Physioacoustic Economy

At

Optimum Frequency

SHASHIKALA

Reg No. 009

A DISSERTATION SUBMITTED IN PART FULFILLMENT

FOR THE DEGREE OF MASTER OF

SCIENCE (SPEECH & HEARING)

UNIVERSITY OF MYSORE, 1979

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U N I V E R S I T Y   O F   M Y S O R E.   1979.

TO

My Parents, Brothers and sisters.

<u>C E R T I F I C A T E</u>

This is to certify that the Dissertation entitled “Physioacoustic “ECONOMY AT OPTIMUM FREQUENCY” is bonfide work in Part fulfillment For the degree of M.sc., (Speech and Hearing) carrying 100 marks of The student with the register number 9.

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C E R T I F I C A T E

This is to certify that this dissertation entitled “PHYSIOACOUSTIC ECONOMY AT OPTIMUM FREQUENCY” has been prepared under my Guidance and Supervision.

N. P. Nataraja 3/8/79

G U I D E
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D E C L A R A T I O N

This dissertation entitled "PHYSIOACOUSTIC ECONOMY AT OPTIMUM FREQUENCY" is the result of my own study prepared under the Guidance and supervision of Mr. N. P. Nataraja, Lecturer in Speech pathology, All India Institute of Speech And Hearing, Mysore and has not been submitted earlier at any other university for any other diploma or degree.

SHASHIKALA

MYSORE

Reg .No. 009

Date: 3rd August 1979

A C K N O W L E D G E M E N T

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Investigator.

C O N T E N T S

CHAPTER I:

INTRODUCTION.

"Every human society, no matter how primitive, has developed the ability to communicate through spoken and written language has frequently been cited as the single most important characteristic that sets humans apart from other animals" (James F. Curtis, 1978)

Speech is a form of language that consists of sounds by utilizaing the flow of air expelled from lungs.

As Van Riper and Irwin (1958) point out voice is the carrier wave while articulation is the message. The meaning and the content of a message are primarily matters of semantic choice and syntax, an prosody and phone accuracy and in certain instances (and more so in some languages) vocal characteristics.

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

An operational definition of ' good ' voice by Nataraja and Jayaram (1975) states that " the good voice is one which has the optimum as its fundamental (habitual) frequency."

The optimum frequency when resonated through the vocal tract is perceived as optimum pitch.

Fisher describes optimum fitch as follows:

“1. It is the best or the most favourable for speaking; easiest to phonate and most free of strain.

2. It has greater intensity.

3. Vocal folds being in a most elastic, more normal states, is more responsive to the force of the subglottic air pressure. They can swing widely apart and they pull back more quickly, and

4. Optimum pitch is located within the total range of voice as to permit effective variation in pitch for intonations.”

Optimum pitch is not a single pitch, rather it is a range which is produced with least expense of energy. There will be maximum intensity and good quality (Van Riper and Irwin, 1959).

Regarding the location of optimum pitch there are controversies. Some consider that the optimum pitch is a frequency one – fourth above the lower limit of the pitch range a person can produce (Pronovast, 1942; Fisher, 1942; Fairbanks, 1960; Berry and Eisenson, 1962). According to some others, optimum pitch is one – fifth above the lower limit of the pitch range (Brownstein and Jacoby, 1967). Few others consider frequency one – third from the basal tone of the pitch range is optimum pitch (Berry and Eisenson, 1962).

“Maximum increase or swell in intensity at a particular pitch level” has been considered as optimum pitch (wentworth, 1940; Berry & Eisenson, 1962; Murphy, 1964, Fisher, 1966; West et al., 1968; House, 1959). But results of the study by Thurman (1958) do not support this. west et al. (1968) state that there are two such swellings or maximum increase in intensity in the pitch range.

There are other methods which employ “coughing” and “laughing” to locate the optimum frequency.

The above described methods are subjective and lack experimental evidences.

An attempt has been made by Nataraj (1972) to locate the optimum pitch objectively finding the natural frequency of the vocal tract.

As is seen, the review of literature on optimum pitch reveals that, at optimum pitch there must be greatest efficiency and maximum intensity with least effort. Thus exposes that need to study the characteristics of optimum pitch objectively.

STATE OF THE PROBLEM:

The problem is to study whether the vocal mechanism functions most efficiently with least effort at optimum pitch level, as located by the present technique, when compared to other pitch levels.

Hypothesis:

There will be no difference in Physioacoustic economy of function of the vocal mechanism at optimum pitch level when compared with other pitch levels.

As it will not be possible to study the efficiency of the vocal mechanism directly, it was planned to study the measurable parameters that would reflect the efficiency of the vocal mechanism. That is, intensity, phonation duration, and mean air flow rate. Hence the following auxillary hypotheses have been proposed.

Auxillary Hypotheses:

1. There will be no difference in intensity range at optimum pitch level as located by the present technique when compared with other pitch levels.

2. There will be no difference in duration of phonation at optimum pitch level as located by the present technique when compared to other pitch levels., and

3. There will be no difference in mean air flow rate at optimum pitch level as located by the present technique when compared to other pitch levels.

METHODS AND RESULTS:

To verify the the above said hypotheses, following experiments were done using subjects of different age and who were considered as normals by the experimenter. The study was planned to measure the intensity range (maximum intensity – minimum intensity), maximum phonation duration and mean air flow rate at the following frequency levels:-

1. At optimum frequency,
2. At 50 Hz. above optimum frequency,
3. At 100 Hz. above optimum frequency,
4. At lower limit of the frequency range.
5. At 200 Hz above optimum frequency.

Experiment 1 (a): Find the natural frequency of vocal tract to determine the optimum pitch:

The natural frequency was determined by recording the response of the vocal tract for frequency range of 100 Hz to 5000 Hz, as described by Nataraja (1972).

Optimum pitch was obtained by dividing the natural frequency of vocal tract by eight in adult males (Nataraja, 1972) and by five in females (Shanths, 1973).

Experiment 1 (b): Finding the fundamental frequency of the voice while phonating the vowel /a/:

The fundamental frequency was read directly from the tacho unit meter, when the subject as phonating the vowel /a/ in his normal speaking pitch.

Experiment 2 (a): Finding the intensity range:

The subject was instructed to phonate as loudly as possible and a softly as possible. The range between the two gave the intensity range.

Experiment 2 (b): Finding the frequency range:

The subject was asked to phonate his lowest possible and highest possible pitches and the reading was directly from the tacho unit meter of the stroboscopic unit. The difference between the two gave the frequency range of the subject.

Experiment 2 (c): To determine the maximum duration of phonation:

The maximum duration of phonation was obtained by asking the subject to phonate as long as possible, keeping the intensity and frequency constant after taking a deep inhalation. A stop watch was used to time the duration of phonation.

Experiment 2 (d): Finding the mean air flow rate during the phonation:

The subject was instructed to take a deep breath and phonate the vowel /a/ into the mouth piece of expirograph. The total volume of air expelled during phonation was directly measured and read from the calibrated paper of the expirograph.

The time taken for obtaining this phonations volume was noted using a stop watch. Mean air flow rate was obtained by dividing the phonation volume by the time taken for obtaining this phonation volume.

The date were analyzed.

Limitations:

1. The experiments were done on only limited number of subjects.
2. More accurate and sophisticated instruments could not be used to measure the mean air flow rate.

Implications:

1. The study verifies the present technique of measuring the optimum pitch.
2. The information will be useful in diagnosis and therapy of cases with voice disorders.

DEFINITIONS USED IN THE PRESENT STUDY:

Natural Freqency of the Vocal Tract:

The vocal tract considered as a tube or cavity, responds more readily to a sound wave, whose frequency is same as its formant frequency than to a sound wave of another frequency. This frequency of maximum response, in terms of intensity, is called the natural frequency of the vocal tract for the vowel /a/ position (Samuel, 1973).

Optimum Frequency:

Optimum frequency is one which is the natural frequency of the vocal tract by eight in males and by five in females

Fundamental Frequency:

Fundamental frequency is used and measured in the present study, is the direct reading obtained from the t tacho unit in combination with the sound pressure level meter and stroboscope, for the vowel /a/.

Intensity Range:

This is the range between the loudest possible intensity minus the softest possible intensity that an individual can produce.

Maximum Duration of Phonation:

The maximum amount of time an individual can sustain phonation of the vowel /a/ at a particular frequency and the intensity level after maximum inhalation, is known as maximum duration of phonation.

Mean Airflow Rate:

It is the ratio between the phonation volume and the duration in obtaining this volume.

CHAPTER II

: REVIEW OF LITERRATURE:

"The act of speaking is very specialized way of using the vocal mechanism. The act of singing is even more so, Speaking or singing dem and a combination or interaction of the mechanism of respiration, phonation, resonance and articulation" (Boone, 1971).

The simple definition of voice states that the voice is the "sound produced primarily by vibration of vocal folds".

Nataraja and Jayram (1975) have defined good voice operationally "the good voice is one which has the optimum as its fundamental (habitual) frequency."

Michel and Wendal (1971), while discussing the definitions of voice, state that " the random house dictionary lists 25 primary and secondary definitions of voice, the first of which is: ' the sound or sounds uttered through the mouth of the human beings in speaking, shouting, singing, etc., If we expect the ' scientific definitions to be less variable and more precise than the ' lay ' definitions we will be disappointed".

One cannot proceed further without defining his terms because in science the definitions are most fundamental phenomenon of the condition under study. The precision of phenomenon will be determined by the specificity of the definition. (Nataraj and Jayaram 1975).

Several authors have defined voice differently. The definition offered by Judson and Weaver (1942) states that voice is the " laryngeal vibration (phonation) plus resonance". And they call phonation as laryngeal vibration.

Fant (1960) defines voice using formula F = S.T., in which the speech sund F_o is the product of the source S_o and the transfer function of the vocal tract T.

He further states that " when discussing production of speech, it should be noted that the source, S_o of the formula, P= S.T., is an acoustic disturbance, superimposed upon the flow of respiratory air and is caused ………. by a quasiperiodic modulation of the air flow due to the opening and closing movements of the vocal folds".

Some definitions of voice restrict the terms to the generation of sound at the level of larynx, while others include the influence of vocal tract upon the generated tones, and still others broaden the definition to include aspects of tone generation, resonance, articulation and prosody.

Michel and Wendahl (1971) define voice as " in the laryngeal modulation of the pulmonic air stream, which is then further modified by the configuration of the vocal tract".

"All thought and feelings and action that may be embodied or suggested on vocal utterance is expressed or appreciated through the medium of one or more of the following factors " (Erickson, 1926). Erickson has listed the basic factors of human voice as pitch, volume and time. The normal voice should possess certain characteristics of pitch, loudness and quality which will make the meaning clear, arouse proper emotional response to ensure a pleasant tonal effect upon the hearer (Berry and Eisenson, 1962.)

It is apparent that a 'good' voice is a distinct asset and a poor voice, may be an unfortunate handicap. If a person's voice is deficient enough in some respect that it is not a reasonably adequate vehicle for communication or if it is distracting to the listemer, one can consider this as constituting a disorder.

In general, the following requirements can be set to consider a voice as adequate:

1. The voice must be appropriately loud.
2. Pitch level must be appropriate. The pitch level must be considerered in terms of age and sex of the individual. Man and Women differ in vocal pitch level. That is, with the age the pitch changes.
3. Voice quality must be reasonably pleasant. This criterion implies the absence of such unpleasant qualities as hoarseness, breathiness, harshness and excessive nasal quality.
4. Flexibility must be adequate. Flexibility involves the use of both pitch and loudness inflection. An adequate voice must have sufficient flexibility to express a range of differences in stress, emphasis and meaning. A voice which has good flexibility is expressive. Flexibility of the pitch and flexibility of loudness are not separable, rather they tend to vary together to a considerable extent.

Functionally, larynx is a valve and a sound generator. As a valve is regulates the flow of air into and out of the lungs and keeps food and drinking out of the lungs. The two functions are accompanied by a relatively complex arrangement of cartilages, muscles and other tissues.

The larynx and trachea in sound production have been recognized as central organs. The mechanism of human larynx, often regarded as sphincteric, more nearly represents graduated folding or flication. Taking the end of normal expriation as the reference condition, folding decreases with inspiration and increases scuccessively with reserve expiration,
phonation, effort closure and swallow closure (Fink, 1974).

“When vibrating, the vocal folds provide a wide range of quasiperidic, modulations of the air stream accounting for various tonal qualities, reflecting
the different ways the vibrator behaves” (Brachett 1971).

The essential function of larynx has been widely accepted, but the controversy arises regarding the way the vocal cords are set into vibration. There are two theories of phonation, namely.

1. Myoelastic theory or aerodynamic theory and
2. Neurochronexic theory.

Myoelastic or aerodynamic theory was first advanced by Miller in 1843. Minor modifications of the theory have been suggested by To md orf (1975) and Smith (1954). This theory postulates that the vocal folds are set into vibration by the air stream from the lungs to the traches and the frequency of vibration is dependent on their length, tension and mass. These are regulated primarily by the interplay of the intrinsic laryngeal muscles.

Husson (1950) postulated that each new vibratory cycle is initiated by a nerve impulse transmitted from the branch of the vagus nerve.
The frequency of vocal cords are dependent upon the rate of pluses.

delivered to the laryngeal muscles.

According to Fant (1960), the mechanical myoelestic theory of voice production is commonly accepted. Based on the myoelastic theory, he considers the following factors as responsible for determining frequency of vibration of vocal cords:

1. Control of laryngeal musculature affecting the tension and mass distribution of the cords. Increased tension and Smaller mass increases fundamental frequency.

2. Decreased subglottal pressure.
3. Increased degree of supraglottal constriction as in voiced consonants reduces the pressure drop across the glottis, thus reducing the alternating positive and negative pressure and fundamental frequency reduces.
4. A shift in the tongue articulation towards a high front position results in an increased fundamental frequency due to increased vocal tension".

The sounds produced at the laryngeal vibration do not themselves constitute the voice. It will be inaudible and unhuman in quality and consists of fundamental tone and rich supply of over tones. Only when its partials are resonated and intensified by the vocal tract, do they constitute the human voice.

Travis, Bender and Buchanan (1934) State that "……..the voice producing mechanism is a closed system, the various parts of which have interacting effects…………..There is a good reason to suspect that the waves of puff generated by the vocal cords not only effect, but are affected by the resonating system. The vocal cords or generating mechanism and the resonating cavities or modifying mechanism cannot be considered apart from eachother."

Thus, resonators play considerably an important role in the vocal mechanism.

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

It is noteworthy to recall the definition given by Judson and Weaver (1942) in this connection, that voice is " the laryngeal vibration (phonation) plus resonance".

Michel and Wendahl (1971) consider voice as a multidimensional series of measurable events, implying that a single phonation can be assessed in different ways. They have given a tentative list of 12 parameters of voice, most of which can be measured and correlated with specific perceptions, while others are more elusive and difficult to talk about in more than ordinal terms. The twelve parameters presented by them are:-

1. Vital Capacaity.
2. Maximum duration of Sustained (Controlled) blowing
3. Modal frequency range.
4. Maximum frequency range.
5. Maximum duration of sustained phonation.

6. volume / velocity airflow during phonation
7. Glottal wave form.
8. Sound pressure level
9. Jitter of the vocal signal
10. Shimmer of the Vocal signal
11. Effort level (Vocal). and
12. Transfer function of the vocal tract.

VIVTAL CAPACITY:

The importance of respiration and phonation to the act of speaking has been well recongnised by the speech clinicians. As Michel and Wendahl (1971) put " the human speech is a myoelastic aerodynamic process." The airflow components of speech, including subglottal pressure, airflow rate, phonation air volume, the Bernoulli's effect and the like have been under intersive study. The measurement of vital capacity is important as it provides an estimate of the amount of air potentially available for the production of voice. The mechanical function of lungs as an air power supply for phonation was tested through the measurement of both static and timed vital capacity.

I t has been assumed that superior vital capacity for example, as in professional singers or athletes arose from a higher than average or normal vital capacity of untrained singers or nonathlets. The results of the study done by Nadoleczny and Luchsinger (1934) support the above assumption. But results of the study by Hicks and Root (1968) and Sheela (1974) found that there was no significant difference between trained and untrained singners.

Yhnagihara and Koike (1967) have related vital capacaity to volume; while Hirano, Koike and von Leden (1968) have indicated a relationship between vital capacity and maximum phonation duration. In the former study, it was reported that the phonation volume and the ratio of phonation volume to the vital capacity, both decrease as the subjective pitch level decreases. Thus correlation coefficients ranging from 0.59 to 0.90 were observed between the vital capacity and phonation volume. Hirano et al. (1968) correlated phonation quotient (vital capacity/ Phonation duration) with flow rates in normal subjects, indicating that higher flow rates were generally associated with shorter phonation durations or longer vital capacities.

Koike and Hirano (1968) derived a measure, which theyreferred to as “Vocal Velocity Index”. This term refers to the ratio of mean flow rate to the vital capacity. The mean airflow rate during phonation (in C.C./ Sec) was obtained by dividing the phonation volume by the maximum phonation time. This index demonstrated no significant varience between normal male and female subjects. Iwata and Von Leden (1970) suggest from the results of their study that the application of vocal velocity index as a useful objective measure of the laryngeal efficiency.

MAXIMUM DURATION OR SUSTAINED BLOWING:

Maximum duration of sustained blowing is defined as the maximum length of time an individual can maintain an oral flow of air (Micheal and Wendahl, 1971), This provides an estimate of the amount of control of respiratory mechanics (Piacek and Sander, 1963)

MAXIMUM FREQUENCY RANGE:

Maximum frequency range is defined as the highest and lowest frequencies an individual can phonate.

MAXIMUM PHONATION DURATION TIME OR MAXIMUM DURATION OF PHONATION

Maximum duration of phonation refers to the maximum amount of time an individual can sustain phonation after taking a maximum inhalation (Michel and Hendahl, 1971). Many variables are found to affect the duration. Namely, (a) the frequency of phonation, (b) the sound pressure level of phonation, (c) the vowel being phonated, (d) the general physical condition of the individual and (e) the amunt and kind of training the individual has had. That is, the athlets generally do better than non-athlets and trained singers do better than untrained singers (Lass and Michel, 1969).

Ptacek and Sander (1963) appear to be the first to suggest that the maximum duration of phonation. The results of their study indicated that males could sustain phonation for longer time than females for low frequencies and sound pressure levels. As the frequency and sound pressure levels increased, the phonation durations between males and females tended to become more similar.

Normal phonation duration studies have been reported by many investigators.

Vankiper (1954) studies that individual shall be able to sustain phonation to atleast 15 seconds. According to Fairbanks (1950), 20-25 secs. is normal. Luchsinger (1965) states that phonation time varies from 20 to 30 seconds among males.

VOLUME VELOCITY AIRFLOW:

Flow rates for normal phonation in the modal register appear to be in the vicinity of 100 CC per second (Kunze, 1962; Isshiki, 1964). Isshiki reported flow rates of around 60 CC per second to accompany falsette phonation and McGlone (1966, 1967) observed flow rates of approximately 70 CC per second during vocal fry phonation.

It would seem a desirable variable to measure since airflow in quite probably related to fundamental frequency and definitely related to subglottal pressure.

GLOTTAL WAVE FORM:

Glottal wave form cannot be easily defined as some of the other parameters. Basically an index of glottal wave form can be obtained by calculating (1) the opening time of vocal folds, (2) the closing time of vocal folds, (3) the time the vocal folds are opened and (4) the time the folds are closed all during a single vibrate signal.

It is very complex to measure this.

SOUND PRESSURE LEVEL RANGE:

Sound pressure level range is defined as the maximum and minimum sound pressure levels an individual can produce at specific points in his frequency range (that is, 25^{th}, 50^{th} and 75^{th} percentile points of modal frequency range.).This measure should not be confused with the sound pressure level most often used by an individual when he is producing phonation (that is, monitoring).

JITTER:

Jitter of the vocal signal is defined as cycle to cycle variation in period that occurs when an individual attempts to sustain phonation at a constant frequency.

SHIMMER:

Shimmer of the vocal signal is defined as the cycle to cycle variation amplitude that occurs when an individual attempts to sustain phonation at a constant frequency and intensity.

The amount of shimmer in any given case will be dependent upon the model frequency level, the total frequency range and the sound pressure level relative to each individual voice. It is suggested that Shimmer be measured in decibels.

EFFORT LEVEL:

Effort level is defined as the degree of perceived effort in the production of phonation (Michel and Wandahl, 1971).

TRANSFER FUNCTION OF VOCAL TRACT:

Transfer function of vocal tract is defined as the particular modification of the laryngeal signal imposed by the configuration of supraglottal structures.

Basically, there are three aspects of voice namely, pitch, loudness and quality.

PITCH:

Pitch is the psychological correlate of frequency. That is, pitch is the subjective impression of frequency of a sound. But frequency of a sound does not uniquely determine it’s pitch (Stevens and Davis, 1938).

Though there is no definite one to one correlation between pitch and frequency, there is correlation in the sense that when frequency of the done is raised. the perceived pitch too seems to be raised. Frequency and pitch are related logarithmically. Doubling the frequency (intensity being unchanged) raises the pitch by an octave (Judson and Weaver, 1965).

Although pitch is defined often in terms of pure tones, it is clear that noises and other aperodic sounds, have more or less definite pitches. The general pitch of complex tones according to Stevens and Davis (1935) depends upon the frequency of its dominant component, the fundamental frequency in a complex tone is one perceived. Plomp (1967) states that the periodicity of pitch has been found in a complex tone. Even in complex tones, where the fundamental frequency is absent or weak, the ear is capable of perceiving the fundamental frequency.

Even though pitch has a correlation with frequency, it varies with duration and the intensity of the cone. The terms pitch and fundamental frequency can be used interchangeably as they mean the rate of vibration of vocal cords during phonation (Ohala, 1978).

It was not until more recently that experimental evidence was offered to show that the vocal cords produce the sounds of voicing by means of their vibration which is turn inturrupt the air stream passing through the glottis into the vocal tract proper and that is lengthening and consequent tensing of vocal cords which change the rate of vibration, that is, the pitch of the voice.

Erickson (1959) is of the opinion that the vocal cords are the ultimate determiners of the pitch and that the same general structure of the cords seem to be determining that factor in the range of frequencies that may be produced.

The frequency of vibration of any vibrator is determined by the mass, length and tension of the vibrator. The relationship between each of these three factors and the frequency is expressed as:

$$F= \frac{1}{2} L \sqrt{T/M}$$

Where F is frequency, L is the length of the Vibrator, T is the Tension of the Vibrator and M is the mass of the Vibrator.

The formula indicates that the frequency varies inversely with length (L), directly with the square root of mass per unit length (M) and directly with the square root of the tension of the vocal cords (T).

This formula is not applicable for vibration of vocal cords as precisely as in the cases of musical instruments and this does not explain all vocal cord conditions.

The fundamental frequency changes as a function of age. A series of investigators dating back to 1939 have provided date on various vocal attributes at successive age from infancy to old age (Fairbanks, 1942, 1949; Samuel, 1973; Usha Abrham; 1978; Curry, 1940; Snidecor, 1943; Hanley, 1949; Mysak, 1950).

The aging trends for males with respect to central tendency is, one of the progressive lowering of pitch level from infancy through middle age followed by a progressive raise in the old age. The voice of newborn has a pitch around 440 Hz (Grutzman and Plateau, 1905) with growth of larynx the child's voice gradually changes. The voice change is most prominent at puberty.

In the female population, there is general lowering of pitch levels from seven years of age to pubertal age as the male pattern and are attributed
to the laryngeal growth. Unlike males, there is little change after puberty upto the advancing age.

The analysis of speech of individuals show that there is a pitch which is more frequently used by them. This pitch is known as ' Habitual Pitch Level' or 'Model frequency'.

To study the fundamental frequency of voice, there have been many attempts.

The Mechanism underlying pitch variation has been dissussed by Zemlin (1968). He says "increase in length of the folds seem to result in decrease in cross sectional area (mass) which according to wood's formula will result in increase in pitch".

Muller ( ) showed that although the primary mechanism for raising pitch as tensing of vocal cords via the cricothyroid muscles, it was also possible to change pitch by the subglottal pressure, that is, aerodynamic conditions at glottis.

Lieberman's (1967) Ps (Subglottal pressure) causes Fo (Fundamental Freqeuncy) hypothesis supports the variation in pitch in speech, is accompanied not by the action of the laryngeal muscles by variations in Ps (Subglottal air pressure.).

Isshiki (1959) after electric stimulation experiments on dogs, noted that pitch increased when airflow alone was increased and that pitch elevation was accompanied by increasing subglottal pressure when airflow remained constant.

Moore (1937) observed that a general lengthening vocal felds associated with raises in vocal pitch.

Holliin (1960) has found that as the fundamental frequency of phonation is raised, the folds systematically lengthen. It was observed that individuals with the low pitched exhibited generally longer vocal cords than do individuals with higher pitch levels both between the sexes and within individuals.

Hollein and Curtis (1962) found in a laminographic study of vocal cords that the mean thickness of the vocal folds decreased with the pitch, as it was systematically raised. But increase in pitch cannot be accounted solely for a reduction in mass. Tension factor also plays an important role in the pitch changing mechanism. The pitch increases as the tension of the vocal cords increases.

The other factors contributing to the pitch variations are:-

1. Larynx Height: Venderslice recorded the vertical laryngeal movements and subglottal air pressure during connected speech. The results indicated that the former to be better correlated with pitch than was subglottal pressure. Many investigators have found this. That is , the larynx atleast by it’s metrical movements

actively participates in the control of pitch in speech, whether it is found on pitch falls or pitch raises on non terminal or sentence terminal elements.

2. The function of laryngeal muscles: Hirano, Koike and Von Leden (1967) have also found that the sternohyoid is more active for extreme high pitch. Sternophyoid along with sternothyriod shown to be active during lowersing and maintenance of low pitch. Ohala (1972) suggested that it was vertical and antero-posterior tension of vocal cord which could affect the pitch. Steven ( ) suggested that the vertical shifting of larynx may create changes in the vocal cord properties which would affect their sensitivity and subglottal pressure. Shipp, Hall and Ewan (1976) also advocate the “vertical tension” hypothesis. Luchsinger and Arnold (1968) studied the cases of bilateral cricothyriod paralysis. And they found no anterior posterior stretching of vocal cords but the larynx was raising during the production of the higher pitch.

In has been noted for several decades that other things being equal, the average pitch o vowels show a systematic correlation with vowel height. That is, higher the vowel, higher the pitch (Grandell, 1975; Fairbanks, 1953).
The difference in pitch between high and low may be as much as 25 Hz.

Various hypo these have been proposed to account for this. Two of them are: (1) Coupling hypothesis and (2) tongue pull hypotheis. The coupling hypothesis advocated by Atkinson and Lieberman ( ) suggests that when the first formant of vowel is near the fundamental frequency, as is the case with higher vowels – acoustic coupling occurs between the vocal tract and vocal cords, that is, the resonance effectively dictates to the source the frequency at which it can vibrate.

The tougue pull hypothesis offered by Lehiste (1970) and Ladefogd suggests that some how or the other, in producing the high vowel, the tongue pulls on the larynx and affects the tension of vocal cords and the pitch of the voice.

Zemlin (1968) speaking over pitch lowering mechanism states that "……….. a decrease in pitch might be produced either by a decease in tension (and an increase in mass) or by an increase in length of vocal cords".

Though threre are many factors which vary the frequency of vocal cord vibration, it is the vocal cords which are mainly responsible for the determination of frequency.

The vocal cords are capable of vibration at a wide range of frequencies.

There are several studies regarding the maximum pitch range that the vocal cords can produce.

Maximum pitch range has been defined by Michel and Wendahl (1971) as " ………..the highest and lowest frequencies an individual can phonate in each of these three frequency ranges vocal fry, modal and falsetto".

But, it is difficult to distinguish between these three frequency ranges, Hence, in the present study the frequency range has been defined as equal to highest frequency as individual can phonate minus the lowest frequency.

Anderson (1942) reports that "the total range of thevocal mechanism ………… including voice of both men and women extends almostfour octaves from a low tone of 70 to 80 db per second to 1024 d.v. in female voice".

Hollien and Michel (1960) have reported that the mean range for males was just over an octave and a half with frequency limits of 71 to 561 Hz, that of females being almost two octaves within the frequency range.

Most of the studies on frequency range include the falsetto and vocal fry. Therefore they give a range much greater than the modal frequency range. However, falsetto is seldom used in speech though the vocal fry is used at the end of a sentence. In a study by Samuel (1973), the fundamental frequency range for different age groups of Indians ranging from seven years to twentyfive years old age for both the sex, were reported. For malesin the seven years old group, the fundamental frequency ranged from 200-300 Hz. In the twentyfive years old age group, the fundamental frequency ranged from 100-160 Hz. For femals, in the seven year old age group, the fundamental frequency ranged from 230-250Hz. and in twenty five year old age group, the range was 150-220 Hz.

LOUDNESS:

Loudness, an another attribute of voice is the subjective auditory impression of intensity. The term refers to the strength of the sensation received through the ear.

Frequently the term intensity and loudness are used interchangeably. According to Judson and Weaver (1965), loudness in not strictly a physical term, it is comparative psychophysical term describing the degree of sensation which one receives by means of the hearing apparatus, Though intensity can be measured physically, loudness is a matter of individual judgment.

According to Murphy (1964) loudness, though a psychological correlate of intensity, it varies as a function of frequency.

Perkins (1971) reports an experiment where a person was asked to sing the pitch head when the tuning fork was struck. The pitch sung was relatively accurate when the tuning fork was held few feet away and the lowering of the pitch sung was observed when it was held only a few inches away. The sensation of loudness affects the sensation of pitch.

Isshiki (1964) has shown that the optimal valuing and the frequency range used affect the loudness.

According to Murphy (1964) the major determinants of intensity are (1) the strength of the duration of breath pulse, (2) the duration and the force of the closure of the glottis and (3) the coupling factor of the resonator.

Judson and Weaver (1965) say “an increase in intensity may be due to (1) A decrease in the elasticity of the vocal cords, (2) An increase in the tracheal air pressure, (3) A combination of the above”.

The intensity changes have been observed in speech. The range of such change is difference between the least and the intense sound has been estimated to be over 70 dB.

Vander Herg (1956) and Ladefogedd (1960) have demonstrated a relationship between subglottal pressure and intensity, Sound pressure is proportional to the square root of the subglottal pressure.

Rubin (1963) from his study has concluded that the vocal intensity may be raised by increasing airflow keeping the vocal cord resistance

constant or by increasing vocal cord resistance, keeping the air flow constant. Also mechanism of vocal pitch and intensity are so much interrealated
that to attempt to isolate one from another, except for most elementary consideration is virtually impossible.

From this result it might be supposed that internal laryngeal behavior ought to vary markedly as intensity is increased during phonation, at low pitch and dthat it ought to vary less as intensity is increased during high pitch phonation.

The increase in pitch that usually accompany increase in intensity of phonation can be amounted for by greater tension of vocal cords.

The assessment of loudness has been considered more complex than the assessment of pitch (Perkins, 1971). Denley and Thurman (1960) showed that adequate loudness for comprehension as the primary goal for evaluating loudness, where as, Fairbanks (1960) posits vocal efficiency, maximum output with minimum effort as the first objective.

Coleman (1977) While devicing a fundamental frequency profile of adult male and female voice says that “relationship between Fo and SPL outputs o normal human voice are explored little in quantitative manner. Literature related to the topic has constituted almost entirely of studies using small groups of children.

Wolfe and Sette (1935) studied four professional male singers producing loudest vocal output of which they were capable over a consistent increase in SPL with increasing to for 2 octave range, after which output appeared to decrease with further increase in Fo. The SPL range from lowest to highest Fo produced at maximum efforts by singers was approximately 30 dB.

Wolfe et al., in their second study found that agenerally uniform increase in SPL occurs with increase in Fo. Voice tested had an approximate 3 Octave range and 51dB range from softest to loudest sound produced.

Coleman (1977) cites the study by Stout (1938) who utilized 3 trained male singers to intestigate harmonic structure of vowels in singing in relation to Fo and SPL. He found that with increase in Fo there was concommitent increase in SPL. but that amount of increase varied as a function of vowel produced.

Colton (1969) found that vocal SPL of both singers and naïve subjects was greater in modal than in falsetto pitch range and there was a consistent increase in SPL. as Fo was raised.

The application of data concerning the relationship of Fo and SPL changes in human voice is of more than academic Value. In addition to furnishing cues about normal performance of larynx and vocal tarot there in need to define such performance n disordered voices.

Coleman (1977) to device a profile using these two parameters experimented with 10 adult males and 12 adults females who were judged to be normal. They were matched in terms of training and singing. He found that average Fo range for both males and females was 37 semitones of approximately
3 octaves. The individual range for both sexes were quite similar, that is, from 28.9 to 43.8 semitones for males and from 30.6 to 42.2 semitones for females.

The widest SPL range achieved for a single female was 63 dB and average for female was 51 dB. Widest for a male was 52 dB with average range of 54.8 dB.

Minimum SPL. obtained for a single subject was 48 dB for a female and 51 dB for male and the maximum SPL. achieved for a male was 126 dB and for a female was 122 dB.

Fo- SPL, profile indicated that low frequency were accompanied by low SPL outputs.

The restriction of voice at lower frequency levels is consistent with the impression of singers and the professional voice users of the difficulty in producing vocal loudness variation at low Fo. The mechanism underlying the restriction of SPL range at low Fo has been discussed by Isshiki (1964). He states that “if laryngeal resistance is low at low pitches, a significant increase in airflow rate might produce a condition in which the larynx is unable to close or closes speridically producing a unsteady pitch”.

Vocal resonance serves two function: 1. amplifying the sound and 2. Determining the quality.

Thus, loudness is affected by the factors of resonators and the glottis. Variations in loudness are important for conveying the proper emotional and connotative meaning.

Qualtiy:

Quality is the psychological correlate of resonance and timbre patterns (Murphy, 1964). Perkins (1971) is of the view that “Vocal quality is the psychological problem of relating its subjective perception to its acoustic stimuli”.

The quality is mainly affected by the mode and rate of vocal cord vibrations, characteristics of the resonators and by the relative intensity levels of fundamental frequency and harmonics.

The interaction of pitch and loudness with the dimension of quality can confound the physiological changes to such an extent that variations attributed to pitch or loudness may, in fact, be functions of uncontrolled covarying quality dimensions. IN this context, Berry and Eisenson (1967) state that “it is difficult to separate factors of quality from factors of pitch and loudness”. They give two definitions of quality Psychoacustic definition, that is, the quality is the ‘hearer’s impression of the complex sound wave its harmonic and inharmonic partials and the relative intensity, numbers and duration of these components. Such an impression, he judges INTERNAL of pleasantness’.

The physiologists definition, which states that the ‘ quality depends upon (1) the power and control of respiration; (2) the size, elasticity, length and surface condition of the vocal folds; (3) the size, shape and tension and flexibility of the resonator – articulator mechanisms: and (4) the rigidity, density and surface condition of the wall of the resonator’.

“Optimum pitch” or “natural pitch” level has received considerable attention.

According to Van Riper and Irwin (1959) “ Each person has an optimum pitch, an efficient pitch at which voice will be of a good quality and which will have maximum intensity with the least expense of energy. The optimum pitch is not a single rather it is a range”.

As Darley ( ) puts " each person has a frequency range of tone which he can produce readily and that this range has a central tendency – his optimum or natural pitch level".

It has not only been indentified as the pitch level or range of pitches at which the voice functions most efficiently (Fairbanks, 1960), but also as the pitch at which the optimum quality is observed (Johnson 1963).

West et al. (1947), describe optimum pitch as " that frequency of laryngeal tone at which the largest quantum of energy of the breath stream is converted into sound waves; the frequency at which the greatest carrying power is achieved by the least expenditure of vocal effort, the frequency at which the measurement of vocal bands are best facilitated by factors of resonance."

Fisher (1966) describes optimum pitch as follows:

(1) It is the best or most favourable for speaking, easiest to phonate, and most free of strain.

(2) Optimum pitch has greater intensity.

(3) Vocal folds being in a more elastic and more normal state is more responsive to the force of subglottic breath pressure. They can swing more widely apart and they pull back more quickly, and

(4) this provide effective variation in pitch for intonation.

The approximate median of the range at which the voice functions most easily and most effectively is called the " Optimum pitch". Thus the optimum pitch is the best and most favourable for speaking (Gray and Wise, 1959).

It is accepted that each person in accordance with his unique physical vocal equipment has a pitch level at which a greatest level of power and best resonance occurs under the conditions of greatest physio-acoustic economy. This pitch level is known as the optimum or natural pitch level (Murphy 1964).

According to Thurman (1958) “ the optimum or natural pitch level is that at which the human vocal apparatus operates with greatest efficiency”.

As is seen all the definitions tell only of greatest efficiency, least effort and maximum intensity. However, Perkins (1971) defines optimal vocal functioning hygienically, acoustically and aesthetically. According to him, voice is produced most hygienically when it is produced most effortlessly. According to the acoustical criterion, optimum pitch denotes the range of frequencies at which the voice is most efficient for speech, where loudness is achieved with minimal effort. Regarding aesthetic criterion, he states that “ the hygienld voice, that is, the efficient voice, is also, apparently. an aesthetically acceptable voice”.

Most of the disorders of pitch, the intersity and the quality reveal that their vocal mechanism is not functioning at the optimum pitch level or natural level.

Berry and Eisenson (1962) consider that the asymmetry is coupling between mouth and pharnnx and nose would probably affect the adduction of vocal cords. And further the rigidity of face and neck would also play an equal strain on larynx because they inhibit free laryngeal movements”.

While discussing the general principles of voice therapy, Berry and Eisenson (1962) consider, “ Development of Kinesthesia” of the proper muscle synergy, the proper tensing and timing in the larynx and the pharynx.

The principles of voice theraphy MIDVAS explain about “Approximation” (A)towards the modal pitch (Van Riper and Irwin 1968).

Mary (1969) while dealing with therapy for inadequate pitch level (too high or too low) gives the following as one of the steps in therapy or relearning procedure.

“Find your optimum pitch by counting up from the lowest possible note to one fourth of your total range”.

Murphy (1964) emphasized the use of effective (efficient) vocal habits and the need to maintain the efficient voice without excessive strain in a variety of speaking situations and under stress as a important phase in therapy.

Shyamala (1970) in treating spastic dysphonic case says that it can be eliminated by teaching the case to phonate at an efficient pitch, by modifying the disordered voice by lowering or raising the pitch.

A review of literature on voice therapies indicates that almost in all kinds of voice therapies, the therapist ‘ locates’ optimum or efficient or natural pitch level for the the case and makes the case to use that pitch in his speech.

Thus, the review of literature on voice therapy shows that there is a great need for finding optimum pitch as it is an important step in voice therapy.

There is a lot of disagreement among the authorizes in the field of voice about the location of optimum pitch.

There are several methods of locating optimum pitch (Nataraja 1975).

Wentworth (1940) in her study of fourteen texts found that there were eight different methods. Pronovast (1949) described and experimented with nine such methods.

These methods can be categorized basically into four groups:

1. By finding the total frequency range that a person can use.
2. By locating the ‘swelling of loudness’.
3. ‘Coughing or laughing’ or locating pitch at which a person can produce voice with greatest case.
4. By finding out the ‘ natural frequency of the vocal cords’.

Methods using the Total Pitch Range:

Using the total pitch range, several methods have been tried to locate the optimum pitch. As a first step, total pitch range that a person can produce is determined. That is, the lowest and the highest note including the falasetto, that the person can produce will be determined either by using the musical scale or piano. And then, some consider optimum pitch as a frequency one – fourth above the lower limit of the pitch range that a person can produce (Pronovast, 1942; Fisher, 1942; Fairbanks 1960); Berry and Eisenson, 1962).

Some others recommend optimum pitch as the frequency one third from the basal tone of the pitch range (Herry and Bisenson , 1962). Still others consider that one-fifth from the lower limit of the total

pitch range that person can produce as the optimum (Brownstein and Jacoby 1967)
And also some other suggest the mode of pitch range that a person can produce including falsetto, while still others locate the optimum pitch at the median of the pitch range that a person can produce (Gary and Wise, 1959).

Pronovast (1942) located median pitch levels in six superior male voices and found they approximated with level that was about one – fourth of the total pitch range. Link (1953) in case female voices found that the median pitch level comprised one fifth of the total pitch range.

The method given by Fairbanks (1959) has been considered as the most satisfactory method, by Johnson et al. (1967) for estimating a person’s natural pitch level. While discussing the limitations of the method, they say that “ the procedures just stated serves very well if the individual is able to sing a scale and has a pitch range that is not too severely restricted”. They suggest modifications of the method in such situations.

Eventhough Johnson et al. (1967) point out limitations and suggest modifications, it remains confusing as there are several methods which differ from each other and as many of them have no experimental evidences, In general, therse methods cannot be used with cases who do not have a concept of pitch or pitch range.

Locating the Swelling of Loudness:

Several people have recommended and advocated these methods (Wentworth 1940; Berry and Eisenson, 1962; Murphy, 1964; Fisher, 1942; West et al., 1968; VanRiper and Irwin, 1958). Basically these methods assume that at particular pitch level there will be maximum increase in resonance and as such there will be maximum increase in intensity, when the subject produces voice at several pitch levels covering the total pitch range. The results of the study by Thurman (1958) do not support the usual procedures of locating optimum pitch by resonance reinforcement in a fixed region. But clinically it has been found to be useful to establish the optimum pitch level (Johnson et al., 1963). West et al. (1968), state that for male speakers there are two such swellings. But his statement has not yet been supported by any experimental evidences.

The subjective judgement of loudness has discussed earlier is also dependent on the frequency of the sound. Hence the feeling of increase in loudness by the clinician need not reflect the maximum resonance in the vocal tract. Further it may not be possible to locate the swelling of loudness as each individual monitors the loudness (voice) by auditory feed back involuntarily.

This phenomenon seems to be the best explanation for explaining the fallacies of the above methods. Apart from these, these methods are purely subjective, as either experimenter or the subject has to locate the swelling of loudness.

House (1959) discusses the vocal swell method of eastimating natural frequency and demonstrated that presumably perceptible changes in overall voice level would result when a harmonic of the fundamental frequency coincides with the centre of the vocal tract resonance. Thus, perceptible increase in loudness will reflect this match rather than reflecting an increased laryngeal efficiency. He concludes that vocal swell method is of little value.

Methods employing “Coughing and Laughing” and other methods:

Many have advocated these methods (Wentworth, 1940; Pronovast, 1942). A pitch at which a person coughs or laughs has been considered as optimum pitch in these methods. Or the note at which the speaker experiences
the greatest case is the optimum pitch level (Fisher, 1966).

No experimental evidence are there to support the above methods and from the study of these above methods, it is obvious that these methods are subjective.

Methods using the Natural Frequency of the Vocal Tract:

From the definitions of the optimum pitch it is clear that optimum pitch is one it which maximum resonance occurs in the vocal trat of the particular individual. An attempt has been made by Nataraja (1972) to overcome the above mentioned draw backs by developing an objective method of locating optimum pitch by measuring the natural frequency of the vocal tract.

In this experiment an external sound source of frequency range from 100 to 5000 Hz with a consistent intensity was used to stimulated the vocal tract of good speakers. It was presumed that the good speakers were using the optimum pitch. The frequency which showed maximum increase in intensity was considered as the natural frequency of the vocal tract. Fundamental frequency of voice of the same good speaker was determined using stroboscope.

A definite and consistent relationship of 8 & 1 was found between the natural frequency of the vocal tract and the fundamental frequency of voice in case of good male speakers age ranging from 20 to 25 years. The predictive validity was also tested and it was valid. Hence,

$$\text{Optimum pitch} = \frac{\text{Natural frequency of vocal tract}}{8}$$

This method was tried therapeutically with dysphonics and they were helped to use these frequencies as their fundamental frequency of voice , using the stroboscope. Follow up of these subjects has shown that they were using the optimum frequency as the fundamental frequency of their voice.

As a part of study Shantha (1973) arrived at a relationship between the fundamental frequency of vocal cords and natural frequency of vocal tract in good voices in the age range of 20 to 25 years in females. A definite and consistent relationship of 5: 1 was found between the natural frequency and the fundamental frequency of good voices in the /a/ position.

An attempt has been made by Geetha Pai (1974) to find whether the natural frequency of vocal tract determined by an external sound source (as described by Nataraja. 1972) concides with the formant 1 and 2. She has concluded that the natural frequency of the vocal tract do not coincide with any of the formants. She supports that the natural frequency determined by the above technique does consider the vocal tract as a whole.

Nataraja and Jayaram (unpublished paper) while considering the classification of voice disorders state that there is no need for classification of voice disorders from the point of view of voice therapy. It is possible to give a voice which is hygienic to the vocal mechanism and which is also socially acceptable aesthetic voice by achieving optimum frequency. Further they also state that determining optimum frequency is useful in diagnosis and therapy of voice disorders.

Further it has been considered by Jayaram (1975) from his study “As attempt at an objective method of differential diagnosis of dysphonics.” Thus locating optimum frequency has been found to be essential in diagnosis and treatment of voice disorders and the objective method of locating optimum pitch has been found to be useful in determining optimum frequency.

However, it is necessary to confirm that there is physioacustic economy at the optimum pitch which has been determined by measuring the natural frequency of vocal tract. That is, to find out whether the pitch is produced with minimum energy or the vocal cords are set into vi-bration with less sublottal air pressure.

Hence the present study has been planned to study the physioacupustic conditions at this pitch by measuring the phonation duration, mean air flow rate, the sound pressure level range and its place in pitch range.

CHAPTER III: METHODOLOGY

To study the Physioacoustic economy at optimum frequency with reference to other frequencies the maximum phonation duration, mean airflow rate and intensity range were measured at

1. Optimum frequency
2. 50 Hz above optimum frequency.
3. 100 Hz above optimum frequency.
4. 200 Hz above optimum frequency
5. 50 Hz below optimum frequency or a lower limits of the frequency range.

The pitch range (highest frequency the subject could phonate lowest frequency the subject could phonate) was also measured to determine the place of optimum frequency in the pitch range, as this would give an indication regarding the possibilities of variation of pitch within the pitch range.

SUBJECT:

10 subject (5 males and 5 females) were selected randomly from the population of All India Institute of Speech and Hearing. They were examined for any speech and hearing problem by the experimenter.

TEST ROOM:

One of the acoustically treated audiometric room (Room C) was used for the experiment.

Experiment No. 1 (a): Finding natural frequency of vocal tract : to determine the optimum frequency:

Step 1: The Instrumental set-up:

The following instruments were arranged as shown in the block diagram 1.

1. Beat frequency oscillator (B & K Type 1022).
2. Audio frequency analyzer (B & K Type 2107)
3. Condenser microphone (B & K Type 4144) with prea ampilifer.
4. Probe speaker.

Step 2.

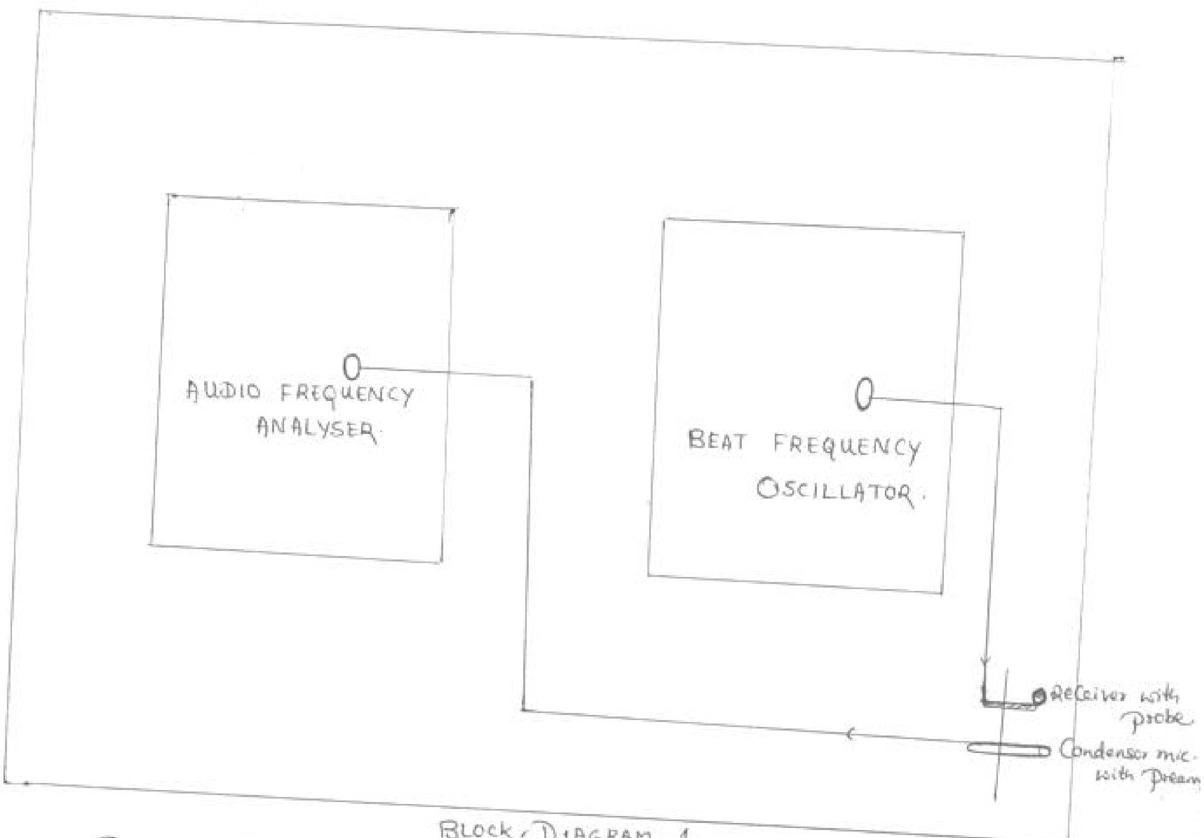
The subject was told what was to be measured and he /she aws seated. The following instructions were given to the subject:

"Keep your mouth open as when you say /a/ (like this – demonstation). Then the probe speaker will be introduced into your mouth, Please take care not to see that probe speaker and the condenser microphone are not in contact with any part of your mouth. Then, I will introduce the test tone into your mouth and you have to keep still till I ask you to remove".

The experiment was demonstrated.

Step 3:

The probe speaker was introduced into the mouth of the subject which was kept open in the vowel /a/ position. Tone ranging from 100 Hz to 5 KHz was introduced into the vocal tract through the probe speaker. The response of the vocal tract was picked up by the condenser microphone at the lips and directly read from the meter of the audio frequency analyzer, The frequency at which there was maximum response or maximum deflection



BLOCK DIAGRAM - 1
SHOWING THE SCHEMATIC ARRANGEMENT OF THE EQUIPMENT FOR THE MEASUREMENT OF NATURAL FREQUENCY OF THE VOCAL TRACT.

of the pointer in the meter of the audio frequency analyzer was taken as the natural frequency of the vocal tract. In order to obtain the optimum frequency, the natural frequency was divided by 8 for males and by 5 for females.

Experiment 1 (b): To determine the fundmental frequency of voice while phonating /a/ :

Step 1: Instrumental set – up:

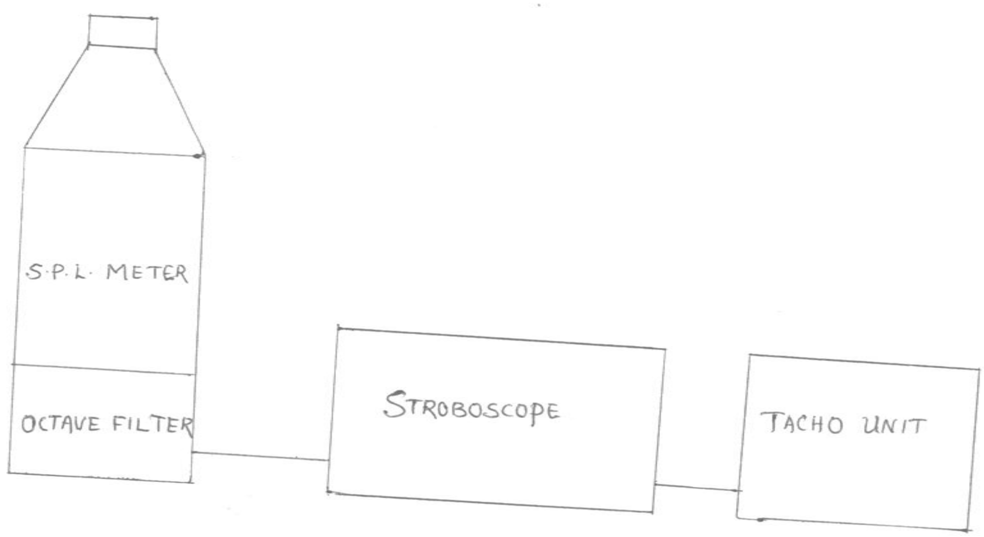
The following equipments were arranged as shown in the block diagram 2 to measure fundamental frequency of voice.

1. SM Meter (B & K Type 2203) with octave filter set (B & K type 1613)
2. Stroboscope (B & K Type 5066).
3. Tacho unit (B & K Type 5527).
4. Condensor michrophone B & K Type 4145 & 4144) with preamplifer.

Step 2:

The subject was told what was being measured and was instructed to phonate vowel /a/ in his natural speaking pitch as long as he could in front of the microphone of the SPL Meter. The input pulses wree fed to the stroboscope through SPL Meter with octave filter set. The fundamental frequency of voice was directly read from the meter of the tacho unit.

Experiment 2. To determine, intensity range, the frequency range, and maximum phonation duration:



BLOCK

DIAGRAM -2

SHOWING THE SCHEMATIC ARRANGEMENT OF THE

The instrumental setup in Experiment 1 (b) was used here also, to determine:

(a) the intensity range,

(b) the frequency range, and

(c) the maximum phonation duration.

Experiment 2 (a): Finding the intensity range:

The subject was asked to phonate the vowel /a/ as loudly as possible and a softly as possible in front of the microphone at:

i) Optimum frequency

ii) 50 Hz above optimum frequency

iii) 100 Hz above optimum frequency

iv) 200 Hz above optimum frequency

v) 50 Hz below optimum frequency or lowest frequency level at the frequency range.

The subject was asked to maintain the frequency at each level using the tache unit reading as visual one. Three reading at maximum and minimum, intensities and at all the five frequency levels were taken.

Experiment 2 (b): Finding the frequency range:

The subject was told what was to be measured and was instructed to phonate vowel /a/ in his lowest possible and highest possible pitches in front of the microphone, keeping the intensity constant as for as possible.

The frequency was directly reading from the meter of the tacho unit. Three reading for each subject ws taken at highest and lowest pitches.

Experiment 2 (c) : Determining the maximum phonation duration:

The subject was asked to take a deep inhalation and phonate vowel /a/ in front of the microphone of SPL. Meter keeping the frequency and intensity constant an long as possible. This was done using the readings of tacho unit and SPL Meter as visual cues at:

i) Optimum frequency,
ii) 50 Hz above Optimum frequency,
iii) 100 Hz above optimum frequency,
iv) 200 Hz above optimum frequency, and
v) 50 Hz below optimum frequency as lowest frequency level of the frequency range.

As soon as the subject started phonating, a stop watch started and it was stopped when the variations in the intensity and / or frequency exceeding $\pm$ 5 dB and $\pm$ 10 Hz respectively.

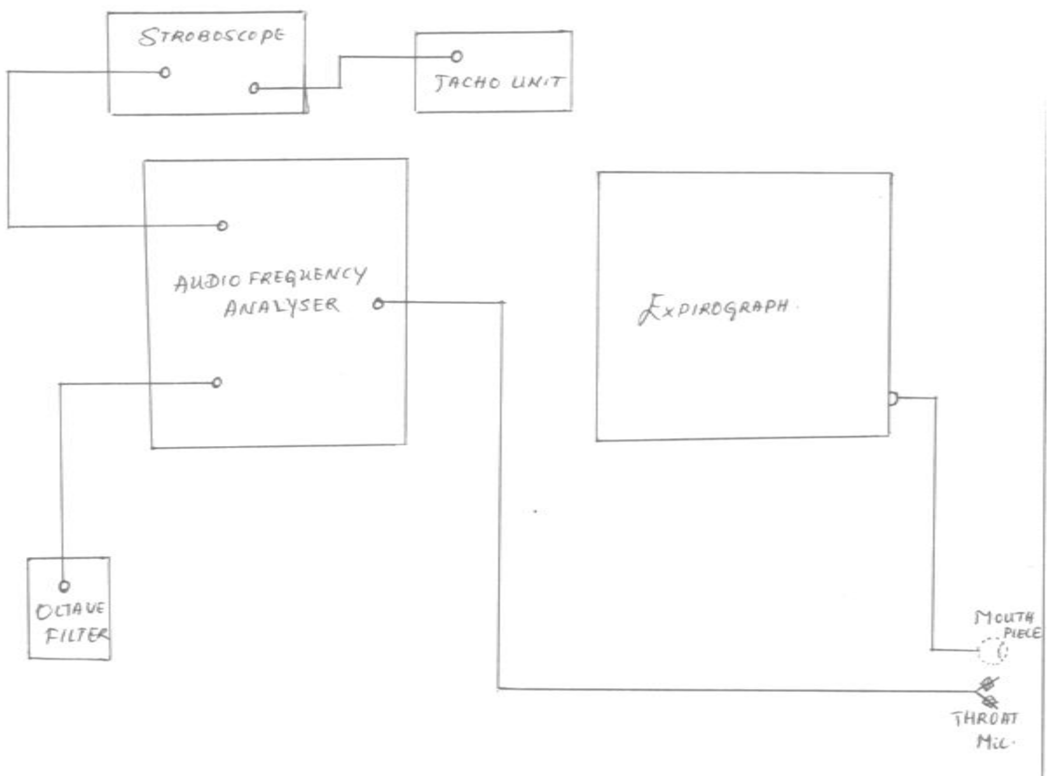
There readings were obtained for each subject at each frequency level. The longest of the three at each frequency level was considered as maximum duration of phonation at that particular frequency level.

The subject was asked to repeat this after sufficient rest between successive trails at each frequency level.

Experiment 2 (d): To determine the mean airflow rate during phonation:

Step 1:

Instruments of experiment 2 (c) with an addition of expiropgraph were used in this experiment as shown in the block diagram 3.



Block Diagram -3

SHOWING THE SCHEMATIC ARRANGEMENT OF THE EQUIPMENTS

It was planned to study using condensor microphone of the SPL Meter which was inserted into the mouth piece of the expirograph. As the air pressure was directly acting on the microphone of the SPL Meter it could not be used. Hence, a threat microphone was tied around the neck of the subject, in place of condenser microphone. This was done to feed a part of the voice singnal to the audio frequency anayzez (used in place of SPL. Meter) and tacho unit through strobescope to give a visual cue regarding intensity and frequency to the subject while phonating. (Frequency and intensity have been considered as veriables affecting the mean airflow rate. Hence, it was necessary to control the frequency and intensity while measuring mean air flow rate).

Step 2:

The subjects were instructed to take a deep breath and phonate vowel /a/ into mouth piece of expirograph at:

i) Optimum frequency
ii) 50 Hz above optimum frequency
iii) 100 Hz above optimum frequency
iv) 200 Hz above optimum frequency, and
v) 50 Hz below optimum frequency or lowest frequency level of the frequency range.

with the throat microphone tied over the laryngeal prominence.

The total volume of the air collected during phonation and the duration for which this volume of air collected was noted using expirograph and stop watch. A ± 5 dB and or ± 10 Hz variations in intensity not frequency were permitted.

There reding at each of the five frequency levels were measured with sufficient intervals in between the trails.

Mean airflow rate was obtained by total volume of air collected during phonation divided by the time taken for obtaining the volume of air.

The lowest of the three readings ws considered as the mean air flow rate at that particular frequency level.

RELIABILITY CHECK:

To check the reliability three subjects from each group were selected randomly, from the sample tested and the measurements were taken again.

No significant difference were observed between the two readings.

CHAPTER IV: RESULTS AND DISCUSSION:

Experiment 1 (a): Finding the natural frequency of the vocal tract to determine the optimum frequency:

The natural frequency was found to vary from 900 Hz to 1050 Hz in males and from 900 Hz to 1100 Hz in case of females.

Table 1. repsents the optimum frequency of the subjects.

Table 2

SUBJECTS	MALES Optimum Freq.	MALES Fundamental Freq.	FEMALES Optimum Freq.	FEMALES Fundamental Freq.
1	110	120	200	210
2	110	115	180	200
3	110	110	190	200
4	120	110	220	230
5	130	125	200	210

The optimum and fundamental frequencies of both males and females.

Experiment 1 (b): To determine the fundamental frequency of voice while phonating the vowel /a/:

The fundamental frequency ranged from 110 Hz to 125 Hz in males and from 200 to 230 Hz in females.

Table 1, also reveals the fundamental of both male and female subjects.

As there were not much differences between the fundamental frequencies and optimum frequencies, the subjects were considered as having "good voice 2 (Nataraja and Jayaram, 1975).

Experiment 2 (a): Finding the intensity range:

The mean of intensity range (Maximum – Minimum) observed in males ranged from 26.6 dB to 52 dB. The maximum intensity range of 73 dB was observed at optimum frequency. The minimum intensity range ws 12 dB at -50Hz.

Table 2 shows the intensity range (in dB) for each of the male subjects at each frequency level and also the mean intensity range at each frequency level.

TABLE 2

SUBJECTS	Optimum frequency	+ 50 Hz	+ 100 Hz	+ 200 Hz	- 50 Hz.
1	55	40	47	50	21
2	73	15	46	18	13
3	42	35	39	20	41
4	50	38	31	38	38
5	40	33	27	25	20
Mean	52.0	32.2	38.0	30.2	26.6
0.05 level confidence	+	+	+	+	+

Inspection of the table reveals that intensity range for each frequency of the male subjects is greater at optimum frequency when compared with other frequency levels. The difference varies from 27 dB to 5 dB (except in subject 3, where the difference is only 1 dB, when a comparision is made between optimum frequency and -50Hz). However the intensity. Further, a comparision of means also reveals that the range at optimum frequency is greater than when compered to the mean of intensity range at other frequency levels. The minimum difference of 14 dB is seen when a comparision is made between optimum frequency and +100 Hz. The intensity ranges are still lower at other frequencies.

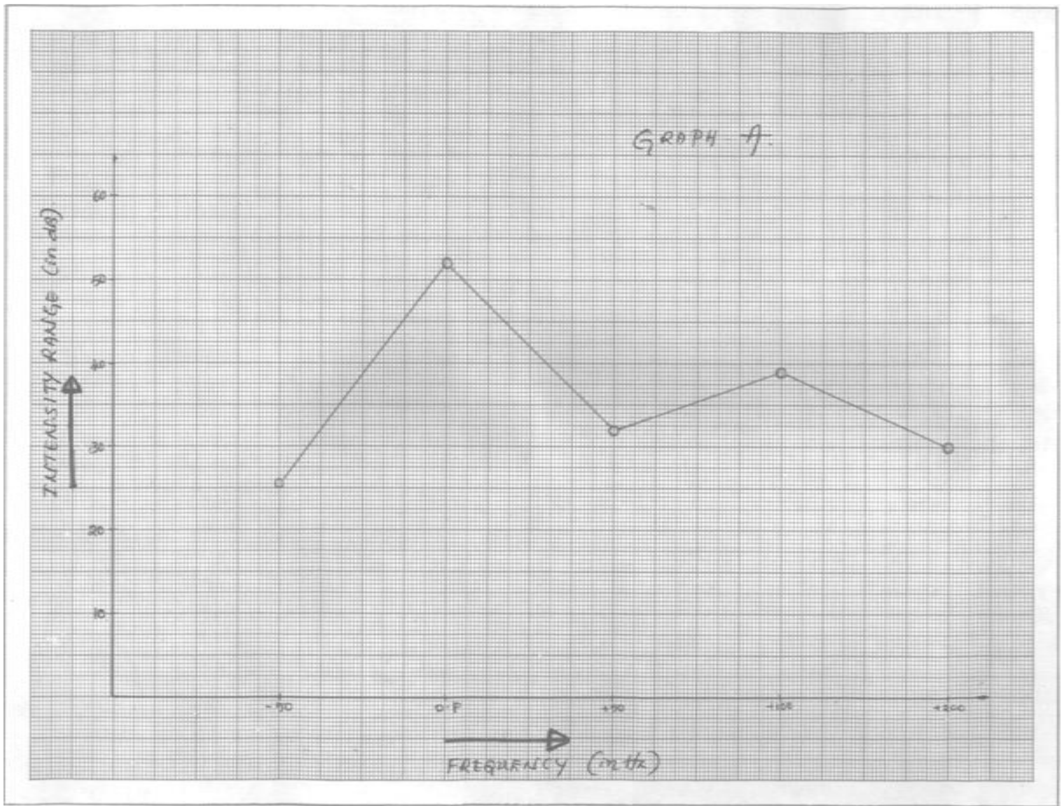
Graph A. also reveals tht the intensity range at optimum is greater.

Thus, hypothesis, that there will be no difference in intensity range at optimum frequency when compared to the other frequency levels in males, is rejected. That is, the intensity range at optimum frequency is greater when compared with other frequencies.

The statistical analysis was done using Wilcoxom matched – pairs signed – ranks test. The difference in intensity range between optimum frequency and other frequency levels was found to be significant at 0.05 level of confidence. Hence, the hypothesis (1) there will be no difference in intensity range at optimum frequency when compared with other frequency levels is rejected in males.

The mean of the intensity range (maximum – minimum) ranged from 26 dB to 45.4 dB in females.

The maximum intensity range 60 dB was observed at optimum


GRAPH A.
INTENSITY RANGE (in dB)
60
50
40
30
20
10
FREQUENCY (in Hz)

frequency and a minimum range of 20 dB was seen at 200 and -50 Hz

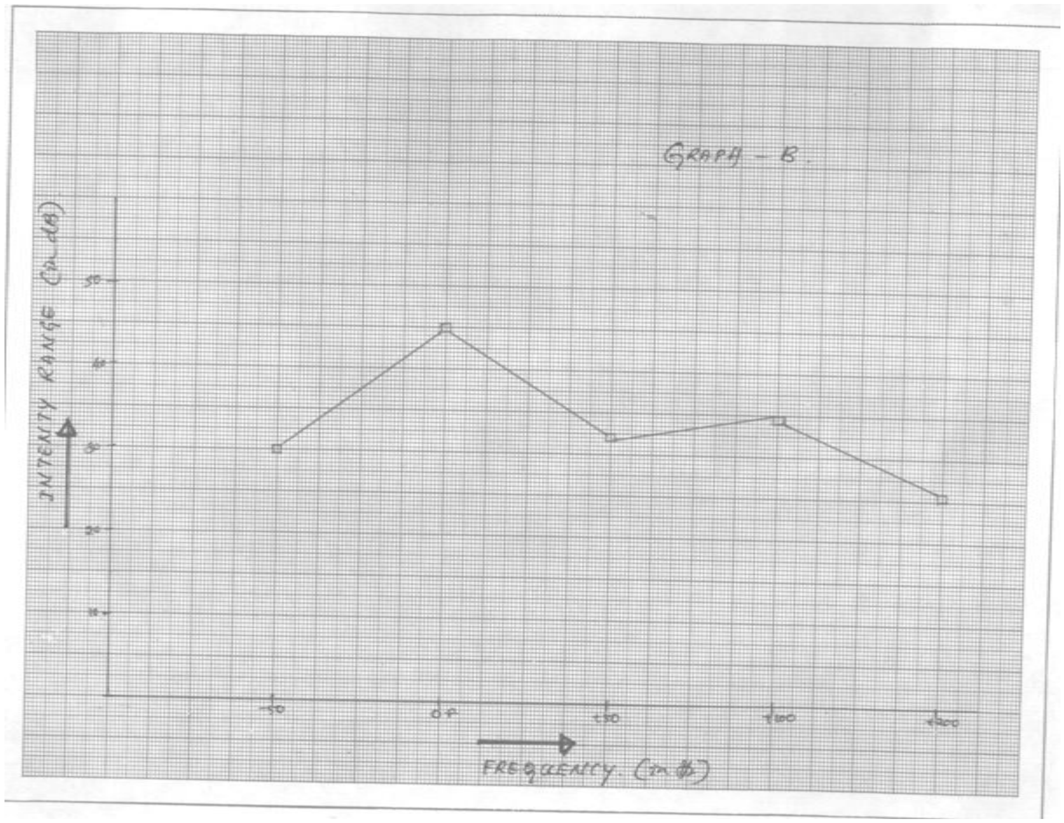
Table 3, shows that at optimum frequency the intensity range is greater when compared to other frequencies. the difference is found to vary from 2 dB to 12 dB.

TABLE 3

SUBJECTS	Optimum frequency	+ 50 Hz	+ 100 Hz	+ 200 Hz	- 50 Hz
1	37	22	35	25	20
2	40	37	27	20	31
3	43	34	21	25	33
4	60	46	50	40	45
5	47	26	35	20	25
Mean	45.4	33.0	33.6	26.0	30.8
0.05 level confidence		+ +	++	++	++

At optimum frequency each subject shows a greater intensity range than other frequency levels. Further, it also shows greater intensity range at optimum frequency when mean of the intensity range at optimum frequency is compared with the means of other frequencies.

The minimum difference of 11.6 dB is observed when a comparison between optimum frequency and + 100 Hz is made. Still lower intensity ranges are observed at other frequencies. This is shown in Group B.


GRAPH - B.
INTENSITY RANGE (in dB)
FREQUENCY.

Hence, the hypothesis (1) is rejected. That is, the intensity range is greater at optimum frequency than at any other frequency in female also.

The statistical analysis also supported that the difference in intensity range between optimum frequency and other frequency levels is significant at 0.05 level of confidence. Hence, the hypothesis that there will be no difference in intensity range at optimum frequency when compared to other frequencies is rejected in case of females also.

Therefore, it can be concluded that there is an acoustic economy at optimum when compared with other frequency levels interms of intensity range both in males and females.

Experiement 2(c) : Determining the maximum phonation duration (MPD):

the mean of MPD of 21,2 seconds was observed at optimum frequency in case of male subjects.

The MPD of 25 seconds was seen at optimum frequency and a minimum of 6 seconds at +200 Hz.

Table 4, indicates the MPD at each frequency level for males. The table shows that MPD is longer at optimum frequency when a comparision is made with other frequencies. This difference ranged from 3 seconds to 8 seconds, At optimum frequency, each subject shows longer MPD than other frequency levels.

When means of MPD are compared, the mean MPD is longer at optimum frequency. The shortest mean of MPD of 6 seconds is found at + 200 Hz level. That is, the mean MPD ranges from 21.2 seconds to 6 seconds.

TABLE 4

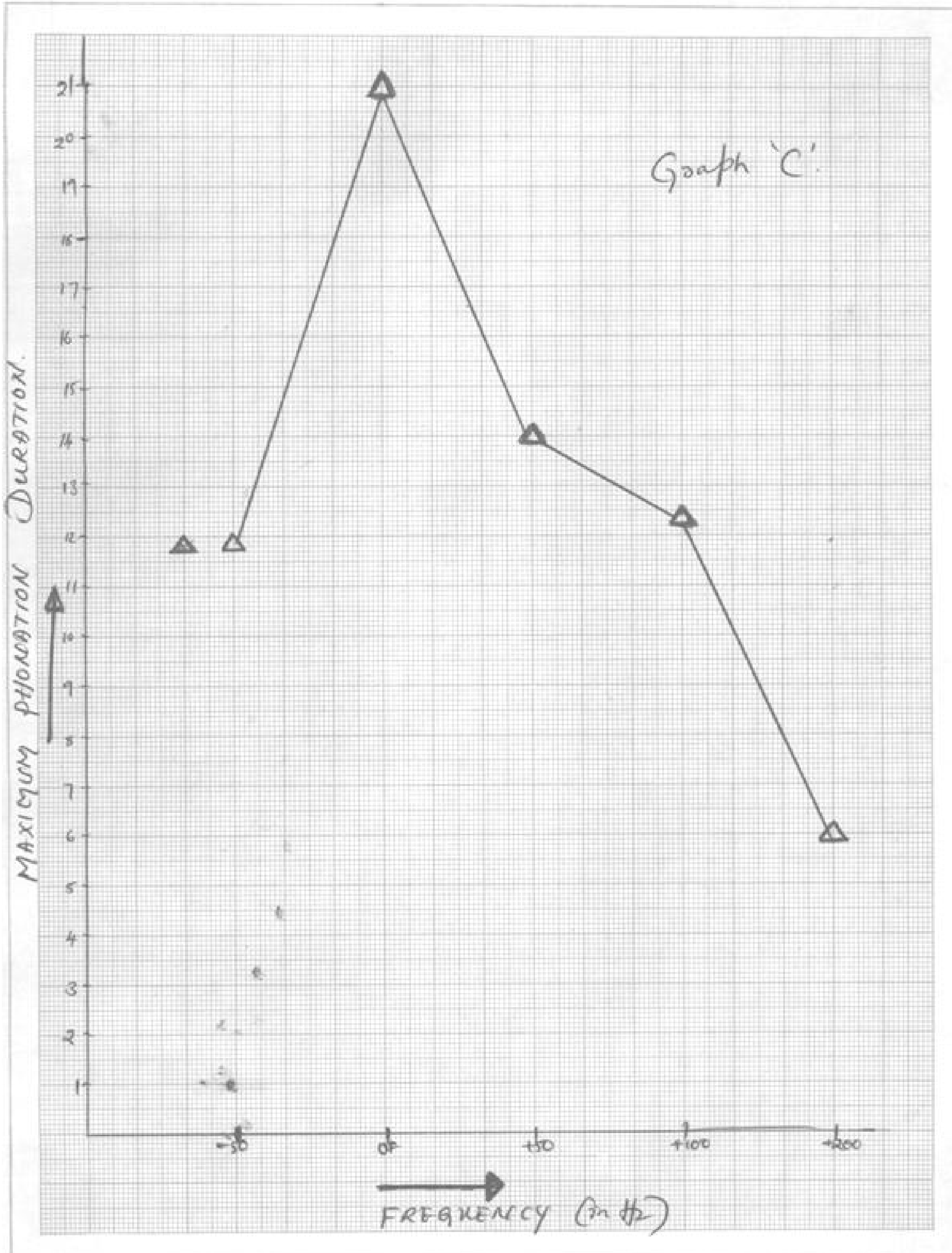
SUBJECTS	Optimum frequency	+ 50 Hz	+ 100 Hz	+ 200 Hz	- 50 Hz
1	21	11	10	6	14
2	25	18	16	9	12
3	18	10	10	8	13
4	21	13	11	10	13
5	21	18	15	7	7
Mean	21.2	14.0	12.4	6.0	11.8
at 0.05 level confidence		+ +	++	++	++

Table 4, showing maximum phonation duriation (in seconds) at difference frequency levels for males.

A difference of 13.8 seconds is seen when a comparision of mean MPD is made between optimum frequency and + 200 Hz.

A minimum difference of mean MPD is 7.2 seconds, when a comparision is made between optimum frequency and +50 Hz. Still shorter MPDs are observed at other frequency levels.

Graph C, also reveals that the MPD at other frequency levels are shorter when compared with optimum level. Thus, the hypothesis (2), that there will be no difference in MFD at optimum frequency when compared with other frequencies is rejected.


Graph 'C'
MAXIMUM PHONATION DURATION.
FREQUENCY (in Hz)
-50
0
+50
+100
+200
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1

The difference in MPD between optimum frequency and other frequencies is also statistically significant. Thus the hypothesis (2) is rejected with reference to males.

The mean MPD 14.2 seconds in case of males in found to be longer at optimum frequency than at any other frequency level. The MPD was found to be 20 seconds at optimum frequency and 6 seconds at +200 Hz 12.4 seconds at +100 Hz.

TABLE 5

SUBJECTS	Optimum frequency	+ 50 Hz	+ 100 Hz	+ 200 Hz	- 50 Hz
1	11	9	8	7	9
2	14	12	18	8	11
3	14	12	8	8	10
4	12	9	6	6	8
5	20	12	12	7	7
Mean	14.2	10.8	9.4	7.2	9
At 0.05 level confidence		+	+	+	+

Table 5, represents the MPD at each frequency level for females. Analysis of the table reveals that the MPD is longest at optimum frequency when compared to other frequency levels for each subjects. The difference ranged from 1 second to 8 seconds when the MPD of optimum frequency is compared with other frequencies.

Further, on comparision of means, the mean 14.20 seconds is longer seen at optimum and shorter at other frequencies. Mean of 7.2

seconds is seen at +200 Hz which is the shortest. The graphical representation (Graph D) also shows the shorter MPD at other frequency levels when compared to optimum frequency.

Statistical analysis also reveals that there is significant difference of MPD between optimum frequency and other frequency levels at 0.05 level of confidence. Hence, the hypothesis (2) that there will be no difference in MPD at optimum frequency when compared to other frequencies is rejected in case of females, also.

Thus, males and females can phonate for longer durations at optimum frequency when compared with other frequency levels. That is, maximum Physioacoustic economy is achieved at optimum frequency both in males and females interms of MPD.

Experiemnt 2 (d): To determine the mean airflow rate during phonation:

The mean of the mean air flow rate (MAF) of 48.98 c.c.,/ second was observed at optimum frequency in case of male subjects.

Table 6, reveals the MAF at each frequency level males. Inspection of the table reveals that the minimum MAF of 22.50c.c.,/second has been observed at optimum and maximum MAF of 225 c.c.,/ second at +250 Hz frequency level. At optimum frequency each subject shows minimum MAF rate when compared with other frequency levels.

Further, when means of MAF are compared, a minimum of 48.98 c.c.,/ second is observed at optimum frequency and a maximum of 134.166 c.c.,/ second seen at +200 Hz. That is, a difference of 85.08 c.c.,/ second is observed when a comparison of means made between optimum frequency and +200 Hz. The minimum difference of 20.43 c.c., / second is observed

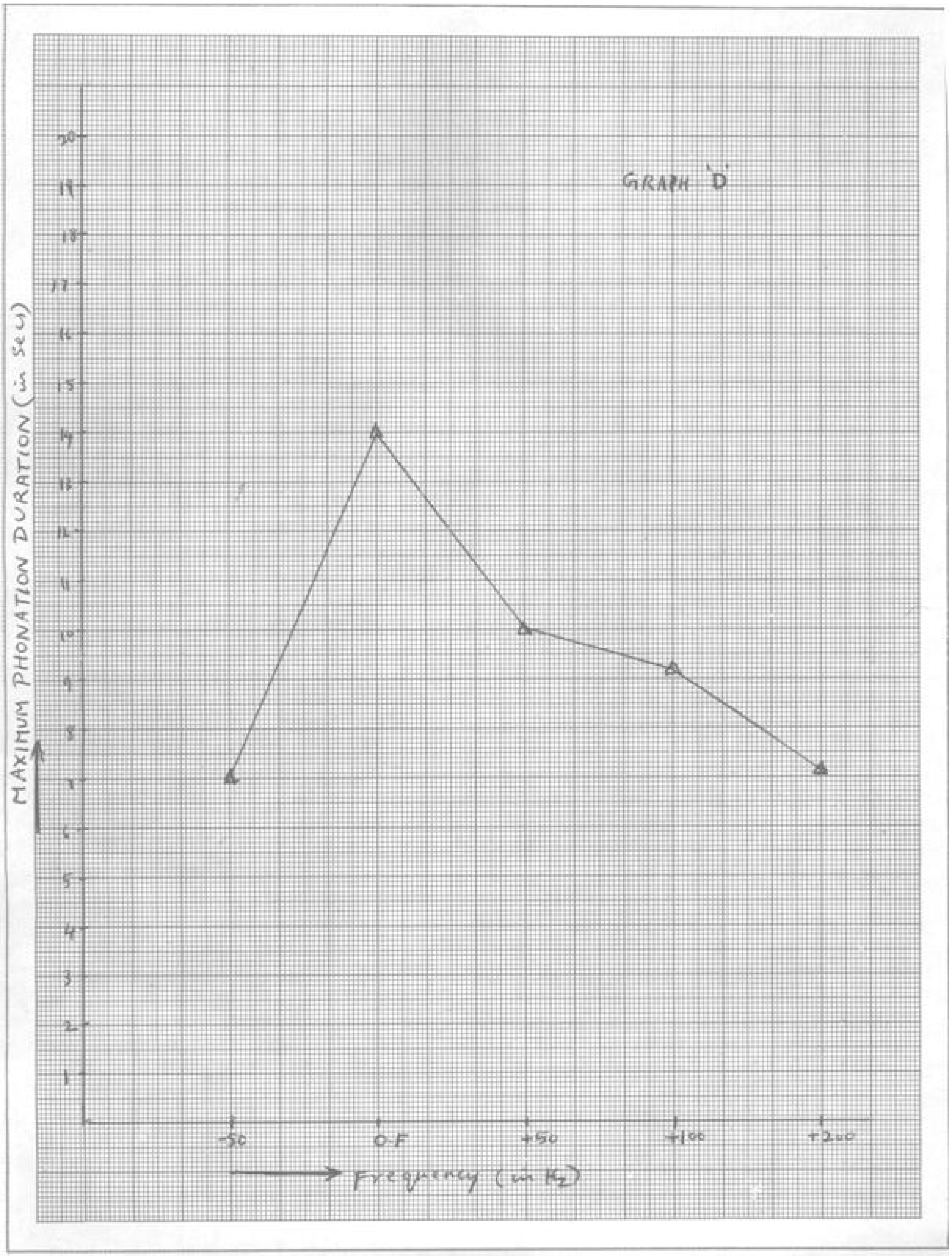

GRAPH 'D'
MAXIMUM PHONATION DURATION (in sec)
Frequency (in Hz)
-50
O.F
+50
+100
+200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

TABLE 6

Table 6, showing the data on Mean Air flow rate (in c.c..,/ seconds at different frequency levels for males:

SUBJECTS	Optimum Frequency	+ 50 Hz	+ 200 Hz	+ 200 Hz	+ 50 Hz.
1	22.50	72.72	75.00	200.00	70.58
2	28.84	78.94	85.73	112.50	30.00
3	53.57	60.00	75.00	58.33	68.13
4	40.00	105.00	68.18	75.00	58.33
5	100.00	120.00	217.50	225.00	120.00
Mean	48.98	87.33	104.38	134.116	69.41
At 0.05 level confidence	+	+	+	+	+

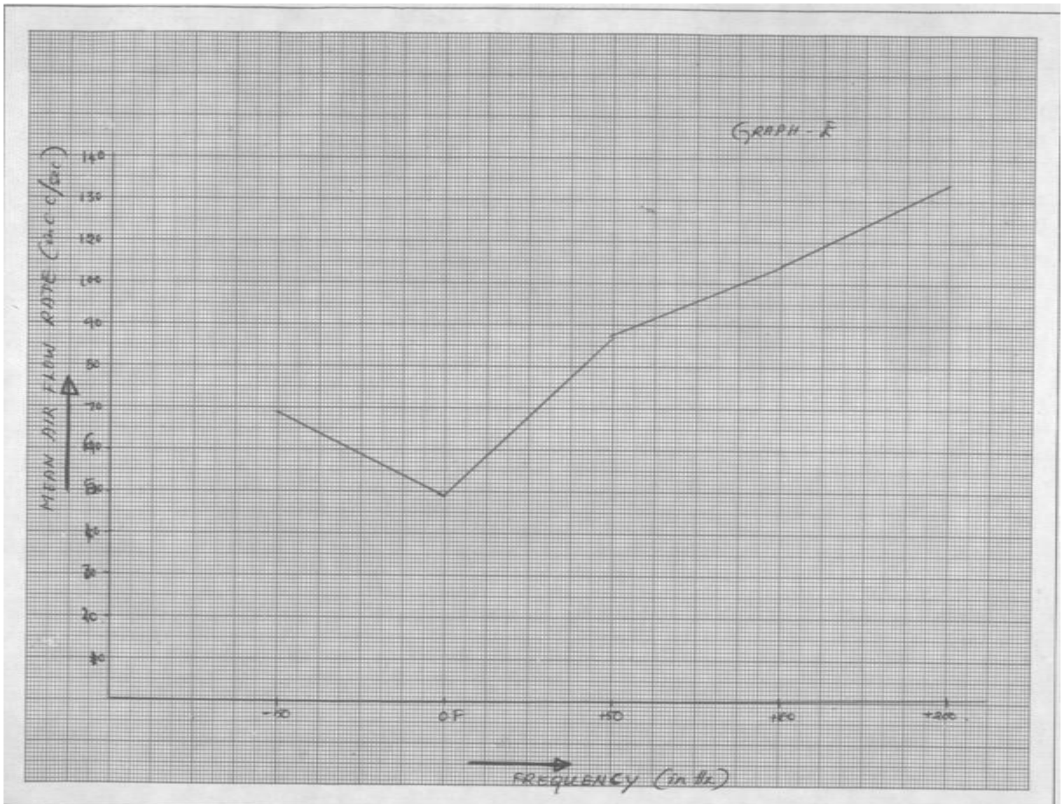
WHEN OPTIMUM FREQUENCY is compared with – 50.Hz.

The Graph (E) also reval the minimum MAP at optimum frequency and higher MAF at other frequencies.

Thus, the hypothesis (3) that there will be no difference in MAF at optimum frequency when compared with other frequencies, in rejected in male subjects.

The statistical analysis also reveals that there is a significant differences in MAF between optimum frequency and other frequencies. Thus, the hypothesis (3) is rejected.

The mean MAF of 37.99 c.c.,/second was seen at optimum frequency in case of females.


GRAPH - E
MEAN AIR FLOW RATE
FREQUENCY (in Hz)
140
130
120
90
70
50
20
-50
0 F
+50
+200

The MAF of 30 c.c., / second was the minimum at optimum frequency and 128.57 c.c.,/ second was the maximum MAF at 200 +Hz.

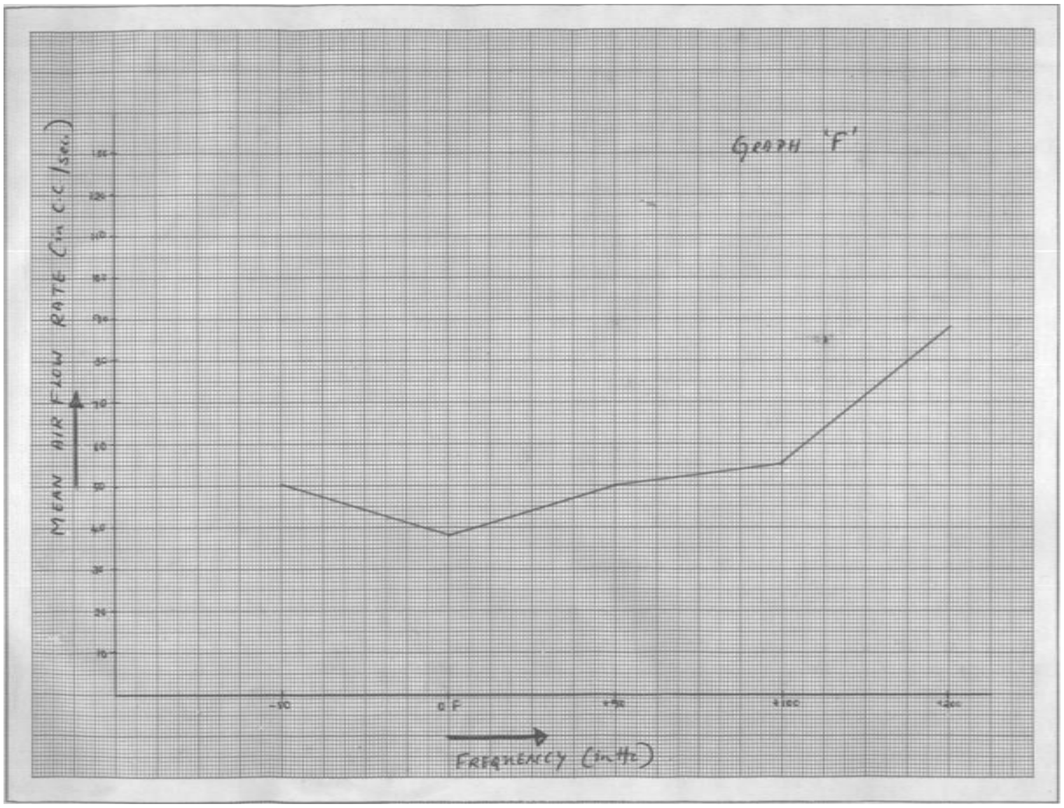
TABLE 7

SUBJECTS	Optimum Frequency	+ 50 Hz	+ 100 Hz	+ 200 Hz	- 50 Hz
1	53.70	60.00	125.00	128.57	60,00
2	50.00	66.60	66.60	75.00	66.66
3	37.50	46.75	45.00	85.71	42.88
4	18.75	41.5 0	37.50	58.00	37.50
5	30.00	37.50	50.00	75.00	50.00
Mean	37.99	50.42	65.82	87.86	51.40
At 0.05 level confidence		+	+	+	+

Table 7, reveals MAF at differen frequency levels for females . The table indicates minimum MAF of 30 c.c.,/ second at optimum frequency and a maximum of 128.57 c.c.,/ second at + 200 Hz.

A minimum mean of 37.99 c.c., / second at optimum frequency and a maximum mean of 87.86 c.c.,/second at + 200 Hz was observed. That is , a maximum difference of 49.87 c,c.,/ second is observed when optimum frequency and + 200 Hz are compared. The minimum difference was 12.46 when optimum frequency and + 50 Hz are compared.

The graph (F) also shows minimum MAF at optimum frequency when compared with other frequency levels.


GRAPH 'F'
MEAN AIR FLOW RATE (in c.c./sec.)
FREQUENCY (in Hz)

Thus, the hypothesis (3) is rejected. The statistical analysis of MAF also shows a significant difference in MAP between optimum frequency and other frequency levels. Hence, the hypothesis (3), that these will be no difference in MAF at optimum frequency when compared with other frequencies
is rejected, in case of females also.

Thus, both males and females show minimum mean air flow rate at optimum frequency than at other frequencies.

Hence, it can be concluded that there is maximum Physioacoustic economy at optimum frequency interms of mean airflow rate both is case of males and females.

Experiemnt 2 (b): Finding the frequency range:

The frequency range (highest – lowest frequency) was found to be 1240 Hz in males and 670 Hz in females.

This measurement was done to find out location of optimum frequency in the total frequency range of both males and females.

The male subjects showed variation of frequency range fro 320 Hz to 1230 Hz. The location of optimum frequency in this range varies from 1/7 to 1/31. However, when the mean optimum frequency (116 Hz) of the group is located in mean frequency range of the group (72 – 752 Hz) it was found to be 1/20 of the range (Ref Table G)

Similarly, in case of females (Ref Table E), the frequency range varies from 300 to
670 Hz. Avariation of 1/6 to 1/67 is observed when the optimum frequency is located in frequency ranged exhibited by females. when female group is considered as a whole the mean optimum frequency (198 Hz) is found to be 1/13 of the mean frequency range (164 to 628 Hz). Thus, both males and

females do not show any exact location of their optimum frequency, in the frequency ranges, shown by them. Hence, it can be concluded from the results of this experiment that it is not possible to locate optimum frequency,
either in males or I females, as 1/3 or ¼ or 1/5 from the lowest frequency of the frequency of the frequency range an individual can phonate as described by Pronovast (1942), Fisher (1942), Fairbanks (1960), Berry and Eisenson (1962) and Brownstein and Jecoby (1967).

Thus the results of the present study indicate there is “maximum physioacoustic economy” at the optimum frequency as located by an objective method of locating optimum frequency by Nataraja (1972). That is, it will be possible to produce a wider range of intensity and phonate for a longer duration with minimum use of airflow, at the optimum frequency than at other frequencies.

Further, the optimum frequency as located by this method meets the criteria of optimum pitch as described by Fisher (1966). That is , optimum pitch is “(1) the best or most favourable for speaking, easiest to phonate, and most of strain: (2) optimum pitch has greater intensity; (3) vocal folds being in a more elastic, more normal state, in more responsive to force of subglottic breath pressure. They can owing more widely apart and pull back together more quickly; and (4) This provides effective variations
in pitch for intonation.”

Murphy (1964) who state that “each person accordance with his unique physical vocal equipment has a pitch level at which the greatest power and best resonance occurs under the conditions of the greatest physio-economy”. The optimum frequency located by this method also shows greatest physioeconomy and thus fits into the description of optimum frequency given by Murphy (1964).

House (1959) while commenting on methods of locating optimum pitch using vocal swell method, states that presumably perceptible changes in overall voice level would result when a harmonic of the fundamental frequency coincides with center of the vocal tract resonance, thus perceptible increases in loudness will reflect this match rather than reflecting an increased laryngeal efficiency and he concludes that vocal swell method is of little value. However, present method of locating optimum frequency. makes use of the maximum increase in intensity when the vocal tract is stimulated by purtones ranging from 100 Hz to 5000 Hz. Geetha (1974) from her study using this technique concluded that the natural frequency of the vocal tract does not coincide with my of the formants.

The results of the present study have indicated that there is maximum physioacoustic economy at optimum frequency using this method. Thus, it is possible to use the resonance of the vocal tract by stimulating with an external source to locate the optimum frequency. Thus it can be concluded, that it is possible to achieve " maximum Physioacoustic economy" at optimum frequency as located by an objective method of locating optimum pitch (Nataraja, 1972).

CHAPTER V:

SUMMARY AND CONCLUSIONS:

Present study was aimed at finding out the Physioacoustic economy at the optimum frequency as located by an objective method of locating optimum pitch as described by Nataraja (1972).

The intensity range, maximum phonation duration, mean airflow rate were measured in 5 male and 5 females subjects with good voice, at optimum frequency, 50 Hz above optimum frequency, 100 Hz optimum frequency, 200 Hz above optimum frequency, and 50 Hz below optimum frequency. The frequency range was also measured to know the location of optimum frequency in the frequency range.

The intensity range (maximum – minimum SPL an individual could phonate) at all the five frequency levels were measured using SPL Meter, stroboscope and tacho unit for all the subjects.

Using the same experimental setup keeping the intensity constant the maximum duration of phonation for each individual at all frequency levels was measured.

The mean airflow rate was determined by dividing the total volume of air collected during phonation and the duration for which the volume of air collected. These were measured using an expirograph and a step watch, at each of the five frequency levels, for all the subjects. The mean airflow rates were measured by keeping the intensity constant at all the five frequency levels using SPL meter, stroboscope and tacho unit. The frequency ranges, the highest and the lowest frequency an individual could phonate were measured using SPL Meter, stroboscope and tacho unit combinations.

Both male and female subjects showed maximum intensity range, and longer phonation durations and minimum mean airflow rates at optimum frequency
when compared with other frequency levels. Same results were also observed when males and females were taken as groups.

Statistical analysis using wilcoxon matched paris – signed ranks test has also revealed (1) that there is significant difference between intensity ranges when a comparision of intensity range of optimum frequency and the intensity ranges at other frequency levels is made, both in case of males and females; (2) in both male and female subjects, the maximum phonation duration has been found to be significantly different from that maximum phonation durations at other frequencies; (3) the mean air flow rates at other frequencies have been found to be differining significantly from that of the mean airflow rate steptimum frequency in both and female subjects.

The locations of the optimum frequency in the frequency range showed greater variations both in case of males and females.

Conclusions:

1. There will be a greater intensity range at optimum frequency than at other frequency levels.
2. The maximum phonation duration will be longer at optimum frequency than at other frequencies.
3. The mean airflow rate will be minimum at optimum frequency than at other frequencies, when the optimum frequency is measured using an objective method of locating optimum frequency as described by Nataraja (1972), both in males and females.

It is not possible to locate the optimum frequency by using pitch range and the location of optimum frequency as used in this study varies from individual to individual, both in males and females.

Recommendations:

1. To carry out the study on larger populations.
2. To carry put the study using more sophisticated instruments like pneuncotacho unit.
3. To carry out the study in aneochoic chamber.
4. To carry out the study using trained singers.
5. To confirm the findings of the present study using electro myograph.

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