinetic dysphonia	"Plateau" - like glottic wave.
Organic dysphonia:	
Vocal nodules	A single notch in the portion corresponding to the adductory phase.
Vocal polyps	Single notch (25%) or a double one (68%) in adductory phase.
Reinke's Oedema	Single notch/double notch, irregular wave, difficult to identify the ascending and descending phases.

Henson et al (1983) reported EGG findings with individuals having normal larynges with distinct phonatory abnormalities like spastic dysphonia (adductor type), Parkinsonism and arsenic poisoning. They reported that the Lx wave forms of individuals with spastic dysphonia showed a relatively longer closure period resulting in decreased Open Quotient. The Sq values were more than normal values, indicating the abnormally short closing time. They attribute this findings to the increased tension of vocal cords as compared to normals.

Lx wave forms of individuals with parkinsonisms indicated, open phase longer than normals, incomplete glottal closure, which may explain the breathiness of their voice. They also reported large values of Jitter and Shimmer.

Similarly Lx wave forms of individuals who suffered acute arsenic poisoning indicated large values of Jitter and Shimmer and very short or incomplete periods of glottal opening.

Haji et al (1986) suggested that the EGG can be considered as a more suitable technique than voice signal methods for perturbation analysis, as EGG wave forms are less complex than voice signals and is unaffected by the acoustic resonance of the vocal tract.

They further reported that the frequency and amplitude perturbation of EGG, especially the amplitude perturbation

1. Open Quotient:

	Mean values of OQ		
	/a/	/i/	/u/
Males	0.69	0.71	0.72
Females	0.74	0.72	0.71

2. Speed Quotient:

	Mean values of SQ		
	/a/	/i/	/u/
Males	1.98	1.74	1.79
Females	2.25	2.28	2.30

3. Speed Index:

	Mean values of SI		
	/a/	/i/	/u/
Males	0.378	0.247	0.266
Females	0.377	0.361	0.362

4. "S" Ratio:

	Mean values of SR		
	/a/	/i/	/u/
Males	1.13	1.12	1.16
Females	1.13	1.10	1.09

5. Jitter:

	Mean values of /J/ (Msec)		
	/a/	/i/	/u/
Males	0.065	0.11	0.067
Females	0.058	0.03	0.048

6. Shimmer:

	Mean values of /S/ (dB)		
	/a/	/i/	/u/
Males	0.033	0.066	0.15
Females	0.700	0.370	0.44

Chandrashekar (1987) studied Lx wave forms of dysphonic males and females in vowels /a/, /i/ and /u/ at comfortable level. He reported values of different parameters of Lx wave forms as follows:

1. Open Quotient:

	Mean values of OQ		
	/a/	/i/	/u/
Males	0.53	0.54	0.56
Females	0.55	0.55	0.54

2. Speed Quotient:

	Mean values of SQ		
	/a/	/i/	/u/
Males	3.00	2.04	1.90
Females	2.93	2.24	2.57

3. Speed Index:

	Mean values of SI		
	/a/	/i/	/u/
Males	0.23	0.21	0.23
Females	0.13	0.37	0.38

4. "S" Ratio:

	Mean values of SR		
	/a/	/i/	/u/
Males	1.23	1.29	1.28
Females	1.24	1.14	1.46

5. Jitter:

	Mean values of /J/ (Msec)		
	/a/	IV	/u/
Males	0.70	0.41	0.25
Females	0.20	0.19	0.19

6. Shimmer:

	Mean values of /S/ (dB)		
	/a/	IV	/u/
Males	0.78	0.17	0.74
Females	0.87	0.91	0.92

Waryam Singh (1988) has reported the use of electro-laryngograph for speech rehabilitation in near-total laryngectomy with myo-mucosal valved neo-glottis.

"For the past two years electro-laryngography has been used to study the site and nature of function of the neoglottis in speech production" (Waryam Singh 1987). The electrolarynogography wave form has been used for therapy in a speech rehabilitation programme. This low cost non-invasive technique provides qualitative and quantitative information about vocal cord vibration (Abbetton and Fourcin, 1984).

Waryam Singh (1987) performed electrolarynogography on eight patients who had undergone the operation of near-total laryngectomy with myo-mucosal neoglottis.

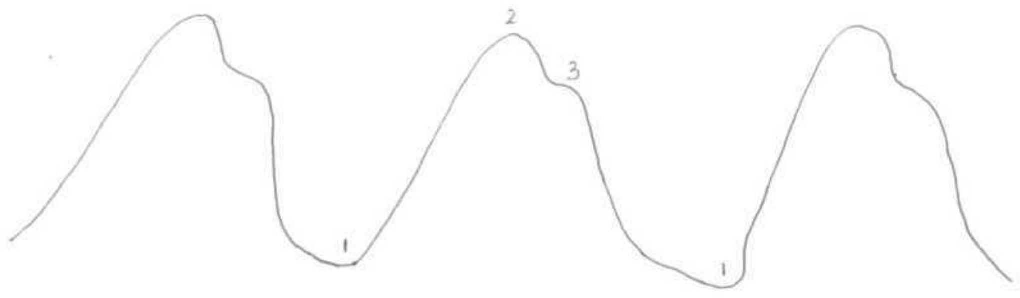
The electrolaryngography recording of all the patients showed a smooth and regular wave pattern, very similar to that of a chest register wave form of a normal and healthy adult larynx.

The recordings demonstrate clearly whether the neoglottis is closed or open. The amplitude variation represents the varying degree of neoglottal vibratory activity.

Individual transient variations of a creaky voice and falsetto register seen in normal and healthy adults were also seen briefly on the recordings of the patient, but the most consistent wave form appears to be very similar to that of a chest register of a normal healthy adult.

The EGG wave patterns of the neoglottis and those of the normal larynx demonstrate a close similarity. The wave pattern reveals that the neoglottis not only controls airflow through it, but also vibrates like normal vocal folds.

In near-total laryngectomy with myo-mucosal neoglottis the remnant of the healthy uninvolved thyro-arytenoid muscle with its intact nerve supply is used to fashion the pharyngeal end of the myo-mucosal shunt. It controls the volume of airflow into the pharynx during speech and contracts during swallowing to prevent aspiration.



EGG wave form shows that, with its myo-mucosal covering, the thyroary teroid acts as a vibratory source. It is important that during surgery this muscle is dissected carefully along with its delicate nerve supply, as the presence of healthy muscle with its intact nerve supply is essential for control and mobility.

Balaji (1989) studied 8 dysphonic males and 8 dysphonic females for few laryngeal parameters. He concluded that:

1. Dysphonic males as a group differed from normal males with respect to OQ, SI, jitter and shimmer.

2. Dysphonic females as a group differed from normal females with respect to open quotient and jitter.

3. Dysphonic males did not differ from dysphonic females in any of the parameters

4. Electrolarynogograph could differentiate normals and dysphonics on more parameters.

Ronbean, Muller and Arabia Guidet (1987) concluded from study on the evolution of trace during the change of laryngeal mechanism. They concluded saying that, the decrease of amplitude of the EGG signal accompanied by a change in the shape of the wave when passing from mechanism I (chest voice) to mechanism II (Falsetto).

Hanson et al (1988) made an attempt to compare the findings between EGG and PGG for the cases with recurrent laryngeal nerve paralysis, superior laryngeal nerve paralysis, combined recurrent and superior laryngeal nerve paralysis with ideopathic causes, individual patients with resection of vegal nerve and normals.

These studies of patients with carefully selected lesions of laryngeal nerves indicates that there are specific variations in the vibratory pattern of different lesion to laryngeal innervation. It appears that glottographic measures can provide useful information regarding pathological phonation.

The two measure OQ and SQ require knowledge of maximal glottal area which is not easily derived from the EGG waveform. Thus electroglottography alone could not provide the information necessary to calculate these parameters. The simultaneous use of PGG and EGG signals provided complimentary information, as has been previously noted.

Roch, Comti, Eyrand, Dubreuil (1990) conducted a study with synchronization of glottography and laryngeal stroboscopy. They reported that, the observations of the vibration of the vocal cords with synchronization allows:

1. To achieve a better understanding of the EGG curve.
2. To observe the variability of the variation cycle-by-cycle, which stroboscopy does not allow, especially in case of morphological pathology, this variability is great.
3. To approach the intrinsic muscular behaviour in functional voice disorders.

Childers et al (1990) conducted a study in order to correlate vocal fold physiology and electroglottography. They selected few parameters such as:

1. The instant of the opening of glottis.
2. The instant of the closing of the glottis.
3. The instant of maximum opening of the glottis and compared between normal larynges and patients with disorders. They also made measurements using synchronized ultra high speed laryngeal films and EGG wave form collected from normals and pathological voices.

Their research findings suggest that:

1. Specific EGG features are associated with certain gross vibratory characteristics of both normal and pathologic voices (Lee & Childers 1989, Pinto, Childers and Lalwani, 1989). Although supporting data are still limited, even subtle vibratory characteristics appear to be reflected by the EGG wave form (Hicks, Bae, Childers and Moore, 1987).

2. The EGG is confirmed as useful for analysis/synthesis purposes, as well as for modelling laryngeal behaviour (Childers, 1986).

Unfortunately, the limitations include:

1. EGG based voice performance impression (such as Fo, loudness, quality factors, etc.) confirm what the clinician already can hear or can measure in the other way.

2. The EGG reveals little about voice quality. For eg. a breathy voice with complete glottal closure (Childers and Krishnamurthy, 1987).

3. EGG cannot recognize some significant features of vocal-fold physiology. Photographic evidence reveals that the vocal folds can vibrate with many variations in the amount and region of contact, and with changes in fold contours and do not involve contact. Because the EGG is designed to monitor vocal fold contact (not movement per sec), it

is unable to monitor these non-contact types of vibratory patterns.

4. The waveform is not in a form that can be understood or communicated.

Fundamental frequency in phonation:

Fundamental frequency is the lowest frequency that occurs in the spectrum of a complex tone. In voice also, the fundamental frequency is considered the lowest frequency in the voice spectrum. This keeps varying depending upon several factors.

"..........both quality and loudness of voice are mainly dependent upon the frequency of vibration. Hence it seems apparent that frequency is an important parameter of voice" (Anderson 1961). The fundamental frequency in phonation for adult males and females (Indian population) as reported by different investigators are as follows:

Investigators	Males	Females
Sheela (1974)	126	217
Jayaram (1975)	123	225
Nataraj & Jagdeesh (1984)	141	237
Vanaja (1986)	127	234
Nataraja	119	223

All these studies showed a significant difference between males and females for fundamental frequency.

Thus it is apparent from above studies that males use a significantly lower fundamental frequency when compared to females. It is also seen that change in fundamental frequency is associated with a change in prescribed voice quality.

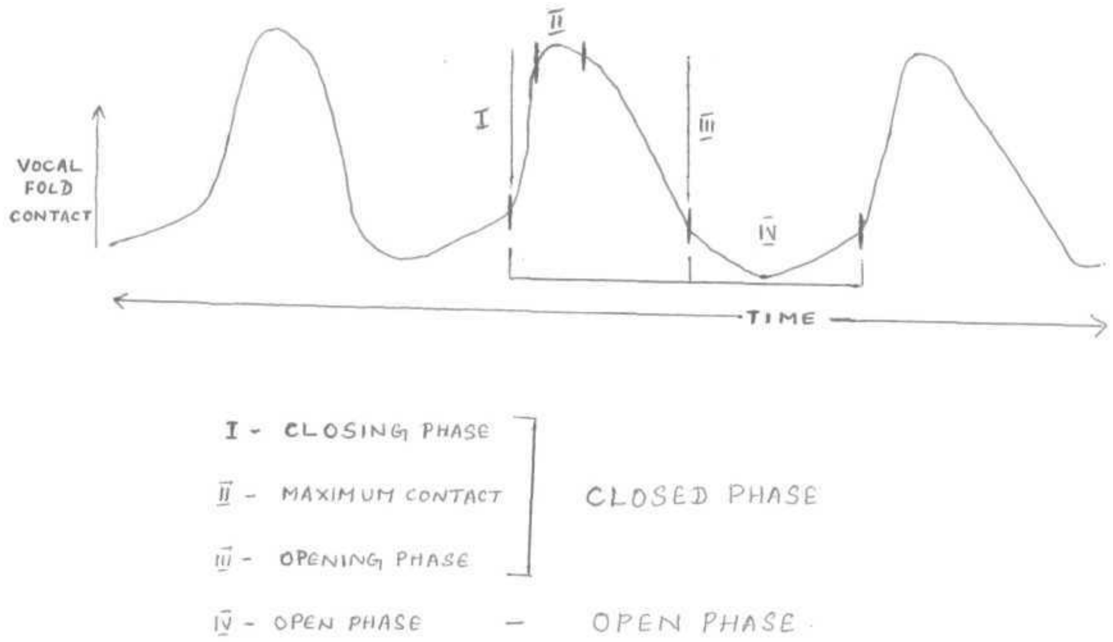
Fourcin et al (1989) in their tutorial review state that details of vocal fold vibration can be related to a typical Lx cycle for normal modal voice. Four main features of this waveform can be seen quite clearly:

I. A steep rising edge.
II. A maximum peak.
III. A shallow falling edge.
IV. A trough essentially constant with time.

These correspond to the vocal fold:

I. Closing phase.
II. Maximum closure.
III. Opening phase and
IV. Open phase Lecluse (1977).

The relative durations of these phases can change with the voice quality. The phases (I to III) are often referred collectively as "closed phase" since the folds are in some degree of contact since the start of the closing phase (I) to the end of the opening phase *(III),* as against the open phase (IV).



VOCAL FOLD OPEN & CLOSED PHASES & THE LARYNGOGRAPH OUTPUT WAVEFORM

They say that the waveform plots mentioned above, can be gained with various software packages. Plots relating to OP, CP, OQ, CQ, Ox, Sx and Vx are only available as research tools at present.

One measure which was the subject of their experimental work was the automatic measure of vocal fold closed and open phases in each vocal fold vibratory cycle. In relation to the figure above, these relate to the length of (IV) open phase (OP) and (I-III) the closed phase (CP) (Davis and Lindsey 1986; Lindsey, Davis and Fourcin 1986). These measures can be expressed in various ways:

a. as a ratio:

i. Open to closed phase ratio: OP/CP.

ii. Closed to Open phase ratio: CP/OP.

b. as a quotient which is the percentage of current cycle (Tx) for which the open or closed phase exists:

i. Open quotient (OQ) = L(OP/Tx) x 100)]%

ii. Closed quotient (CQ) = L(CP/Tx) x 100)]%

The ideal definitions of CP and OP can be observed in the figure and it can be seen that these rely on a visual interpretation of the Lx wave shape. They are events on Lx which are difficult to locate reliably by an automatic procedure, thus various compromises are employed. The currently employed methods for automatic estimation of OP and CP parameter are described by Davis et al (1986).

Experimental measures of closed (or open) quotient can be investigated in the long or short term. In short term these data are plotted time alligned with the original speech and Lx wave forms. Measures or OQ and/or CQ are being used in the investigation of the effect of training on the singing voice (Howard & Lindsey, 1987), Lindsey and Howard (1989). Investigations of long term closed quotient changes are based on closed quotient Scattergram (Qx = Closed quotient against fundamental frequency of excitation scattergrams) in which each CQ value, measured in a cycle-by-cycle basis, is plotted against the corresponding Fx value.

Tx = Fundamental periodic time of excitation.

Fx = Fundamental frequency of excitation.

Sx = Silent larynx excitation interval duration distribution.

Qx = CQ excitation scattergram.

Howard, Lindsey & Allen (1990) did a study to test the hypothesis that training/experience and the vocal improvement which the investigators assumed to result from these, can be related to increasing value of measurable parameter. Again the closed quotient measurements derived automatically from the laryngograph output are directly compared with measurements obtained from an automatic inverse filtering technique.

Two octave ascending and descending major scales and a two minutes read passage were analysed for each subject. For every cycle in the Lx wave form the closed quotient (CQ) values and the corresponding fundamental period were measured using the automated Lx based analysing technique. The scattergram of CQ against logarithm of fundamental frequency or Qx (18) were also produced.

1. They found that the trained subject read the passage with a wide fundamental frequency range, suggesting an expressive reading style, and with a range of CQ values.

2. Moreover, during his Sung scale, he maintains CQ towards the high end of his spoken CQ range.

1. The untrained subject used wide range of both fundamental frequencies and CQ values. He has a slightly lower fundamental frequency range when compared to the trained singer, but be used considerably lower CQ values throughout.

2. When he sings the scale the CQ values are at the lower and of his speaking range.

3. The untrained subject who did not find the top notes of the scale easy to attain, exhibits a drop in CQ values for these notes whereas a trained counterpart maintains high CQ values.

The trained subjects (i.e. 5 years of training) had a high mean CQ (0.50%) though the singing mean CQ values are higher than the speech mean CQ i.e., the most highly trained singers seem to be using a more acoustically efficient voice in their normal speech than untrained singers.

The CQ means were significantly different for trained and untrained subjects. They state that the acoustic excitation to the vocal tract is produced when the vocal folds come into contact. When the vocal folds separate, an acoustic path exists via the open glottis to the subglottal cavities. Sound energy that takes this path is completely lost to the listener since it is absorbed in the essentially anechoic environment of the lungs.

Less acoustic energy will be lost to the listener due to the coupling in of the subglottal cavities if the time in each vocal fold vibratory cycle during which the folds are together is increased i.e., the value of CQ is high. Other effects of this action include: (a) less stored lung air being vented in each cycle with the reduced open phase, improving the efficiency of energy usage and enabling notes to be held for a longer time; and (b) less breathiness of voice quality.

Thus by increasing CQ, the professional singers are able to make use of natural acoustic consequence of an adjustment to the manner in which the folds vibrate to increase overall system efficiency, by means of:

a. An increase in output acoustic energy associated with.

b. A decrease in expenditure of stored input energy.

Howard, Lindsey and Palmer (1991) conducted a study of 21 adult female singers and measured the close quotient for prose reading and singing notes of two octaves. They also took into account the number of years of training in singing.

The Lx was time differentiated and the positive peak were used to measure the start of the closed phase. The end of the closed phase was marked when the negative going Lx waveform crosses a fixed ratio (7:3) of the current cycle's amplitude. The time between the start of the closed phase in one cycle and that in the next cycle gave the fundamental period for that cycle. The CQ was given by (Closed phase)/ (Fundamental period) x 100%.

The results showed that in singers with less or no training exhibited a definite falling of CQ values as Fo increases while those towards the other end i.e., trained singer's have rising CQ values as FO increases.

Fourcin (1990) discusses a convenient and clinically oriented way of quantitatively estimating laryngeal closed phase variation in speech. The term voice quality according to Fourcin refers to those characteristics of laryngeal excitation in the vocal tract which are best able to define its resonances. In pathological condition, three quantitatively defineable factors can transform the "quality" of the speaking voice from being poor and inappropriate to being acceptable. These factors are:

i. The frequency range and regularity of vocal fold vibration.
ii. The rapidity of vocal fold closure.
iii. The effectiveness of closure of vocal folds during each period of vibratory cycle.

Clinically the use of the electrolaryngograph in the study and examination of the normal and pathological voice has been based on the analysis of period to period range and regularity. Dx and Cx plots provide a quite effective basis for the rapid clinical appraisal of the voice features relating to the frequency range and regularity of vocal fold vibration. An other important characteristic is that they can be derived directly from the source of excitation in the larynx, rather than being inferred from measurement made on acoustic output of the vocal tract.

The second factor is important if the closure of the vocal folds is not well defined in time. The Lx waveform can be used directly to gain some insight into such conditions in a relatively sensitive way by the direct measurement of the time from the onset of closure to its peak. In addition Lx can be combined with acoustic analysis to provide a quantitative measure of spectral definition by the use, for instance, of inverse filtering of the acoustic signal on the basis of "closed phase" information the interval between the onset of vocal fold contact and vocal fold separation.

When formant energy decay occurs substantially within the closed phase of each period of vocal fold vibration, good voice quality is produced because the resonant response of the vocal tract is then sharply defined with minimum of internal energy loss. If the closed phase is short, formant energy is prematurely lost by sub-glottal damping and vocal tract resonance are less well defined.

The third factor in voice quality is formally defined by the closed phase duration to the extent that the closure is patent. The inter arytenoid gap which is often associated with breathy voice production will introduce damping in addition to that attributable to the low closed-to-open phase ratio which normally characterizes this condition. In many practical situations the two effects are quite closely related and there would certainly be clinical and more general assessment-advantage in arriving at a simple approximation to the third factor by considering the closed phase measurements alone. Palmer, Allen, Howard, Lindsey and House (1990) did a study on laryngeal coarticulation at different segmental and prosodic environment. They used waveform from the larynogograph to measure these effects. The methods were:

1. Observing the cycle-by-cycle change in the closed quotient (the percentage of each larynx period that is taken up by the closed phase).

2. Laryngeal co-articulation occurs in English VCV sequences specifically in the form of a healthy vowel offset before "S". Lindsey et al (1991) suggest that this results in a reduction in the higher frequency energy associated with increased subglottal damping.

They used intervocalic /h/ and /?/ and concentrated on the laryngeal level to test the hypothesis that "CQ" decreases in anticipation of a following voiceless fricative (during which vocal folds will be abducted) and that VD increases before /?/ (or a glotally reinforced stop) in preparation for complete closure at glottis.

The Lx period (Tx), the closed phase, duration, the open phase duration and the corresponding CQ were calculated by three different methods. In all the methods the point of vocal fold closure is taken as positive peak in the differential of the Lx waveform. The point of opening is derived by three alternative methods:

1. As the negative peak in the Lx differential.

2. As the crossing point of a fixed ratio of 70:30 of the current cycle's peak to peak amplitude.

3. As the point at which the opening slope has the same amplitude value as the point of closure for that cycle.

A comparison of measurements of glottal closed phase derived on the one hand from inverse filtering, and on the other hand from the Lx waveform using the second of the above mentioned methods has shown a high degree of correlation between measurements made from the two methods.

The data revealed that all the four subjects recorded had a significant decreases in the CQ before /h/, as measured from the mid point of the first vowel, and three of the four subjects had a significant rise in the CQ value before the glottal stop /?/. The mean CQ value was 47% for each utterance.

Thus the review of literature indicates that the study of vocal fold vibration using EGG provides a very useful information in understanding the physiology of both normal and abnormal voice productions. Such an information will be of great help in the diagnosis and treatment of voice disorders. Many parameters have also been used to measure the vocal fold abnormalities. Inspection of the literature shows that a new parameter - the closed quotient, can give more information regarding the effeciency of the glottis. But there are few studies relating CQ measures to perceived voice quality.

Hence, the present study was aimed to obtain a relationship between CQ and perceived voice quality and to find usefulness of different parameters in the indication of glottal effeciency.

METHODOLOGY

The purpose of the present study was to determine the reliability&validity of soft-ware programme for automatic extraction of glottal parameters.

2) to determine the relationship closed quotient (CQ) and the quality of voice.

3) To determine the relationship fundamental frequency (fo) and the following parameters:

   1. Closed quotient
   2. Open quotient
   3. Speed quotient
   4. Speed index

Need for automatic extraction: From the display of EGG wave form different points are marked to obtain the durations of different phases. These points are marked in the manual method of extraction by the investigator and hence

a) It is time consuming and laborious.

b) The number of cycles which can be analyzed are limited using this method, owing to the above-mentioned drawback.

c) This method is subjective hence the possibilities of errors in marking the different points on the Lx waveforms thus may lead to erroneous results.

d) Inter-personnel reliability for the measurements obtained using this method is not good thus, the automatic extraction becomes mandatory.

A program was developed by a computer engineer. Averaged normal wave was synthesized and based on that the program was written, in 'C' language, in order to automatically extract the glottal parameters. 1) CQ, 2) FO, 3) OQ, 4) SQ & 5) SI. This program basically uses cut-off points on positive and negative peaks in percentages, to calculate different periods used for determining the glottal parameters. The cut of points were required to determine the closed period and open period as shown in the diagram. The program has the facility for selecting and varying the following.

a) Sample file name
b) positive and negative cut-off %.
c) Number of cycles to be analysed - depending on the need this can be decided. It is a known fact that the reliability and validity would improve with the analysis of more cycles of samples.
d) Starting point of the consecutive cycles to be analysed.

The program was called "E.G.G.".

The experiment was divided into two parts:

Part A - validity of automatic program.

Part B - comparison of glottal parameters with perceived quality of voice.

PART A

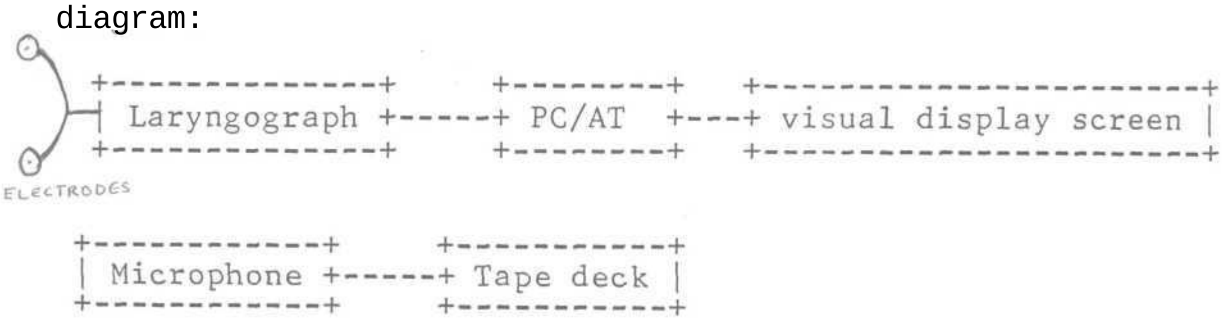
A total of 30 normal adults (15 males and 15 females) were subjects for the study. The age range of the subjects was between 18 to 31 years. All subjects were free from any speech and hearing problems and any ear, nose and throat problems at the time of measurement.

Instrumentation:

The following instruments were used for the present study:

1. Electrolaryngograph (kay elemetrics corporation)
2. PC/AT 386 SX with speech interface unit voice and speech systems)
3. Recording Deck (Sonodyne) with unidirectional microphone.
4. Software for acquisition, display and analysis.

The instruments were arranged as shown in the block diagram:



The signal from the laryngograph was fed to the computer to obtain the display of the glottal waveforms ana the starting point used to measure different parameters of the glottal waveforms FIG.2 shows the glottal waveform of a normal subject.

The computer programme had facilities to display the glottal waveform in terms of time vs amplitude (in secs) on x-axis and y-axis respectively. The time at any given point could be measured by moving the cursor horizontally based on which the glottal parameters were calculated by the computer. Using the newly developed software, automatic extraction of the glottal parameters was also possible.

The investigator provided the following details to the computer:

a) file name of the sample
b) positive, negative cut-off percentage .
c) number of cycles to be analysed
d) the starting point of the consecutive cycles to be analysed.

Fig. 3 shows the display of results using the manual extraction program for 10 cycles. Fig. 4 shows the display of results using the automatic method of extraction using same glottal wave for 100 cycles.

Procedure:

1. The subject was seated comfortably in front of the instruments.

2. The subjects were instructed as follows: "Now I am going to place these electrodes on your neck and when I say please say /a/ in your natural pitch and loudness and prolong it till I say "stop". Try to maintain the pitch and loudness level constant".

3. The two electrodes were placed on the neck ones the thyroid alae.

4. The gain out the speech interface unit was adjusted to be within an optimum value to avoid distortion.

5. The position of the electrodes were adjusted until clear lx waveform appeared on the display screen when the subjects phonated. Their voice was simultaneously recorded using an audiotape using a microphone and a recording deck.

6. Thus the voice signal was recorded and stored on hard disc of the computer at a sampling rate of 8KHz.

Manual extraction of parameters:

From each subject's phonation that was recorded and stored, ten successive cycles of glottal waveforms were selected for analysis. From the display of the waveform the time (milli secs) of the starting point, of the ten successive cycles selected, was also noted. Each cycle was analysed by marking the cursor at various points as shown in Fig. 2, to obtain the duration of various phases of the vocal fold vibration. After marking different points in each cycle, different parameters of lx waveform were calculated by the computer (average for 10 cycles) i.e. 1) CQ 2) Fo 3) OQ 4) SQ 5) SI.

Automatic Extraction:

7. These parameters were also calculated by using the automatic extraction program "(EGG)" for 10 and 100 cycles (average values). Here again, the starting time was same as that used for manual extraction the negative cut off peak percentage was changed between 0.075, 0.1 and 0.12 while that of positive peak was kept constant at 0.05.

8. The Number of harmonics clearly visible for each sample were obtained and noted using a different program (LTAS).

Thus, the data for both manual (10 cycles) and automatic methods of extraction (10 & 100 cycles) for the 30 subjects were analysed. T-tests, spearmans were used in order to find out the extent to which the values obtained by the two methods approximate each other.

Subjects: Apart from the subjects used in Part-A, six trained singers were taken for the study, of which, three were males and three were females. The subjects had undergone a minimum of 4 years of training in singing. The age range of the subjects was between 18-38 years. These subjects were free from speech and hearing, ear, nose, throat problems at the time of experiment.

The details about the subjects have been described in table-A.

TABLE- A

Subject description	Age rage	No. of subjects Males	Females	Total
Trained singers	18-38	3	3	6
Untrained singers	18-31	15	15	30
Total	18	18		36

Instrumentation: The instruments used were described in part-A.

Procedure: Apart from the procedure used in Part-A, the following were also included. The subjects were untricted as follows.

a) "Say /a/ at the lowest possible pitch without straining yourself at a normal loudness level and prolong it till I say "stop". Try to maintain the pitch and loudness level constant".

b) Now say /a/ at the highest possible pitch, loudness level and prolong it till I say "stop". Try to maintain the pitch and loudness. constant.

The subjects phonation for all the three pitches was recorded on both computer and taperecorder and 10 successive cycles of glottal waveforms were selected from each sample for further analysis. The time (insecs) of the starting point, of the 10 successive cycles selected, was also noted. Each cycle was analysed using manual and automatic as described in part-A.

The number of harmonics clearly visible for each sample were obtained noted using as described in part-A.

Perceptual evaluation

Perceptual evaluation was done for the recorded voice samples using five judges. These judges were post graduates in speech and hearing.'they were asked to listen to the sample and rate them on a 5 - point rating scale with one being very poor voice quality and +ive being very good voice quality. The most frequent rating was given to the sample. On this basis, three groups were separated were as follows:

a) poor voice quality - samples which had a score of one/two
b) satisfactory - samples which had a score of three.
c) Good voice quality four and five.

Thus, the sets of data for both manual extraction method (10 cycles) and automatic extraction (10 & 100 cycles), for the 30 subjects for three different pitches of phonation were analysed. The data was subjected to statistical analysis were and t-test and spearmans correlation were done. Thus 30 sets of data in part A and 18 sets of data in part B were obtained.

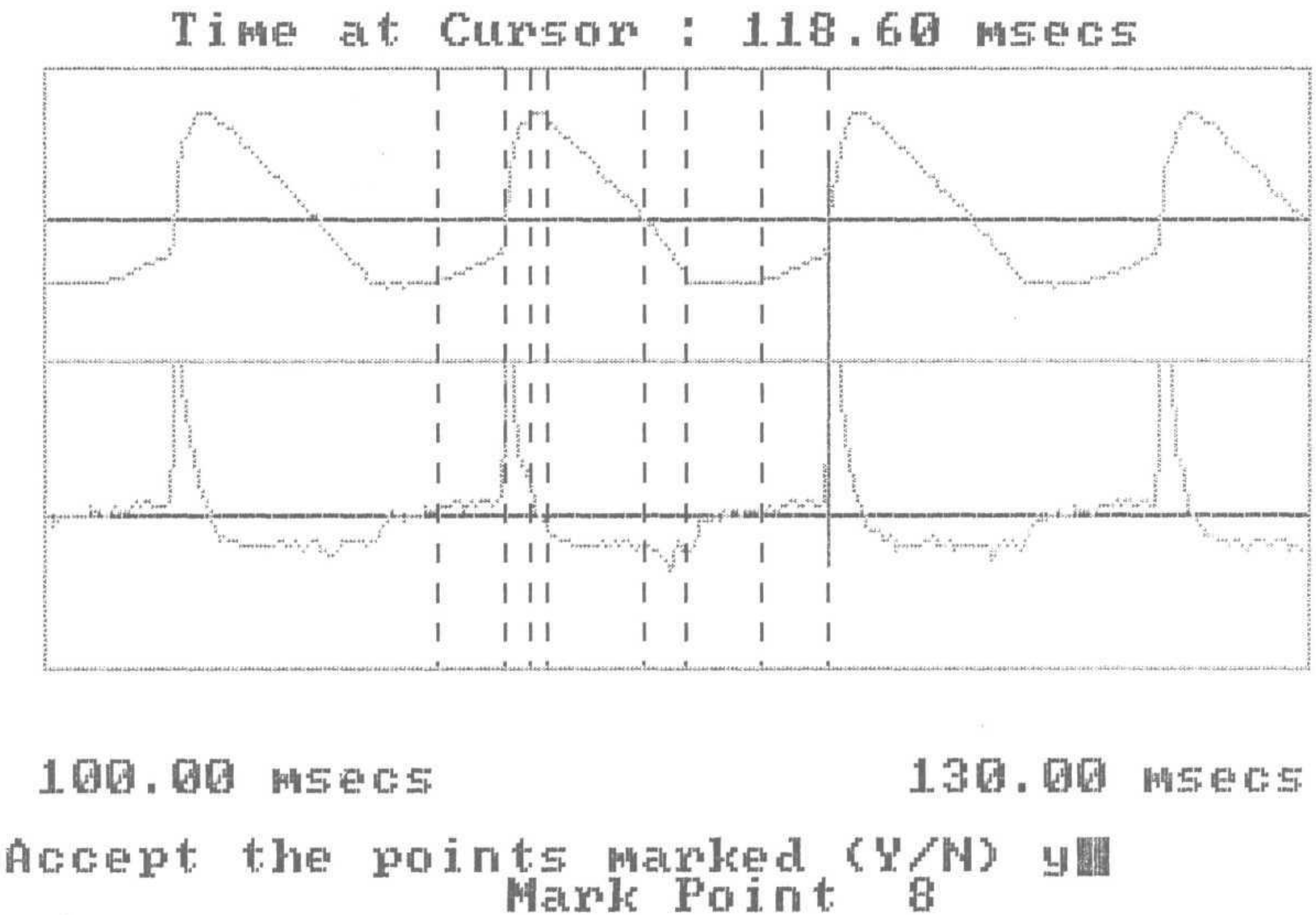


FIG: 2. Lx WAVEFORM DISPLAY

```
+-----------------------------------------------------------------------------+
|                                                                             |
|                      VAGHMI - Glottal Measurements                          |
|                                                                             |
|                            +----+                            +----+         |
| Open Time [msecs]         |0.40|     Close Time [msecs]     |1.80|         |
|                            +----+                            +----+         |
|                                                                             |
|                             +----+                           +----+         |
| Opening Time [msecs]        |2.20|    Closing Time [msecs]   |3.30|         |
|                             +----+                           +----+         |
|                                                                             |
|                             +----+                           +----+         |
| Open phase  [msecs]         |2.60|    Close Phase [msecs]    |5.10|         |
|                             +----+                           +----+         |
|                                                                             |
|                             +----+                 +----+            +----+ |
| Total Period [msecs]        |7.70|  Open Quotient  |0.34|  S Ratio   |1.00| |
|                             +----+                 +----+            +----+ |
|                                                                             |
|                            +------+                +----+                   |
| Fo [in Hz]                 |129.87|  Speed Quotient |0.67|                   |
|                            +------+                +----+                   |
|                                                                             |
|                                                   +-----+                   |
|                                    Speed Index    |-0.20|                   |
|                             +-----+               +-----+                   |
|                             |OK   |                                         |
|                             +-----+                                         |
+-----------------------------------------------------------------------------+
```

Fig. 3 showing display of results by mannual extraction method.

```
 EGG Analyser  Vers 2.0 - Nov 1992 -by Ranna M V
 ALL INDIA INSTITUE OF SPEECH & HEARING, Mysore-6

Enter EGG File name [dat]: bala5
Enter sampling rate :  8000
Enter number of cycles to process : 10
Is signal Unipolar(U) or Bipolar(B) : U
Enter positive threshold in percentage : 0.07
Enter negative threshold in percentage : 0.1
Enter starting point in Secs :      0.1
Enter file name to store result:      bala5.egg
>>>The averaged values for 10 cycles :
Open  Time     :  1.9625 mSecs
Opening Time   :  3.3125 mSecs
Close Time     :  0.725 mSecs
Closing Time   :  1.8125 mSecs
Speed Quotient :  1.83
Open Quotient  :  25.5698
Close Quotient :  76.223
Speed index    :  0.292671
Frequency      :  130.31 Hz

Total Time elapsed : 17.5824 Secs.
```

Pressing Time : 0-2198 Secs

FIG: 4

RESULTS AND DISCUSSION

As revealed by the review of literature the parameters closed quotient, fundamental frequency, open quotient, speed quotient and speed index have been useful in studying the laryngeal conditions of both normals as well as pathologicals. Closed quotient has been found to be an important parameter in the estimation of glottal efficiency. However not much data is available which relates these parameters to the quality of voice. Therefore the present study was aimed at examining the glottal parameters especially the closed quotient and its relationship with perceived voice quality.

The following parameters were obtained from each subject for the phonation of /a/.

1. Closed quotient.
2. Fundamental frequency.
3. Open quotient.
4. Speed quotient.
5. Speed index.

As the manual method had drawbacks (explained in the methodology) the automatic method of extraction was warranted. Hence in the first part of the study, the data was obtained by using manual method (10 cycles) and automatic extraction method (10 and 100 cycles). The data thus obtained was subjected to statistical analysis and the mean, standard deviation and range were obtained for each method. The significance of difference and correlation between the two methods were found using T test and pearson's - R correlation respectively. Based on the results the positive and negative cut off percentages were selected so as to get the nearest approximation to the manual method.

It was found that by using the positive cut off percentage as 7% and negative cut off percentage as 10%, there was no significant difference between the automatic extraction method and the manual method for all parameters. Further these two methods of extraction showed maximum correlation for all the parameters when the positive and negative cut off percentages were adjusted at 7% and 10% respectively.

Table I shows the mean, standard deviation and correlation co-efficient values for different glottal parameters for phonation of /a/ as obtained by different methods of extraction.

The normative data for different parameters as obtained from the present study is as follows.

Closed quotient:

	Males	Females
Mean	76.53	77.64
Standard deviation	6.59	4.95

No studies are available to compare these norms for closed quotient.

Fundamental frequency:

	Males	Females
Mean	121.60	232.55
Standard deviation	9.41	22.11

The fundamental frequency in phonation for Indian population as reported by other investigators also lie within this range (Jayaram, 1975; Nataraj and Jagadeesh, 1984, Vanaja, 1986; Gopal, 1980; Sheela, 1974).

Open Quotient:

	Males	Females
Mean	25.02	25.23
Standard deviation	6.68	4.95

The open quotient values for Indian population as reported by other investigators do not correlate with that of the present study. This is because the open quotient is defined differently in the present study

$$\text{Open quotient} = \frac{\text{open time}}{\text{total time}} \times 100$$

whereas other investigators have defined open quotient as

$$\text{Open quotient} = \frac{\text{open phase}}{\text{full period of vibration}} \times 100$$

open time + opening time

total time

However, when this definition was used in the present the values of open quotient correlated with that of other investigators (Sridhara, 1986; Chandrashekar, 1987) were

	Males	Females
Mean	0.73	0.66
Standard deviation	0.04	0.18

Speed quotient:

	Males	Females
Mean	4.07	5.08
Standard deviation	2.04	2.22

The speed quotient values for Indian population, as reported by different investigators also lie within the range of present study (Sridhara, 1986; Chandrashekar, 1987).

Speed index:

	Males	Females
Mean	0.53	0.61
Standard deviation	0.20	0.17

The speed index values for Indian population as reported by different investigators, also lie within the range of the present study.

COMPARISON BETWEEN MANUAL AND AUTOMATIC METHODS OF EXTRACTION

Closed Quotient

Table I shows high positive correlation (greater than 0.8) for closed quotient between the manual and automatic extraction methods. Again the difference in their mean value in less for these two parameters. There is no significant difference, even at 0.05 level of significance, between the two methods. The mean of CG? closed quotient as obtained by manual method, Automatic extraction method (10 cycles) and automatic extraction method (100 cycles) are 79.46, 78.13 and 78.32 respectively.

Thus the hypothesis la stating that, "there is no significant difference between the manual and automatic method of extraction of the parameter closed quotient", is accepted.

This suggests that the automatic method is valid in extracting the parameter closed quotient.

Fundamental Frequency

Table I shows high positive correlation (greater than 0.9) for the parameter fundamental frequency between the manual and automatic extraction method. Again, the difference in their mean value is less for these two methods. There is no significant difference even at 0.05 level of significance between the two methods. The mean of fundamental frequency as obtained by manual method, automatic extraction method (10 cycles) and automatic extraction method (100 cycles) are 175.09, 179.66 and 179.65 respectively.

Thus the hypothesis Ib stating that, "there is no significant difference between the manual and automatic method of extraction of the parameter fundamental frequency", is accepted.

This suggests that the automatic method is valid in extracting the parameter fundamental frequency of voice.

Open Quotient

Table I also shows a high positive correlation (greater than 0.8) for the parameters open quotient between the manual and automatic extraction methods. Again the difference in their mean value is less for these two parameters. There is no significant difference, even at 0.05 level of significance between even at 0.05 level of significance between the two methods. The mean of open quotient as obtained by manual method, automatic extraction method (10 cycles) and automatic extraction method 100 cycles are 24.12, 24.22 and 25.88 respectively.

Thus the hypothesis Ic stating that "there is no significant difference between manual and automatic methods of extraction of the parameter open quotient", is accepted.

This suggests that the automatic method is valid in extracting the parameter open quotient.

Speed Quotient

Table I depicts a high positive correlation (greater than 0.8) for the parameter speed quotient between the manual and automatic extraction methods. Again, the difference in these mean value is lesser for these two methods and there is no significant difference even at 0.05 level of significance between the two methods. The mean of speed quotient as extracted by manual method automatic extraction method (10 cycles) and automatic extraction method (100 cycles) are 2.9, 3.69 and 3.74 respectively.

Thus the hypothesis Id stating that, "there is no significant difference between the manual and automatic methods of extraction of the parameter speed quotient", is accepted.

This suggests that the automatic method is valid in extracting the parameter speed quotient.

Speed Index

The study of Table I shows a high positive correlation (greater than 0.9) for the parameter speed index between the manual and automatic extraction methods. Again the difference in their mean value is less for these two methods.

There is no significant difference even at 0.05 level of significance between the two methods. The mean of speed index as obtained by manual method, automatic extraction method (10 cycles) and automatic extraction method (100 cycles) are 0.415, 0.463, 0.462 respectively.

Thus the hypothesis Ie stating that, "there is no significant difference between the manual and automatic methods of extraction of the parameter speed index", is accepted.

This suggests that the automatic method is valid in the extracting the parameter speed index.

The correlation coefficient between the two methods for these parameters show that the parameters, fundamental frequency and speed index have a greater correlation for the two methods as compared to that of the parameters closed quotient, open quotient and speed quotient.

This could be because of the subjectiveness involved in the manual extraction method which could have given rise to small errors in marking the points. The automatic extraction method objective and hence the error is minimal. This means that the automatic method is more accurate than the manual method. Thus, the first drawback of the manual method is taken care of by the automatic extraction method.

The average time taken for analysing (10 cycles) of glottal wave by the manual method was 7 to 8 minutes by an experienced clinician whereas, the average time taken for the analysis of 100 cycles using the automatic method was less than 2 seconds. Thus, the second drawback of the manual method of extraction is taken care of by the automatic extraction method.

The investigation plays no role in deciding the points in the automatic method as the points are selected automatically. This leads to 100% test-retest reliability. Thus the third drawback of the manual method of extraction is taken care of by using automatic extraction method.

More cycles are required to find out the variation especially in the pathological cases for the parameters as a function of time. This requires larger samples and is not feasible by manual extraction method as it is time consuming. Where as the automatic method of extraction can use a sample of even 100 cycles and calculate the parameters in a short time. Thus the fourth drawback of the manual method of extraction is also taken care of by using the automatic extraction method.

Table I shows that the values obtained by 10 cycles and 100 cycles of analysis by the automatic extraction method have a high positive correlation and very less difference in their means for the parameters considered (i.e., open quotient, closed quotient, speed quotient, speed index and fundamental frequency) with the co-efficient of correlation ranging between 0.94 and 0.99.

Thus the hypothesis I-f stating that, "there is no significant difference in the values of the parameters for 10 and 100 cycles of analysis by automatic extraction method", is accepted.

Thus the hypothesis I stating that "there is no significant difference between manual and automatic extraction method for the extraction of the glottal parameters", is accepted.

Further, experimental is carried out by using automatic extraction of the parameters for 100 cycles. This is because of the finding that there is no significant difference between the analysis by manual and automatic extraction method and they had a high positive correlation. Also the automatic extraction of glottal parameters is less time consuming than that of manual method.

Again there is no significant difference between the analysis of 10 and 100 cycles by automatic extraction method and also showed a high positive correlation.

Further, more sample is included by analysing 100 cycles than by analysing 10 cycles. Hence analysis of 100 cycles is preferred compared to analysis of 10 cycles. This becomes more important particularly in pathological cases.

Closed Quotient

The mean, standard deviation and range of closed quotient values for normal nonsingers for low pitch, habitual pitch and high pitch phonation of /a/, for males and females, as obtained by the automatic extraction method (100 cycles) is depicted in Table II.

Comparison of Males & Females

Table III shows that there is no significant difference, even at 0.05 level of significance between males and females for the values of closed quotient for low pitch, habitual pitch and high pitch phonation of /a/ vowel. The mean CQ of males and females for low habitual and high pitch phonation are 79.27 & 78.03; 76.53 & 77.64; and 73.1 and 74.57 respectively. This suggests that there is no effect of sex on the closed quotient values for normals. There are no studies done on this line to support this finding.

Thus the hypothesis IIa stating that, "there is no effect of sex on the closed quotient of non singers", is accepted.

This is because closed quotient is a quotient and does not depend on the period of glottal cycle, which is the major difference seen between males and females.

Relationship with Fundamental Frequency

Table IV shows that there is no significant difference, even at 0.05 level of significance, for low pitch versus high pitch phonation of /a/ for both males and females. However, there is a significant difference of habitual pitch verses high pitch for males at 0.05 level of significant. The mean CQ of males and females for low, habitual and high pitch phonation are 79.27 & 78.03; 76.53 and 77.64 and 73.1 and 74.57 respectively. Table IV also shows that the mean closed quotient of the habitual pitch is greater than that of high pitched phonation. This suggests that there is a decrease in the closed quotient as the fundamental frequency of voice increases.

Thus the hypothesis IIb stating that "there is no effect of changing fundamental frequency on the closed quotient of non singers", is rejected.

Howard et al (1991) state that "subjects with no formal training (in singing) exhibit a downward trend in CQ with raising FO". The finding in the present study is in agreement with that of Haward et al's study.

Relationship with Perceived Voice Quality

Perceptual judgement of voice quality of the audio recording of the samples were done on a five point rating scale by five judges. Rating one indicated very poor voice quality and rating five indicated very good voice quality. The ratings of the five judges were analysed and the inter judge reliability was found to have high correlation (> 0.85). The most frequent rating was given to the sample. On the basis of this there types of voice quality were separated as follows:

a. Poor voice quality - there samples which had score of one a two.

b. Satisfactory voice quality - these samples which had a score of three.

c. Good voice quality - those samples which had a score of four or five.

Table V shows that there is no significant difference, even at 0.05 level of significance, between these three types of voice, qualities (poor, satisfactory and good quality). However, the judges rated the voice based on the fundamental frequency. They rated the high pitch phonation as poorer than the habitual pitch phonation. Again, as discussed earlier, the closed quotient values reduced with an increase in pitch.

Discussing the similar finding in their study, Howard et al (1991) state that, "the main source of acoustic excitation to the vocal tract occurs when the vocal folds rapidly come together. The vocal folds rapidly come together. The vocal tract formats respond to each excitations epoch with the characteristic 'ringing[1], which decays in time as a function of their individual band widths. When the folds separate, an acoustic path exists via the open glottis to the subglottal cavities.

Sound energy that takes this path is completely lost to the listener since it is absorbed in the essentially anechoic environment of the lungs. Other effects of this action include (a) less stored lung air being vented in each cycle with reduced open phase, improving the efficiency of energy usage and enabling notes to held for a longer time, and (b) less breathiness of the voice quality".

The findings of the present study is in agreement with that of Howard et al (1991) study as an increase in close quotient means that the vocal folds are in contact for a longer time and this increase in CQ is associated with good voice quality.

Closed Quotient in Singers

The mean standard deviation and range of closed quotient for singers for low pitch, habitual pitch and high pitch phonation of /a/ for males and females, as obtained by automatic extraction method of (100 cycles) is depicted in Table VI.

Comparison of Males and Females

Table VII shows that there is no significant difference even at 0.05 level of significance, in the closed quotient between males and females. The mean of closed quotient of males and female for low pitch, habitual pitch and high pitch phonation are 83.92 & 82.57; 76.9 & 79.04; and 75.8 and 78.74 respectively. This suggests that there is no effect of sex on closed quotient of singers. No study comparing closed quotient with sex is available to support the findings.

Thus the hypothesis IIc stating that, "there is no effect of sex on the closed quotient of singers", is accepted.

Relationship with perceived voice quality

The perceptual judgement of the voice quality of singers indicated that all singers had a good voice quality. This rating never went below the rating of three. Again, rating was given only to high pitch phonation while the habitual and low pitch phonation were rated four or five by all the judges. The reason for this finding is same as that of non singers.

Thus the hypothesis II stating that "there is no relationship between closed quotient and glottal efficiency", is rejected.

Fundamental Frequency

The mean, standard deviation and range of fundamental frequency for normal non-singers for low pitch, habitual pitch and high pitch phonation of /a/, for males and females, is depicted in Table VIII.

Comparison of Males and Females

The significance of difference for the parameters fundamentals frequency between males and females for low pitch, habitual pitch and high pitch phonation of /a/ is depicted in Table IX.

The mean of fundamental frequency, for males and females, for low, habitual and high pitch phonation of /a/ for non singers are 119.88 & 215.67; 121.6 & 232.55 and 389.78 respectively. Table IX shows a significant difference at 0.01 level of significance between them.

Thus the hypothesis IIIa stating that, "there is no effect of sex on the fundamental frequency of non singers", is rejected.

Relationship with perceived voice quality

Table X depicts that there is a significant difference, at 0.01 level of significance, for the fundamental frequency between poor and good voice quality. Again, there is a significant difference at 0.05 level of significance for fundamental frequency between poor and satisfactory voice quality. However, there is no significant difference even at 0.05 level of significants, between satisfactory and good voice quality. This suggests that the judges might have rated the quality of voice based on the fundamental frequency of voice.

Thus, the hypothesis III b stating that, "there is no relationship between fundamental frequency and perceived voice quality", is rejected.

This finding is in aggreement with that of Anderson (1961) who states that "both quality and loudness of voice are mainly dependent upon fundamental frequency of vibration".

Fundamental frequency in singers

Table XI shows the mean, standard deviation and range of fundamental frequency of singers, for males and females, for low, habitual and high pitch phonation of /a/.

Table XII shows that there is a significant difference at 0.01 level of significance, in fundamental frequency of singers between males and females for low, habitual and high pitch phonation of /a/. This suggests that there is a relationship between sex and fundamental frequency.

Thus the hypothesis III c stating that "there is no relationship between sex and fundamental frequency of singers", is rejected.

Relationship with Perceived Voice Quality

The perceptual analysis showed that all the singers had good voice for low and habitual pitch phonation of /a/. However the quality of voice for some of the high pitched phonation were rated to be satisfactory. No sample got a score of less than three.

Thus the hypothesis III which states that "there is no relationship between fundamental frequency and glottal efficiency", is rejected.

Open Quotient

The mean, standard deviation and range of open quotient of non singers for low, habitual and high pitch phonation of /a/, for males and females as obtained by the automatic extraction method (100 cycles) in depicted in table XIII.

Comparison of Males and Females

Table XIV shows that there is no significant difference between males and females for open quotient for low pitch, habitual pitch and high pitch phonation of /a/ with their mean being 22.26% and 24.74%; 25.02% and 25.23%; and 31.26% and 30.46% respectively. This shows that there is no effect of sex on the open quotient in normals. This is because open quotient is quotient and does not depend on the period of glottal cycle, which is the major difference even between males and females.

Thus the hypothesis IV a stating that, "there is no effect of sex on the open quotient of nonsingers" is accepted.

Relationship with Fundamental Frequency

significant difference at 0.05 level of significance, between low and high pitch phonation and at 0.01 level of significance, between low and high pitch phonation and at 0.01 level of significance, between habitual and high pitch phonation.

Table XIII depicts that there is an increase in the mean of open quotient as a function of fundamental frequency Kitzing and Somerson (1974) state that, "open quotient increases as pitch increased and intensity decreases". The finding of the present study is in agreement with Kitzing and Somerson's (1974) study.

Thus the hypothesis IVb stating that, "there is no relationship between fundamental frequency and open quotient of nonsingers", is rejected.

Relationship with perceived voice quality

Table XVI shows that there is no significant difference, even at 0.05 level of significance between the three types of voice qualities (i.e., poor, satisfactory and good voice quality). However the judges seem to have rated the voice quality based on the fundamental frequency (described under fundamental frequency) with high pitch phonation being poorer again, as discussed earlier open quotient increased with increase in pitch. This may be because the vocal folds are tensed and there is a greater air escape during high pitch phonation as the time for which the cords remain open is longer. This means that the glottis is not converting the D/C source into AC energy effectively. Thus there is an increases in the breathiness of voice and quality becomes poor with an increase in open quotient.

Open Quotient in Singers

The mean, standard deviation and range of open quotient of singers for low, habitual and high pitch phonation of /a/, for both males and females, as obtained by automatic extraction method is depicted in Table XVII.

Comparison of Males and Females

Table XVIII depicts that there is no significant difference in the open quotient of singers between males and females. This is because it is a quotient which does not depend on the period of glottal cycle which is the major difference seem between males and females.

Thus the hypothesis IV c stating that, "there is no effect of sex on the open quotient of singers", is accepted.

Relationship with Fundamental Frequency

Table XIX shows that there is no significant difference in open quotient even at 0.5 level between low, habitual and high pitch phonation of /a/. That is there is no effect of fundamental frequency on the open quotient of singers.

Thus the hypothesis IV d stating that, "there is no relationship between fundamental frequency and open quotient of singers", is accepted.

Relationship with Perceived Voice Quality

As discussed under "closed quotient", all singers had good voice quality with their rating never going below three (rating three was given only for high pitch phonation). The reason for this is same as that for nonsingers.

Thus the hypothesis IV stating that "there is no relationship between open quotient and glottal efficiency"is rejected.

Speed Quotient

The mean, standard deviation and range of speed quotient of nonsingers for low pitch, habitual pitch and high pitch phonation of /a/, for males and females, as obtained by automatic extraction method (100 cycles) is depicted in Table XX.

Comparison of Males and Females

Table XXI depicts that there is no significant difference of speed quotient, even at 0.05 level of significance, between males and females for low, pitch phonation of /a/. However, it also indicates a significant difference at 0.01 level of significance, between males and females for habitual and high pitch phonation of /a/. The mean of speed quotient for males and females, for low habitual and high pitch phonation as obtained by automatic extraction method (100 cycles) are 2.02 and 4.28; 4.07 and 5.09; and 3.34 and 5.58 respectively.

Thus the hypothesis V a stating that, "there no effect of sex on the speed quotient of nonsingers", is rejected.

Relationship with Fundamental Frequency

Table XXII depicts that there is no significant difference in the values of speed quotient, even at 0.05 level of significance, between low and high pitch between low and habitual pitch and between habitual and high pitch phonation of /a/.

Kitzing and Somerson (1974) state the "speed quotient increases with intensity but is not influenced by pitch". The finding of the present study is in agreement with that of Kitzing and Somerson's (1974) study.

Thus the hypothesis V b stating that, "there is no relationship between speed quotient and fundamental frequency of non-singers", is accepted.

Relationship with Perceived Voice Quality

Table XXIII shows that there is no significant difference, even at 0.05 level of significance, between the three types of voice qualities (i.e., poor, satisfactory and good voice quality). Thus the hypothesis V c stating that, "there is no relations between speed quotient and perceived voice quality", is accepted.

Speed Quotient in Singers

Table XXIV depicts the mean, standard deviation and range of speed quotient of singers for low, habitual and high pitch phonation of /a/ a obtained by the automatic extraction method (100 cycles).

Comparison of Males and Females

Table XXV shows no significant difference, even at 0.05 level of significance, between males and females for low and habitual pitch phonation of /a/. However there is a significant difference, at 0.5 level of significance between males and females for high pitch phonation of /a/.

Thus the hypothesis V c stating that, "there is no effect of sex on speed quotient of singers", is partially rejected.

Comparing the mean value of singers and non singers (Table XX and XXIV) there is an increase in the range of speed quotient for non singers. As the singers were said to have good voice quality it be stated that a smaller range of SQ is associated with good voice quality.

Thus the hypothesis V stating that "there is no relationship between speed quotient and glottal efficiency" is partially rejected.

Speed Index

The mean, standard deviation and range of speed index values of non singers for low, habitual and high pitch phonation /a/, for males and females, as obtained by automatic method of extraction (100 cycles) is given in table XXVI.

Comparison of Males and Females

Table XXVII shows that there is no significant difference for of speed index, even at 0.05 level of significance between males and females for low and high pitch phonation of /a/. It also indicates a significant difference, at 0.01 level of significance, between males and females for habitual pitch phonation of /a/ vowel. The mean of speed index of non singers, for males and females for low, habitual and high pitch phonation of/a/are 0.25 and 0.54; 0.53 and 0.61; and 0.46 and 0.65 respectively.

Thus the hypothesis VIa stating that, "there is no effect of sex on the speed index of non singers", is rejected.

Relationship with Fundamental Frequency

Table XXVIII indicates that there is no significant difference in speed index, even at 0.05 level of significance, between low pitch and high pitch, between low pitch and habitual pitch and between habitual pitch and high pitch phonation of /a/.

Thus the hypothesis VIb stating that, "there is no relationship between fundamental frequency and speed index of non singers", is accepted.

Relationship with perceived voice quality

Table XXIX shows no significant difference of speed index values, even at 0.05 level of significance between the three types of voice qualities (i.e., poor, satisfactory and good voice quality.

Thus the hypothesis VIc stating that "there is no relationship between speed index and perceived voice quality of non singers", is accepted.

Speed Index in Singers

Table XXX shows the mean, standard deviation and range of speed index of singers for males and females, for low, habitual and high pitch phonation of /a/ as obtained by automatic extraction method (100 cycles).

Comparison of Males and Females

Table XXXI depicts that there is no significant difference of speed index between males and females for low and high pitch phonation of /a/. It also indicates a significant difference at 0.01 level of significance for habitual pitch phonation. Also, speed index is calculated from speed quotient which shows a significant difference between males - and females.

Thus the hypothesis VI d stating that "there is no effect of sex on the speed index of singers", is rejected.

Relationship with Fundamental Frequency

Table XXXII shows no significant difference of speed index, even at 0.05 level of significance, for males and females, for low, habitual and high pitch phonation of /a/. This suggests that there is no effect of speed index on the fundamental frequency of phonation.

Thus the hypothesis VI e stating that "there is no relationship between speed index and fundamental frequency of singers", is accepted.

Relationship with Perceived Voice Quality

Table XXXIII depicts that there is no significant difference of speed index, even at 0.05 level of significance, for males and females, between the three types of voice quality. This indicates that there is no relationship between speed index and perceived voice quality of singers.

Thus the hypothesis VI stating that, "there is no relationship between speed index and glottal efficiency", is accepted.

SUMMARY AND CONCLUSIONS

The study of the vibratory patterns of vocal folds has drawn attention of researchers. Recently several methods have been developed and the objective methods of studying the movements of vocal folds. One of them in electroglottography. E.G.G. has many advantages over other techniques mainly because it is a non-invasive technique and permits quantification of vocal fold vibration.

As there are not mostly studies in relating the parameters of EGG perceived voice quality, this study was undertaken. Also the newly developed automatic method of extraction was validated and used for obtaining various parameters of EGG.

30 normal subjects (15 males and 15 females) in the age range of 18 to 31 years and 6 trained singers (3 males and 3 females) in the age range of 22 to 38 years were studied using electrography (kay electronics corporation) and PC/AT with speech interphase unit (wipro and voice&speech systems). The following parameters were obtain for low pitch, habitual pitch high pitch phonation of keeping pitch and intensity constant.

1. Closed quotient, 2.fundamental frequency, 3. open quotient, 4. Speed quotient 5 speed index.

The data thus obtained was subjected to statistical analysis to find out the mean, standard deviation, range, significance of difference and correlation across the different pitches for all the parameters.

The following conclusions were drawn on the results:

1. The automatic extraction method using positive and negative cut off points as 7% and 10% respectively is valid in extracting all the glottal parameters studied.

2. There is no significant difference in the values of these parameters either by using 10 or 100 cycles of sample in the automatic extraction method, in case of normals.

3. There is no effect of sex on the CQ values in normals.

4. There is considerable change in CQ values of normals by changing the fundamental frequency of phonation. The CQ value decreases as the fundamental frequency of phonation increases.

5. There is considerable effect of training on the CQ values as singers show a higher value of CQ.

6. CQ can be used as an indicator of glottal efficiency (higher value of CQ is associated good voice quality).

7. There is significant difference between males and females in terms of fundamental frequency.

8. There is considerable effect of fundamental frequency on the perceived voice quality.

9. Fundamental frequency can also be used as cue for estimating the glottal efficiency as the quality of voice goes down with increase in fundamental frequency from habitural pitch to high pitch.

10. There is no effect of sex on the OQ values of normals.

11. There is considerable effect of Fo on OQ in normals (OQ decreases as the fundamental frequency increases).

12. OQ can be used as an indication of glottal efficiency (higher value of OQ is associated reduced voice quality).

13. There is considerable effect of sex on the SQ values of normals.

14. There is no effect of fundamental frequency on the SQ values of normals.

15. SQ is related to glottal efficiency (lower SQ value is associated good voice quality).

16. SQ is related to glottal efficiency (lower SQ value is associated good voice quality).

17. There is an effect of sex on SI values of normals.

18. There is no effect of fundamental frequency on the SI values.

19. SI is related to of glottal efficiency.

Thus the parameters CQ, OQ, SQ, SI & Fo gives valuable information in the estimation of glottal efficiency by desecrating the vocal fold vibratory patterns of normals. It is hoped that the programme for automatic extraction of the parameters would be useful in describing the vibratory patterns even in case of abnormal voice.

RECOMMENDATIONS FOR FURTHER STUDY

These parameters (mainly CQ may be studied with different laryngeal pathologies before, during and after therapy to find out the exact effect of therapy.

1. Other parameters can be considered for further study.
2. Other parameters can be considered for further study.
3. More trained singers may be used as subjects for further study.
4. The study many be carried out by using different consonant vowel combinations.
5. Other vowels may be considered for further study.
6. CQ may be rised abnormal subjects in order to establish the relationship between CQ and different laryngeal pathologies.

TABLE I

		Mean and standard deviation			correlation coefficient	
		manual	automatic 10 cyc	Automatic 100 cys	M vs A 10 No.	A10 vs A100
	CQ	75.67 8.74	78.98 5.11	78.61 5.62	0.83	0.98
	Fo	150.18 58.25	159.78 59.21	155.88 57.94	0.88	0.95
LOW	OQ	24.55 7.81	23.14 6.09	25.04 5.67	0.68	0.98
	SQ	2.37 1.35	2.72 1.82	2.72 1.89	0.81	0.99
	SI	0.334 0.245	0.349 0.250	0.343 0.252	0.89	0.96
HABITUAL	CQ	79.46 8.01	78.13 5.37	78.32 5.34	0.80	0.95
	Fo	175.09 54.02	179.66 56.49	179.65 56.47	0.9997	0.9997
	OQ	24.12 6.05	24.22 5.64	25.88 5.61	0.21	0.94
	SQ	2.9 1.32	3.69 2.129	3.74 2.25	0.85	0.99
	SI	0.415 0.229	0.463 0.248	0.462 0.253	0.90	0.99
	CQ	72.94 9.26	74.93 8.08	74.89 7.54	0.80	0.98
HIGH	Fo	333.47 99.45	348.42 97.44	350.71 102.37	0.96	0.99
	OQ	30.62 9.43	29.34 8.36	29.56 7.77	0.50	0.98
	SQ	2.96 1.88	3.98 2.17	3.97 2.18	0.84	0.48
	SI	0.359 0.223	0.487 0.268	0.483 0.268	0.95	0.99

Table-l snowing mean, SD ana correlation values or dirrerent methods of extraction.

TABLE II

		Mean		SD		Range	
		Males	Females	M	F	M	F
L	A_{1Q}	79.27	78.03	6.34	4.85	66.06-86.39	66.53-83.05
N	A_{10Q}	76.53	77.64	6.59	4.95	65.98-89.04	67.37-83.69
H	A_{1Q0}	73.1	74.57	8.81	6.26	55.82-84.85	65.27-83.03

Table II showing Mean, SD and range of closed quotient values for automatic extraction method for non singers.

TABLE III

	Male vs female (automatic 10 cys)	Male vs female (automatic 100 cys)
L	NS	NS
N	NS	NS
H	NS	NS

Table III showing Significance of difference of CQ between males and females for automatic extraction method for non singers.

TABLE IV

	Low vs Habibual pitch		Low vs High pitch		Habibual vs High pitch	
Sex	A10	A100	A10	A100	A10	A100
Male	NS	NS	NS	NS	NS	S*
Female	NS	NS	NS	NS	NS	NS

Table IV showing Significance of difference of CQ between different fundamental frequencies of phonation for non singers.

NS - NOT SIGNIFICANT AT 0.05 LEVEL

S* - SIGNIFICANT AT 0.05 LEVEL

TABLE V

	Poor vs Satisfactory	Poor vs Good	Satisfactory vs Good
A10	NS	NS	NS
A100	NS	NS	NS

Table V showing Significance of difference of CQ as a function of perceived voice quality for non singers.

TABLE VI

	Mean		Standard deviation		Range	
	Males	Females	M	F	M	F
L	83.92	82.57	0.35	3.37	83.67-84.16	80.12-86.41
N	76.90	79.04	2.16	2.27	74.95-79.23	77.44-80.65
H	75.80	78.74	6.78	9.32	70.81-83.12	68.53-86.77

Table VI showing Mean, SD and range of closed quotient values for automatic extraction method for singers.

TABLE VII

	Male vs female (automatic 10 cys)	Male vs female (automatic 100 cys)
L	NS	NS
N	NS	NS
H	NS	NS

Table VII showing Significance of difference of CQ between males and females for automatic extraction method for singers.

TABLE VIII

Mean		Standard deviation			Range
	Males	Females	Males	Females	Males	Females
Low	119.88	215.67	23.02	37.40	91-96-173-99	107-66-259.62
HB	121.60	282.55	9.41	22.11	109-55-140.83	195.63-274.41
H	349.00	389.78	112.74	92.72	190.85-485.33	305.41-590.77

Table VIII showing Mean, SD and range of fundamental frequency values for automatic extraction method for non singers.

TABLE IX

	Male vs Female (Automatic A10 cys)	Male vs Female (Automatic. 100 cys)
Low	S**	S**
Habitual	S**	S**
High	NS	S**

Table Ix. showing Significance of difference of Fo between males and females for automatic extraction method for non singers.

S** _ SIGNIFICANT AT 0.01 LEVEL.

TABLE X

	Poor vs Satisfactory	Poor vs Good	Satisfactory vs Good
A10	S	S	NS
A100	S	S	NS

Table X showing Significance of difference of Fo as a function of perceived voice quality for non singers.

TABLE XI

	Mean		Standard deviation		Range	
	Males	Females	M	F	M	F
L	104.94	209.47	2.06	27.24	103.48-106.39	180.73-234.92
N	125.67	239.10	7.32	54.77	117.24-130.56	200.37-277.83
H	231.17	359.34	12.69	18.51	219.30-244.55	345.36-380.33

Table XI showing Mean, SD and range of fundamental frequency values for automatic extraction method for singers.

TABLE XII

	Male vs Female (Automatic A10 cys)	Male vs Female (Automatic 100 cys)
Low	S**	S**
Habitual	S**	S**
High	NS	S**

Table XII showing Significance of difference of Fo between males and females for automatic extraction method for singers.

TABLE XIII

Mean		Standard diviation			Range
	Males	Females	Males	Females	Males	Females
A_{100}	22.26	24.34	6.23	4.98	15.27-73-09	19.77-36.43
HB	25.02	25.23	6.68	4.95	12.48-35.77	18.45-35.31
H	31.26	30.46	9.30	6.21	18.83-50.24	20.81-39.20

Table XIII showing Mean, SD and range of open quotient values for automatic extraction method for non singers.

TABLE XIV

	Male vs Female (Automatic A10 cys)	Male vs Female (Automatic 100 cys)
Low	NS	NS
Habitual	NS	NS
High	NS	NS

Table XIV showing Significance of difference of OQ between males and females for automatic extraction method for non singers.

TABLE XV

	Low vs habitual pitch		Low vs high pitch		Habitual vs high pitch	
Sex	A_{1Q}	A_{1Q0}	A_{1Q}	A_{1Q0}	A_{1Q}	A_{10Q}
Males	NS	NS	S*	S*	S**	S**
Females	NS	NS	NS	NS	NS	NS

Table XV showing Significance of difference of OQ between different fundamental frequencies of phonation for non singers.

TABLE XIX

	Low vs habitual pitch		Low vs high pitch		Habitual vs high pitch	
Sex	A_{10}	A_{100}	A_{10}	A_{100}	A_{10}	A_{100}
Males	NS	NS	S*	S*	S**	S**
Females	NS	NS	NS	NS	NS	NS

Table XIX showing Significance of difference of OQ between fundamental frequency of phonation for singers.

TABLE XX

Mean			Standard diviation		Range	
	Males	Females	Males	Females	Males	Females
low	2.02	4.28	1.12	2.12	0.9 to 4.41	1.54 to 8.01
Hab	4.07	5.09	2.04	2.22	1.14 to 7.78	1.94 to 8.05
High	3.34	5.58	1.67	1.99	1.33 to 5.74	2.86 to 8.66

Table XX showing Mean, SD and range of speed quotient values for automatic extraction method for non singers.

TABLE XXI

	Male *vs* Female Automatic A10 cys	Male vs Female (Automatic 100 cys)
Low	NS	NS
Habitual	NS	S*
High	S*	S*

Table XXI showing Significance of difference of SQ between males and females for automatic extraction method for non singers.

TABLE **XXII**

	Low vs habitual pitch		Low vs high pitch		Habitual vs high pitch	
Sex	A_{10}	A_{100}	A_{10}	A_{100}	A_{10}	A_{100}
Male	NS	NS	NS	NS	NS	NS
Females	NS	NS	NS	NS	NS	NS

Table XXII showing Significance of difference of SQ between different fundamental frequencies of phonation for non singers.

TABLE XXIII

	Poor vs Satisfactory	Poor vs Good	Satisfactory vs Good
A10	NS	NS	NS
A100	NS	NS	NS*

Table XXIII showing Significance of difference of SQ as a function of perceived voice quality for non singers.

TABLE XXIV

	Mean		Standard deviation		Range	
	Males	Females	M	F	M	F
L	1.16	1.92	0.37	0.31	1.00-1.32	1.63-2.24
N	1.48	1.48	0.36	1.07	1.06-1.75	0.73-2.24
H	3.30	1.32	1.50	0.86	1.58-4.33	0.51-2.23

Table XXIV showing mean standard deviation and range of SQ for automatic extraction method for singers.

TABLE XXV

	Male vs female (automatic 10 cys)	Male vs female (automatic 100 cys)
L	NS	NS
N	NS	NS
H	NS	NS

Table XXV showing Significance of difference of SQ between males and females for automatic extraction method for singers.

TABLE XXVI

	Mean		Standard diviation		Range	
	Males	Females	Males	Females	Males	Females
low	0.25	0.54	0.22	0.20	0.05 to 0.62	0.21 to 0.77
Hab.	0.53	0.61	0.20	0.17	0.06 to 0.77	0.31 to 0.77
High	0.46	0.65	0.21	0.1	0.1 to 0.67	0.47 to 0.77

Table XXVI showing Mean standard deviation and range of speed index values for automatic extraction method for non singers.

TABLE XXVII

	Male vs Female Automatic A10 cys	Male vs Female (Automatic 100 cys)
Low	NS	NS
Habitual	S**	S**
High	NS	NS

Table XXVII showing Significance of difference of SI between males and females for automatic extraction method for non singers.

TABLE XXVIII

Sex	Low vs habitual pitch A_{10}	Low vs habitual pitch A_{100}	Low vs high pitch A_{10}	Low vs high pitch A_{100}	Habitual vs high pitch A_{10}	Habitual vs high pitch A_{100}
Males	NS	NS	NS	NS	NS	NS
Females	NS	NS	NS	NS	NS	NS

Table XXVIII showing Significance of difference of SI between different fundamental frequencies of phonation for non singers.

TABLE XXIX

	Poor vs Satisfactory	Poor vs Good	Satisfactory vs Good
A10	NS	NS	NS
A100	NS	NS	NS

Table XXIX showing Significance of difference of SI as a function of perceived voice quality for non singers.

TABLE XXX

	Mean		Standard deviation		Range	
	Males	Females	M	F	M	F
L	0.069	0.291	0.099	0.07	0.0067-0.139	0.225-0.367
N	0.180	0.105	0.129	0.381	0.031-271.0	0.164-0.374
H	0.477	0.535	0.220	0.358	0.223-0.614	0.321-0.390

Table XXX showing mean standard deviation and range of SI for automatic extraction method for singers.

TABLE XXXI

	Male vs female (automatic 10 cys)	Male vs female (automatic 100 cys)
L	NS	NS
N	NS	NS
H	NS	NS

Table XXXI showing Significance of difference of SI between males and females for automatic extraction method for singers.

TABLE XXXII

	Low vs habitual pitch		Low vs high pitch		Habitual vs high pitch	
Sex	A_{10}	A_{100}	A_{10}	A_{100}	A_{10}	A_{100}
Males	NS	NS	NS	NS	NS	NS
Females	NS	NS	NS	NS	NS	NS

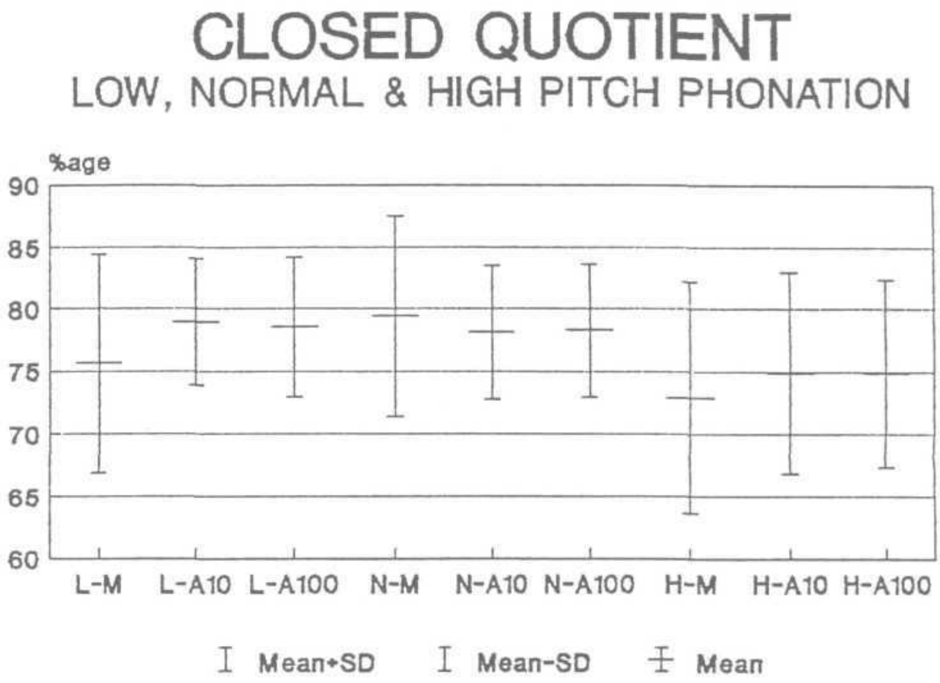
Table XXXII showing Significance of difference of SI between different fundamental frequencies of phonation for singers.

TABLE XXXIII

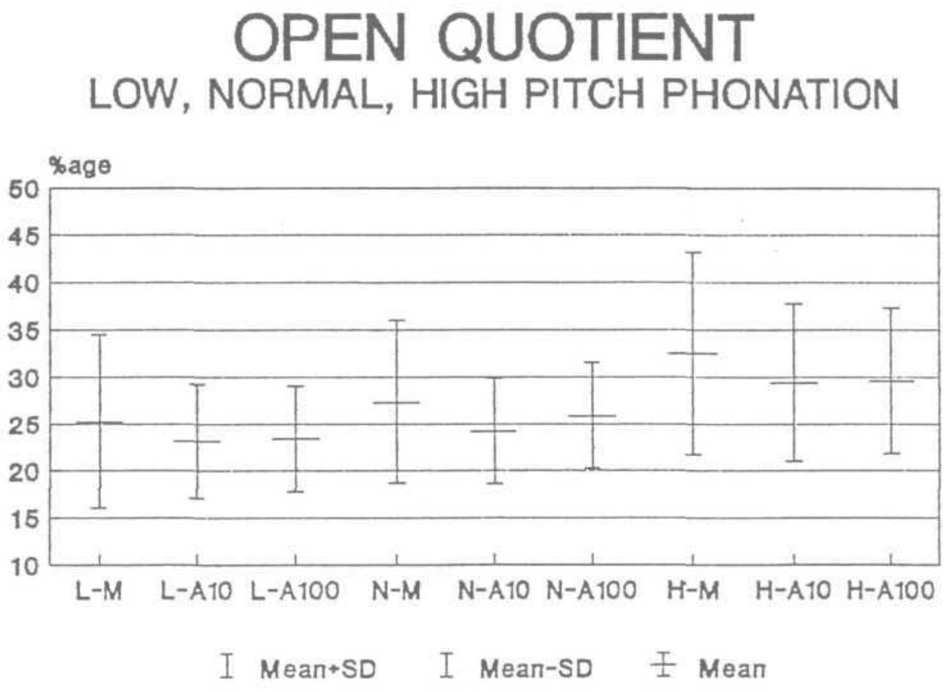
	Poor vs Satisfactory	Poor vs Good	Satisfactory vs Good
A10	NS	NS	NS
A100	NS	NS	NS

Table XXXIII showing Significance of difference of SI as a function of perceived voice quality for singers.

A

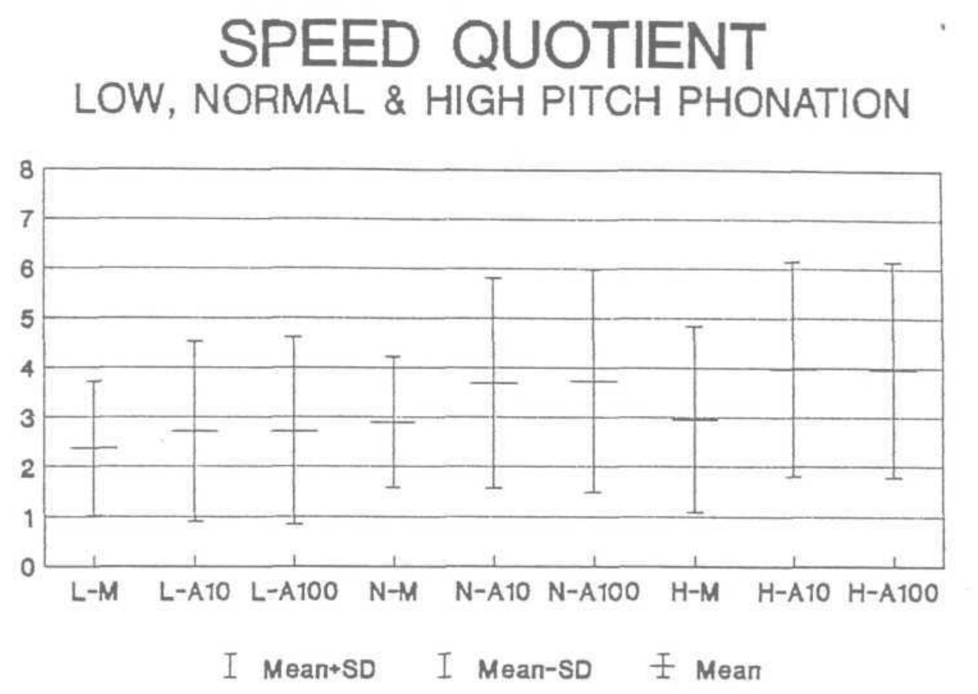


Graph I: Comparing CQ of manual and automatic extraction methods

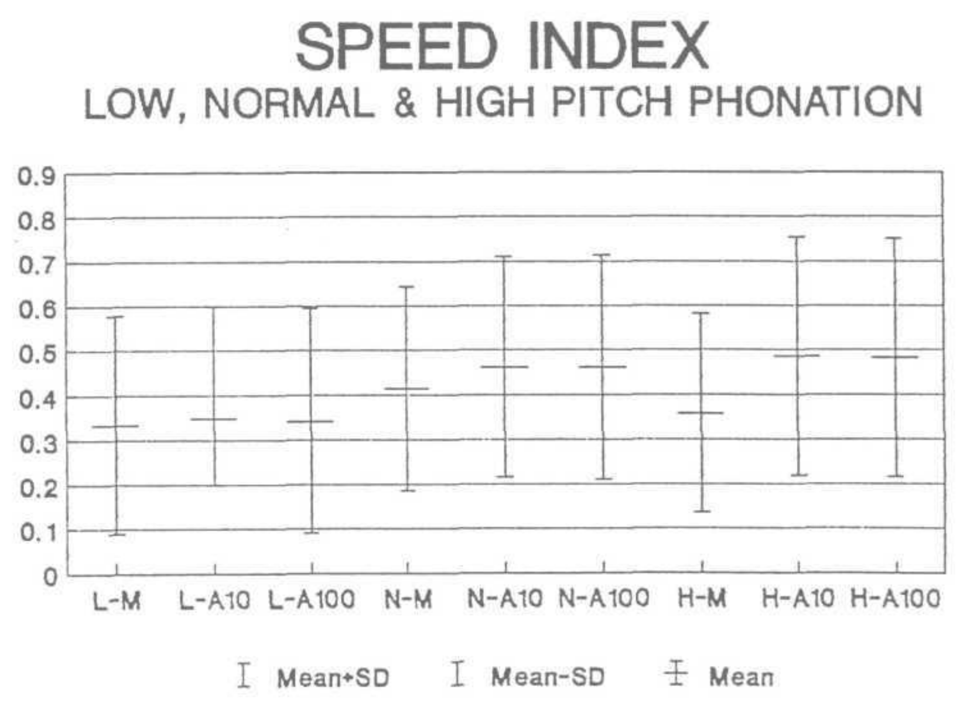


Graph II:Comparing OQ of manual and automatic extraction methods

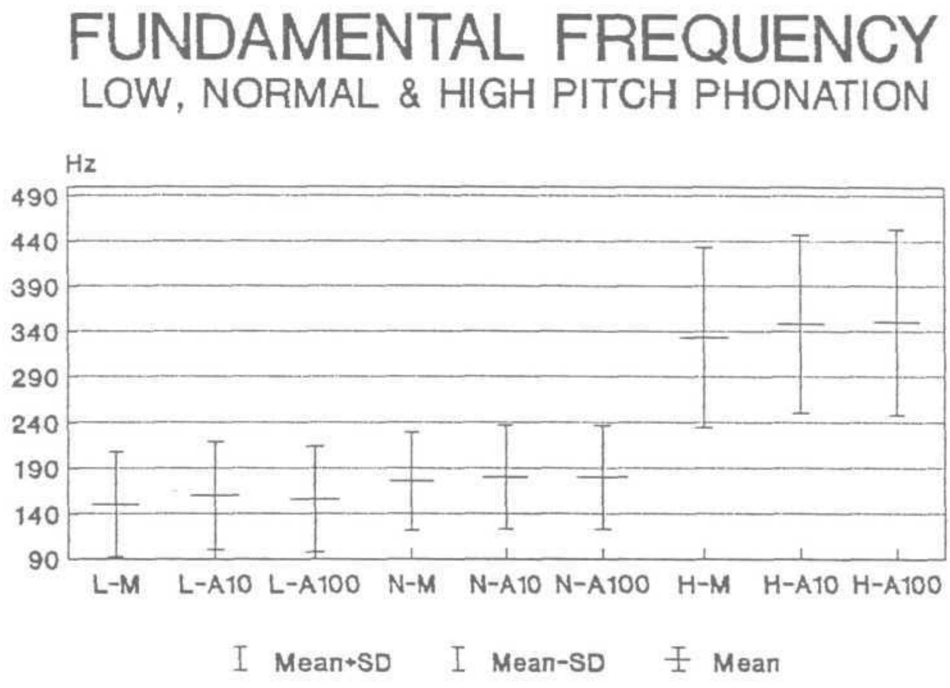
B



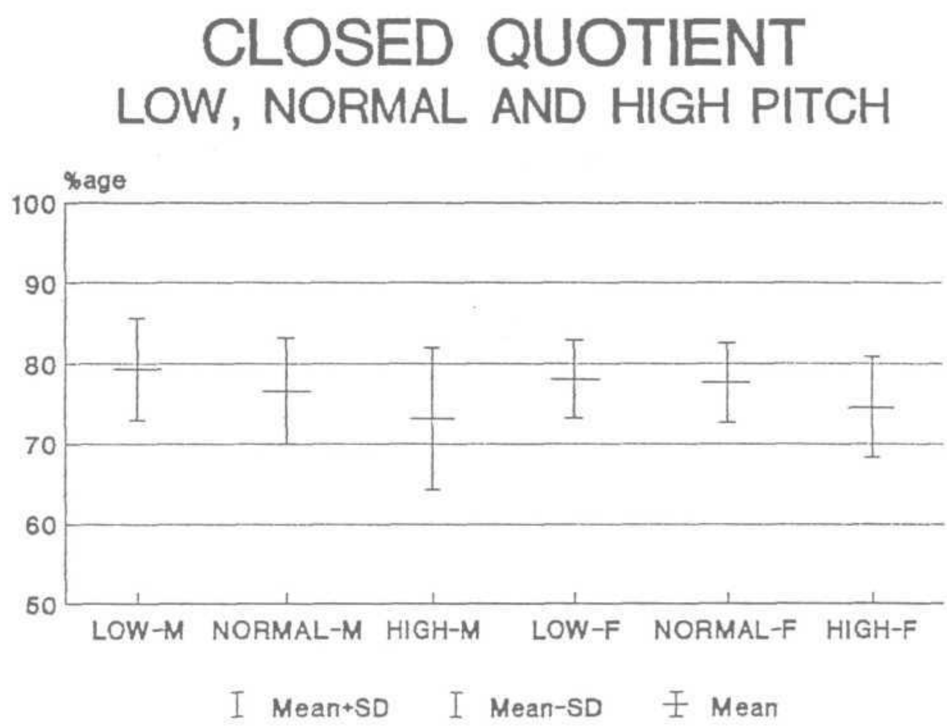
Graph III:Comparing SQ of manual and automatic extraction methods



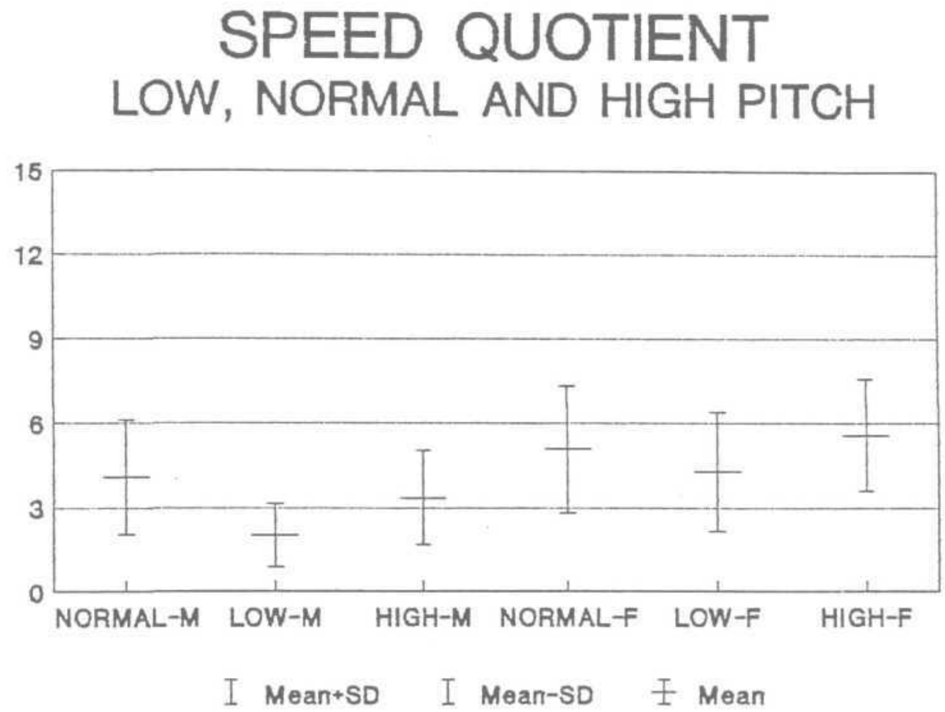
Graph IV:Comparing SI of the manual and automatic extraction methods



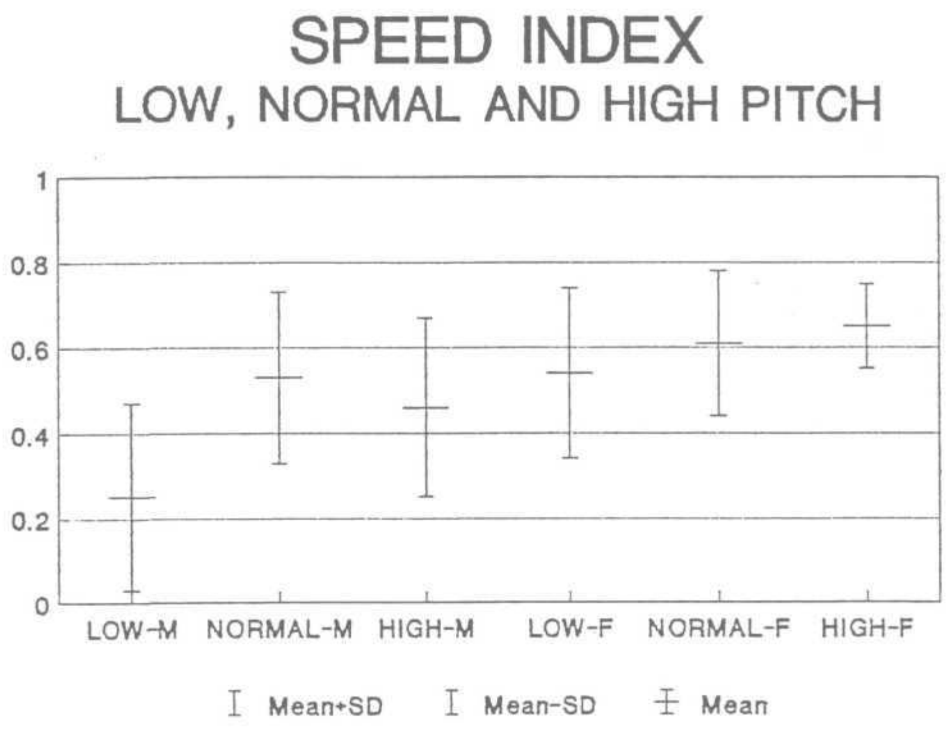
Graph V: Comparing Fo of manual and automatic extraction methods



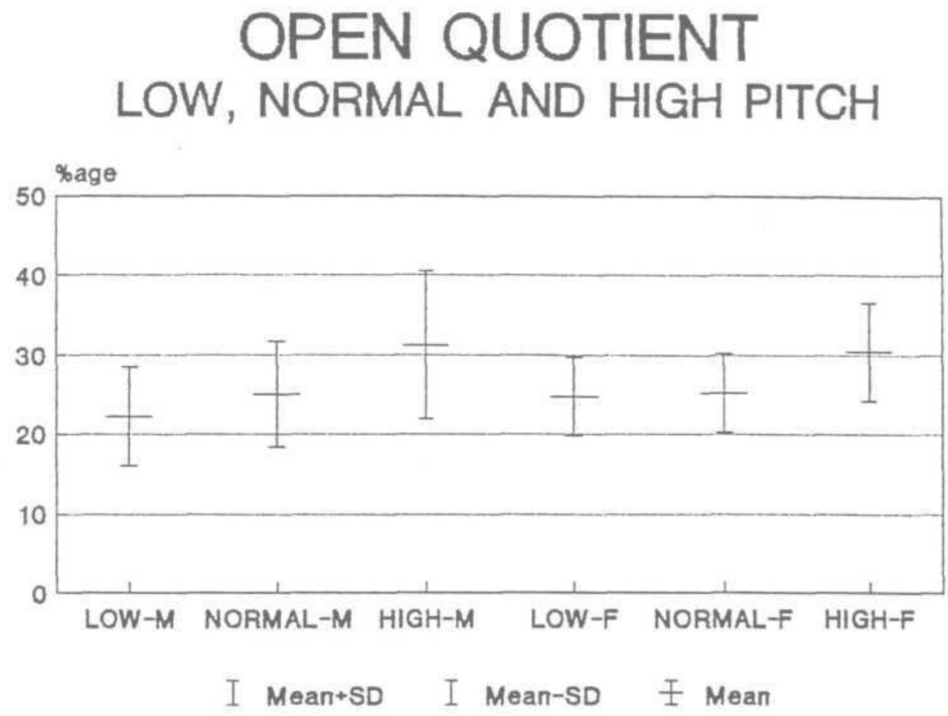
Graph VI:Showing Mean and SD of CQ



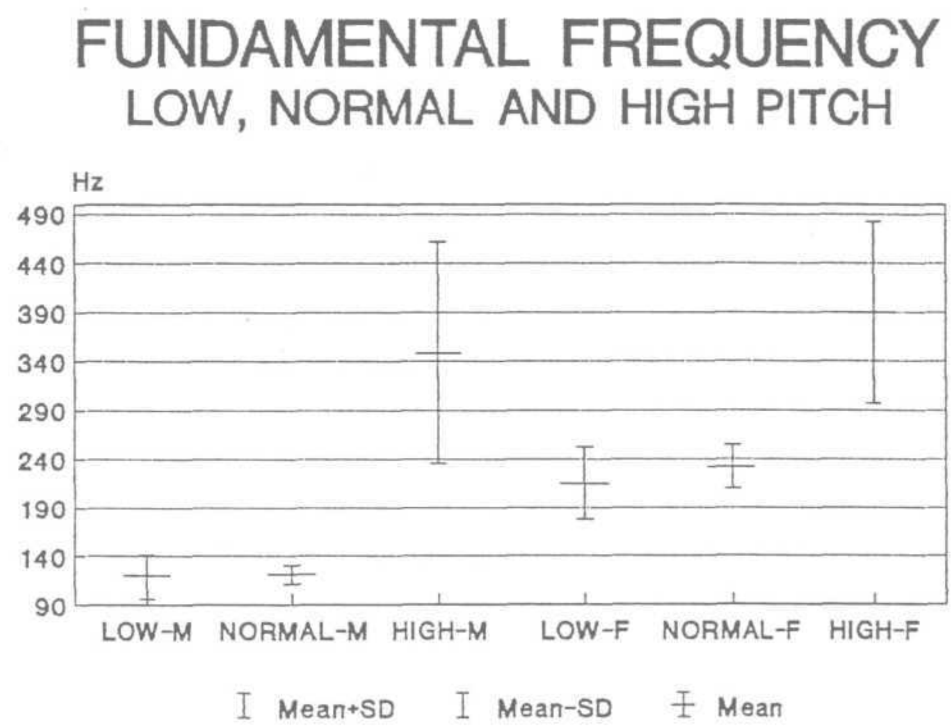
Graph VII:Showing Mean and SD of SQ



Graph VIII:Showing Mean and SD of SI

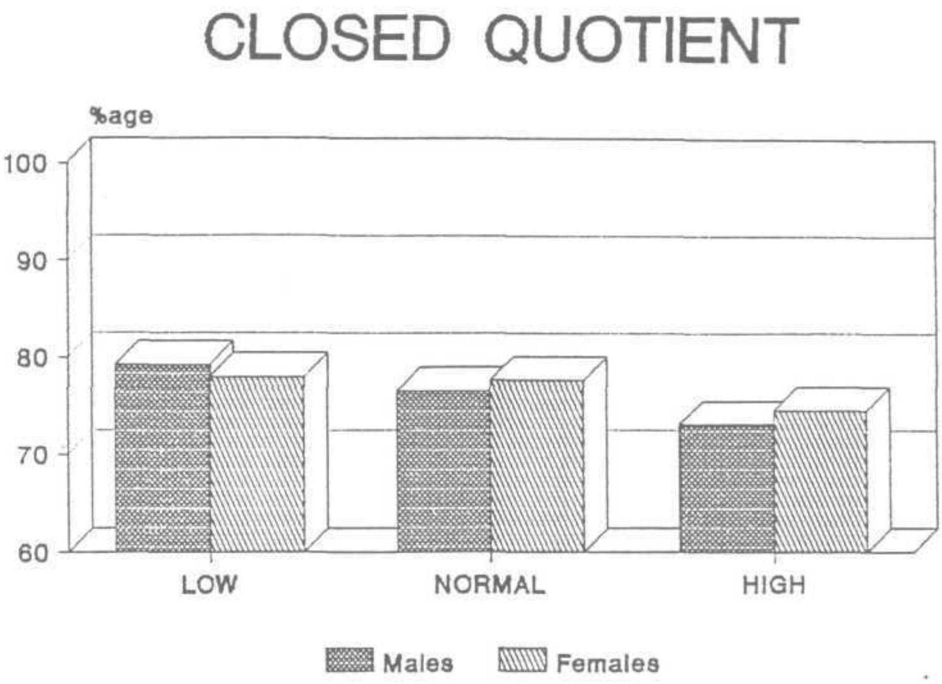


Graph IX:Showing Mean and SD of OQ

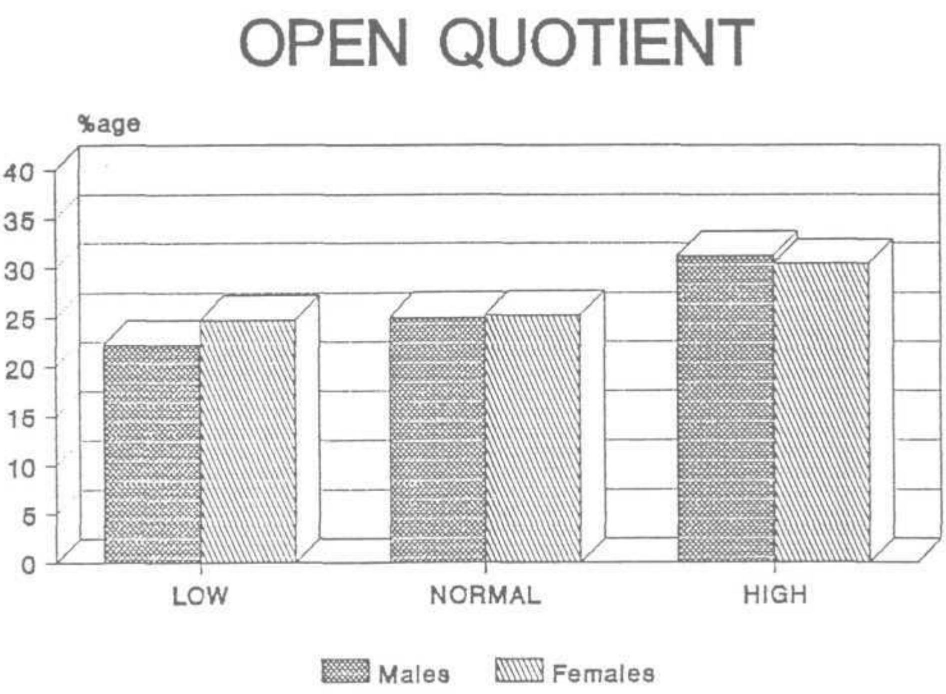


Graph X:Showing Mean and SD of Fo

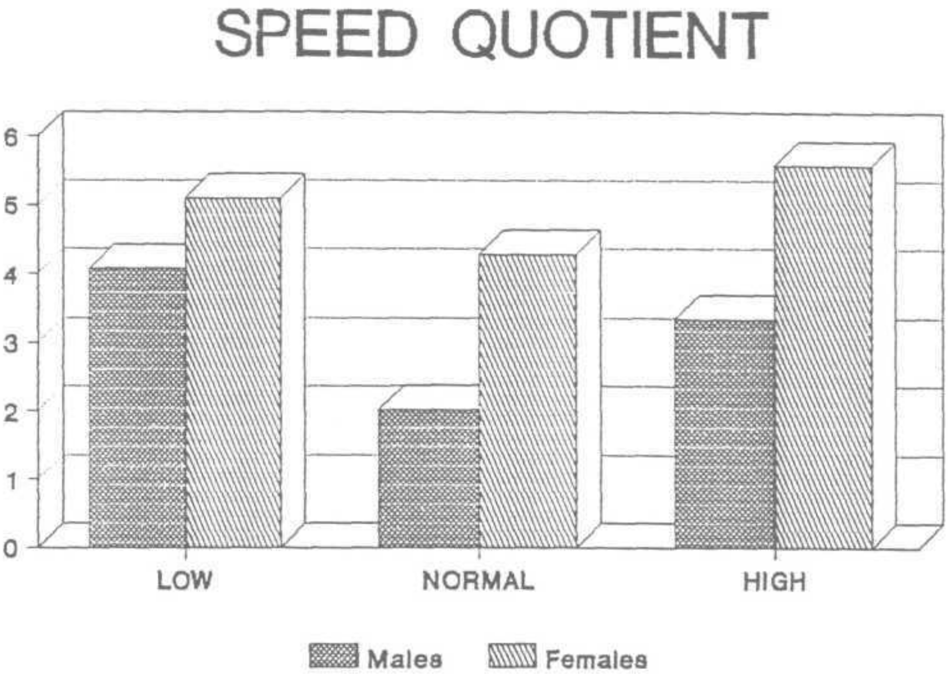
F



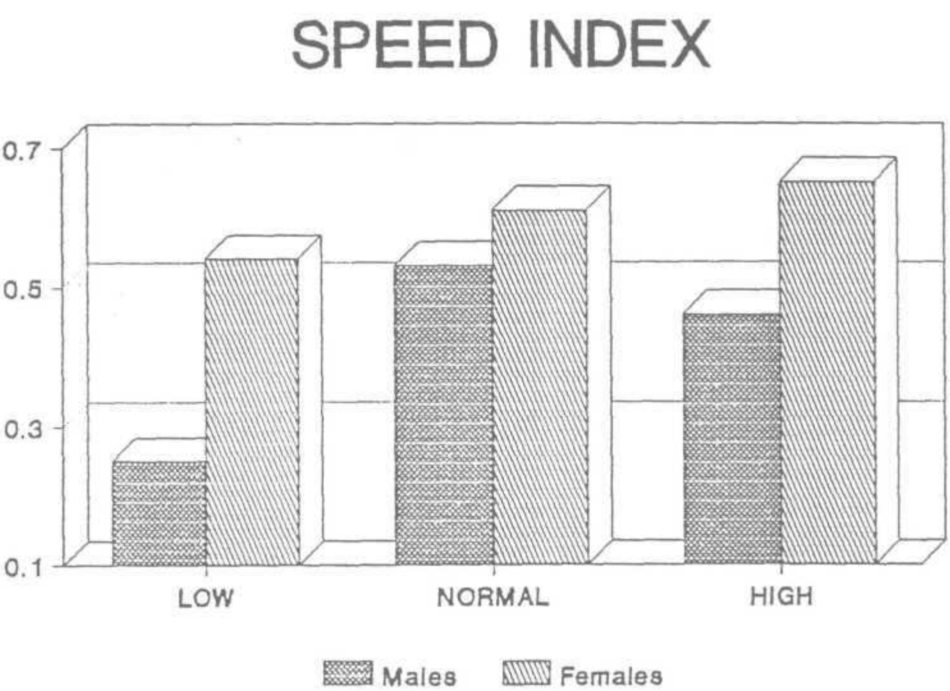
Graph XI:Comparing CQ of Males and Females



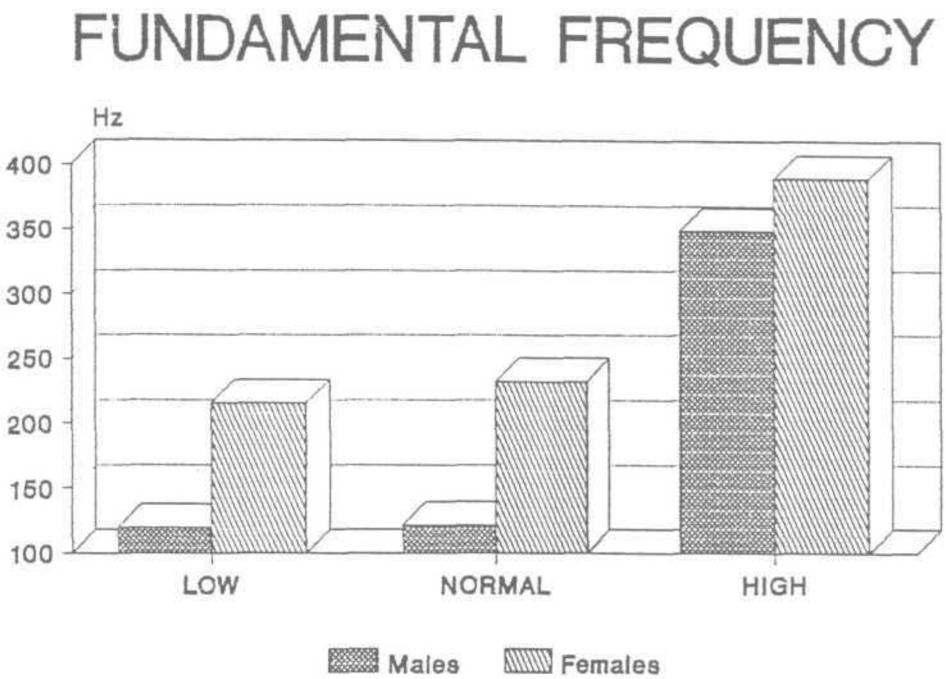
Graph XII: Comparing OQ of Males and Females



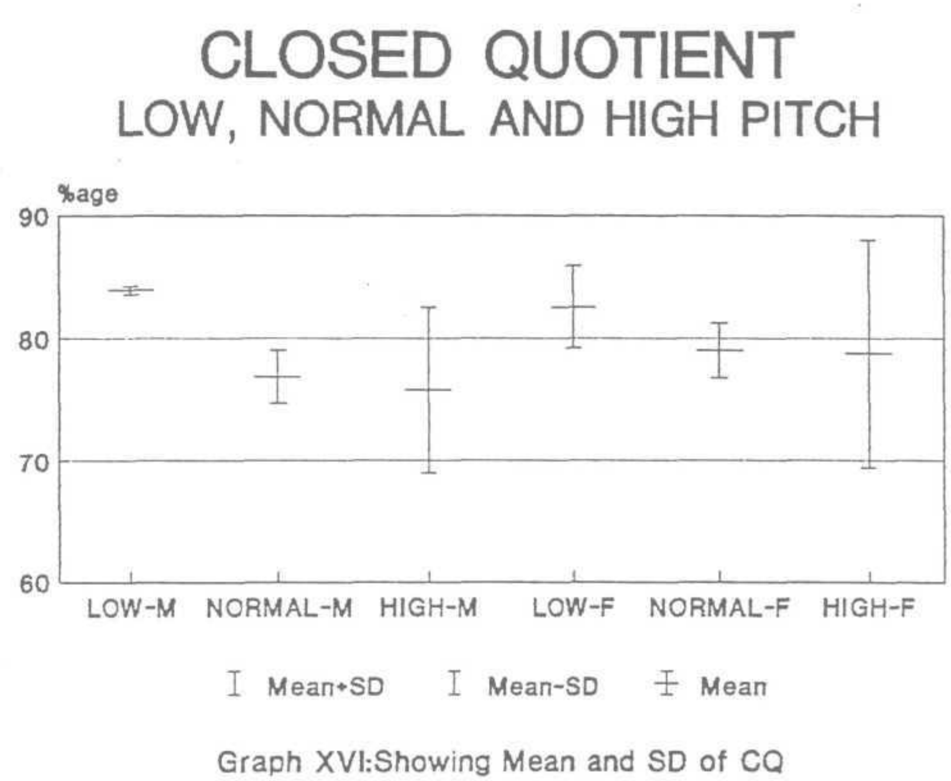
Graph XIII: Comparing SQ of Males and Females



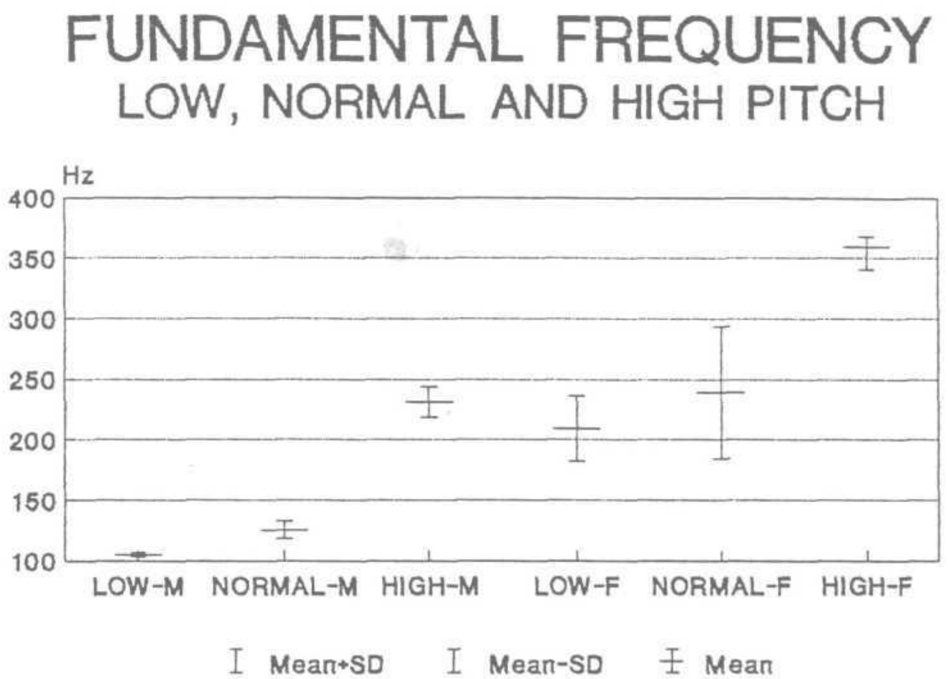
Graph XIV: Comparing SI of Males and Females



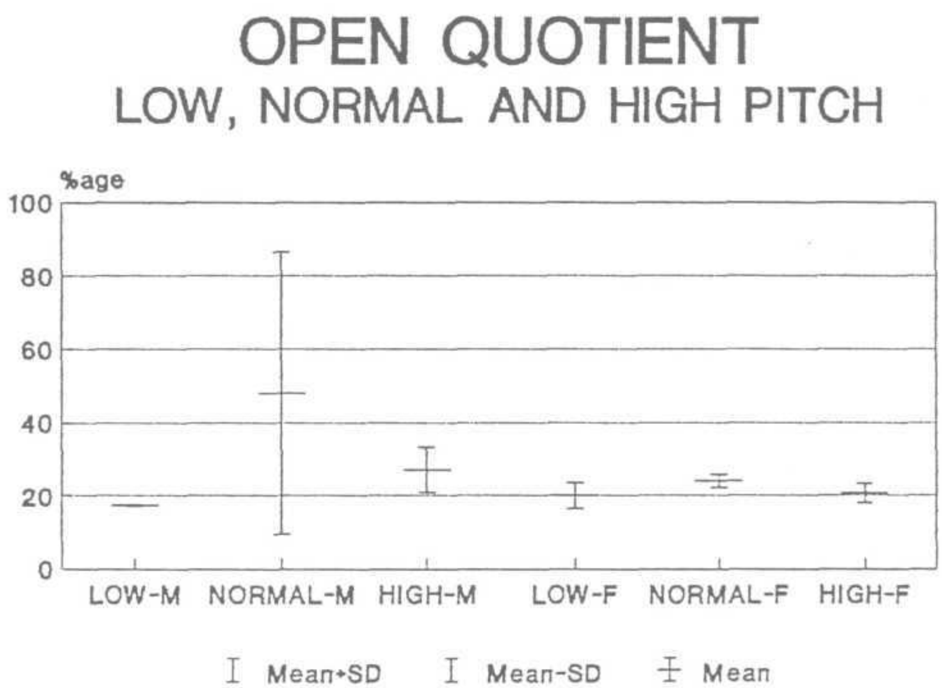
Graph XV: Comparing Fo of Males and Females



Graph XVI:Showing Mean and SD of CQ for Singers

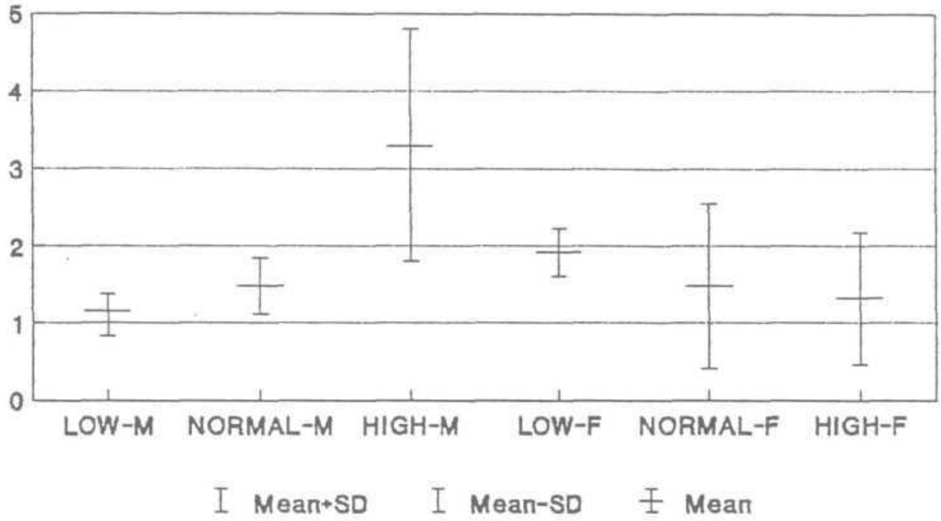


Graph XVII:Showing Mean and SD of Fo for Singers



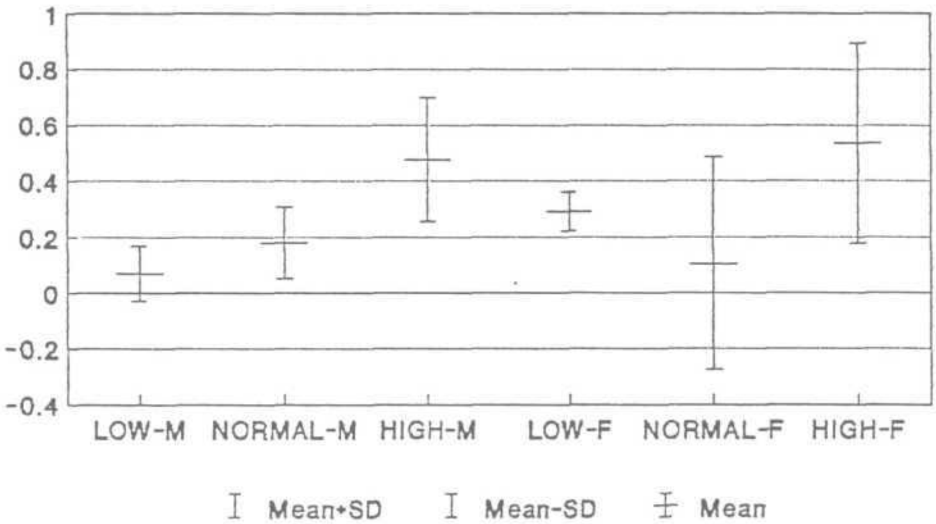
Graph XVIII:Showing Mean and SD of OQ for Singers

SPEED QUOTIENT
LOW, NORMAL AND HIGH PITCH



Graph XIX:Showing Mean and SD of SQ
for Singers

SPEED INDEX
LOW, NORMAL AND HIGH PITCH



Graph XX:Showing Mean and SD of SI
for Singers

BIBLIOGRAPHY

ABBERTON, E.R.M. HOWARD, D.M. AND FOURCIN, A.J. (1989): "Larynographic assessment of normal voice". Clinical linquistics and phonetics, 1989, Vol. 3, No. 3, 281-296.

ANDERSON, V. (1961): "Training of speaking voice". Oxford Univ. New York.

BAER, T. TITZE, R AND YOSHIOKA, H. (1983): "Multiple simultaneous measures of vocal fold activity". In Bless, D.M. and Abbss, J.H. (Eds) vocal fold physiology; contemporary research and clinical issues, San Diego: College-Hill, Chap. 19, PP-227-237.

BALAJI, 0. (1988): "Long term average spectrum and EGG in dysphonies". Unpublished Master's Dissertation.

BERRY, M.F. EISENSON, (1962): "Principles and Practices of Therapy" cited in, Nataraja N.P. (1972): An objective method of locating optimum pitch, Unpublished Master's Dissertation, University of Mysore.

CHANDRASHEKHAR, K.R. (1987): "Electroglottography in dysphonics". Unpublished Master's Dissertation, University of Mysore.

CHILDERS, D.G. MAIK, J.M., LARAR J.M., KRISHNAMURHTY, A.K. AND MOORE, G.P. (1983): "Electroglottography, speech and ultra-high speed cinematography , In Titze, L.R. and Scherer, R.C. (Eds), vocal fold physiology. Biomechanics, Acoustics and phonatory control. Denver; Denver center for the performing arts, Chap. 17.

CHILDRES, D.G., SMITH, A.M. & MOORE, G.P. (1984): "Relationships between Electroglottograph, Speech, and Vocal cord contact", Folia Phoniat, 36, 105-118.

CHILDERS, D.G. et al (1980): "Electroglottography and vocalfold physiology", J.S.H.R., *33,* 245-254.

COLEMAN, R.F. (1971): "Effect of waveform changes upon roughnesss perception". Folia phoniat, 23, 314-322.

COTTON, R.H. et al (1983): "Evaluating vocal fold function", The Journal of Otolaryngology, 12, 291-294.

DEJONCKERE, P.H. & LEBACQ, J. (1985): "Electroglottograph and vocal nodules", Folia phoniat, 37, 195-200.

EMERICK, L. & HATTEN, J. (1974): "Diagnosis and Evaluation in Speech Pathology". New Jersey, Prentice-Hall, Englewood cliffs.

EWAN, W.G. AND KORNES, R. (1974): "Measuring larynx movement using the thyroumbrometer", Journal of Phonetics, 2, 327-335.

FAIRBANKS, G. (1942): "An acoustic study of the pitch of infant wails" Child Dev., 13, (227-232).

FAIRBANKS, G. (1960): "Voice and Articulation Drill Book", New York, Harper and Row Publishers.

FAIRBANKS, G. (1966): "Experimental Phonetics", Urbana: Univ. of Illinois, Press.

FANT, G. (1960): "Acoustic theory of speech production", S. Gravehage, Mounton and Co.

FOURCIN, A.J. (1981): "Laryngographic assessment of phonatory function". ASHA Reports 11, 116-127.

FOURCIN, A.J. (1986): "Electrolaryngographic assessment of vocal fold function". Journal of Phenetics (1989) 14, 435-442.

FOURCIN, A.J. (1989): "An aspect of voice quality in speech pathology" Department of Phonetics and Linguistics, University College, London.

FRANSWORTH, D. (1940): "High speed motion pictures of the human vocal cords", Bell. Lab., Record, 18, (203-208).

HAJI, T., HORIGUCHI, S., BAER, T., & GOULD, W.J. (1986): "Frequency and amplitude perturbation analysis of electroglottograph during sustained phonation", J.A.S.A. 80(1), 58-62.

HANSON, D.G. GERRATT, B.R. AND WARD, H.P. (1983): "Glottographc measurement of vocal dysfunction. A preliminary report", Ann. Otol. Rhinol-laryngol, 92(5), 413-419.

HIRANO, M. (1975): "Phonnosurgery-Basic and clinical investigations", Otologia (Fukuoka), 21, (239-440).

HIRANO, M. KAKITA, Y.: MATSUSHITA, H., & HIKI, S and IMAIZUMI, S., (1977): "Correlation between parameters related to vocal cord vibration and acoustical parameters in voice disorders", Practi. Otol. Kyoto, 70(5), (393-403).

HIRANO, M. (1981): "Clinical examination of voice", Springer -Verlog Wicn, New York.

HIRANO, M. GOULD, W.J. LAMBIASE, A AND KAKITA, Y. (1981): "Vibratory behavior of the vocal folds in a case of a unilateral polyp", Folia Phoniat, *33,* 275-285.

HOLLIEN et al (1977). "Vocal fold vibratory patterns of pulse register phonation", Folia Phonatrica, 29 (200-205).

HOLM, C. (1971). "Examination of vocal fold vibration", cited in clinical examination of voice by Hirono, M.

HOLMER et al (1973). "Echo glotto graphy", Acta otolaryngologica 75 (454-463).

HORII, Y. (1979): "Fundamental frequency perturbation observed in sustained phonation", JSHR, 22, 5-19.

HOWARD, D.M.; LINDSEY, G.A.; ALLEN B. (1991): "Towards Quantification of Vocal Efficiency", Journal of Voice Vol. 4, No. 3, pp. 205-212.

HUSSON, R., (1950): "Properties fundamentals de al neuro-musculature des cordes vocales au cours de la phonation" J. de Physiologie, 43, 1951, (757-759).

HUTTAR, G. (1967): "Relations between prosodic variables and emotions in normal American English Utterances", JASA, 41, (1581).

KELMAN, A.W. (1981). "Vibratory pattern of the vocal folds", Folia Phonetica, *33,* 73-79.

KITZING, P. AND SONESSON, B. (1974). "A photoglottographic study of female vocal folds during phonation", Folia Phoniatrica, 26 (138-149).

KITZING, P. (1982). "Photo and electroglottographical recording of the laryngeal vibratory pattern during different registers", Folia Phoniat, 34, 234.

LASS, N.J., BRONG, G.W., CICCOLELLA, S.A., WALTERS, S.C. & MAXWELL, F.I. (1980): "An investigation of speaker height and weight discriminations by means of paired comparison judgements", J. Phonetics, 8.

LASS, N., & MICHEL, J. "The effects of frequency, intensity and voweltype on the maximum duration of phonation", Univ. Kan.: Unpublished manuscript.

LECLUSE, F.L.E., BROCARR, M.P. & VERSCHUURE, J. (1975): "The Electro-glottography and its relation of glottal activity", Folia Phoniat, 27, 215-224.

MICHEL. J..F. & WENDAHL, R., (1971).: "Correlates of voice production", in TRAVIS, L.E. (ed) Hand Book of Speech Pathology and Audiology, Prentice - Hall, Inc., Englewood Cliffs, N.J. (465-480).

MICHEL, J.F. & HOLLIEN, H. (1968): "Perceptual depreciation in vocal fry and harshness", J. of Speech and Hearing Research, 11 pp. 439-443.

MILLER, R.L. (1959): "Nature of the vocal cord wave", JASA., 31, (667-677).

MOORE, P. & THOMPSON, C.L. (1965): "Comments on physiology of hoarseness", Archieves of Otal. Vol. 81, 97-102.

MOTTA, et al (1990): "Differentiation among normals functional and organic voice disorders", J.S.H..R., 8.

NATARAJA, N.P. (1986). "Differential diagnosis of dysphonics" unpublished doctoral thesis, University of Mysore.

NATARAJA, N.P. & JAYARAM, M. (1982): "A new approach to the classification of voice disorders", J. of All India Institute of Sp. & Hg., 8, 21-28.

OHARIA, J. (1966). "A new photo electric glotographic working papers in phonatics", Univ. of California (Los Angeles) by Hirano M. (Springer-Verlag wien, New York).

PALMER, S.K., ALLEN, B., HOWARD, D.M., LINDSEY, G., HOUSE, J. (1990). "Analysis, synthesis and perception of laryngeal coarticulation", Proc. I.O.A. Vol. 12, Part 10.

PATACEK, P.H. & SADER, E.K. (1963): "Maximum duration of Phonation", JSHD, 28, (171-182).

PEDERSEN, M.R. (1977): "Electrography compared with synchronized stroboscopy in normal persons", Folia Phoniat, 29, 191-199.

PERKINS, W.H. (1971): "Speech Pathology - An applied behavioural science", The C.V. Mosby Co., St. Louis.

RASHMI, M. (1985). "Acoustic aspects of the Speech of Children", Unpublished Master's Dissertation. Univ. of Mysore.

ROCH, J.B., LOMTE, F. EYRAND, A., DUBREUIL, C. (1990): "Synchromization of Glottograhy and laryngeal strobscopy", J. Folia Phon. 42, 289-295.

ROUSEY, C, & MORIARTY, A. (1965): "Diagnostic implications of speech sounds", Spring field, ILL. Thomas.

SHIPP, T. (1979). "Vertical larynx position in singers with Jaw stabilized", In Lawrence, V (Ed) Transcripts of the seventh symposium on care of the professional voice, New York. The voice foundation, Part-I, PP. 44-77.

SHIPP, T. AND IZDEBSK, K. (1975): "Vocal frequency and vertical larynx position by singers and nonsingers", JASA, 58, 1104-1106.

SMITH, S. (1954): "Remarks on the physiology of vibrations of the vocal cords", Folia Phonlat., 6, 166-178.

SONDHI, M.M. (1975). "Measurement of the glottal waveform", J. of Acostic Soc. of America, 57, 228-232.

SORENSEN, D. et al. (1984): "Directional perturbation factors for Jitter and for Shimmer", JCD, 17(3), 143-151.

SORENSEN, D., & HORTI, Y. (1984): "Directional perturbation factors for jitter and for shimmer", Jr. Commun. Dis., 17, (143-151).

SORAN, H.I. (1967). "High speed photography in speech research", cited in clinical examination of voice by Hirano, M. (Springer-Verlag Wien, New York).

SRIDHARA, R. (1986): "Glottal wave forms in Normals", M.Sc, Dissertation, Mysore University.

TAKHASHI (1974). "Significance of perceptual study of pathological voices", Pract otal (Kyoto) 67, 949-953.

TAHHASKI et al (1974). "On the differential diagnosis of larygeal pathologies through the perceptual impression of the voices", Pract otal (Kyoto) 67, 1377-1385.

TSANNDORFF, W. (1925): "Die MeChanik bei der stimmlipepn Schwingung and beim Schnarchem", Z. Hals, Na5, U. obrnbeilk, 12, (241-245).

TITZE, I. AND TALKIN, D. (1981): "Simulation and interpretation of glottographic waveforms", In Ludlow, C.L. and Hart, M.O. (Eds) proceedings of the conference on the Assessment of vocal pathology. ASHA reports II, 48-55.

TITZE, I.R. (1991): "Phonation threshold pressure a missing link in glottal aerodynamics", J. Acost. Soc. of America 91(5).

VANAJA, C.S. (1986): "Acoustic parameters of normal voice", Unpublished Master's dissertation, Univ. of Mysore.

VANDEN BERG (1958): "Myoelastic aerodynamic theory of voice production", JSHR, 1(3), (227-243).

VON LEDEN, H. AND MOORE, P. (1961): "Vibratory pattern of the vocal cords in unilateral laryngeal paralysis", Acta Otolargngology, 53, 493-506.

WARYAM SINGH (1988): "Clinical application of electrolaryngography for speech rehabilitation in near total laryngectomy with myomucosal valued neoglottis", The Journal of Laryngo and Otology, 102, 335-336.

WECHSLER, E. (1977): "A laryngographic study of voice disorders", Br. Jr. Disord. Commun 12, 9-22.

WELCH, G.F., HOWARD, D.M., RUSH, C. (1989): "Real time feedback in the development of vocal pitch accuracy in singing", Psychology of Music 17, 146-157.

YANGIHARA, N. (1967): "Hourseness; investigation of the physiological machanisms", Annals of Otorhinolaryngology, 76, 472-488.