OPTIMUM FREQUENCY—ITS RELEVANCE AND MEASUREMENTS

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This paper discusses the importance of ' optimum pitch ' in the diagnosis and therapy with the voice disorders. The merits and the demerits of methods of measuring optimum pitch and the development of an objective method of locating optimum pitch have also been discussed. Experimental findings supporting that there is maximum physio-acoustic economy at the optimum pitch as located by an objective method of locating optimum pitch have been presented. An attempt has also been made to indicate the possible classification of voice disorders based on the optimum pitch.

The D,C. flow of air is converted into A.C. sound pulses by the abduction and adduction of the four folds. During the production of sound and vocal cord are in adducted position. In this position, they vibrate alternately, opening and closing the global for very short periods. Actually it is the air current from the lungs that separates the vocal folds and opens the glottis. But as the air begins to stream out through the narrow glottis, a suction takes place which draws the vocal folds together again. Immediately, the subglottic pressure again forces the vocal folds apart and the air streams out through the glottis" (Fletcher, 1959). The frequency of vibration of vocal folds are determined by the mass, length and tension of vocal cords. It is believed, that each vibrator has its own natural frequency. Similarly the vocal cords also have their own natural frequency, which is otherwise termed as ' optimum frequency \ .

" The idea of ' optimum' implies a standard in terms of which a thing is judged as being best optimal vocal functioning can be defined aesthetically, acoustically and hygienically" (Perkins 1971).

Optimum pitch is the fundamental frequency of voice at which there is maximum physio-acoustic economy. At this frequency, the voice will be found to be most comfortable and most effective" (Berry and Eisenson, 1962). This pitch varies from individual to individual depending upon their vocal apparatus.

West *et al* (1957) write about optimum pitch as " that frequency of the laryngeal tone at which the largest quantum of energy of the breath stream is

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converted into sound waves, the frequency at which the greatest vocal carrying power is achieved by the least expenditure *of* vocal effort, the frequency at which movements of the vocal bands are best facilitated. by factors of resonance ".

Darley (1964) sums up the concept of optimum pitch very convincingly by stating that " each person has a range of tones which be can produce readily and that his range has a central tendency,i.e the optimum pitch".

'According to Van Riper (1959) each 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-ingle pitch rather it is a range"'.

Fisher (1966) writes about optimum oitch as the best or most favourable pitch for speaking. By definition, optimum is an ideal yet one which a great many individuals have attained quite unconsciously. Sometimes model pitch may be the optimum pitch ". Fisher (1966) lists three practical characteristics of optimum pitch.

1. the easiest to phonatc,
2. has greater intensity with, less effort (The. vocal folds being in a more normal state at optimum pitch, are more elastic than when extremely stretched cr extremely thickened. Being more elastic, they arc more responsive to the force of subglottic breath pressure. They can swing more widely apart and puii back together more quickly. Intensity of the vocal tone depends on amplituted of the vibration and duration of glottic closure.)
3. it is located within the total range of voice as to permit effective variation in pitch for intonations.

The approximate median of the as which the voice functions most easily and most effectively is called the "optimum pitch" according to Gray and Wise (1959). /Thus the optimum pitch is the best and most favourable for speaking. It is accepted that each person in accordance with his unique physical vocal equipment has a pilch 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 of 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"'.

Perkins (1971) defines optimal vocal functioning aesthetically, acoustically and hygienically. Of these vocal hygiene is considered as the most vital criterion.

tt is universally accepted that the voice which is produced most effortlessly is most hygienic/ The hygienic criterion is related with the acoustic criterion which states that "the less the effort for acoustic output the greater the vocal efficiency " (Perkins 1971). These criteria also encompass the view that such a voice will be aesthetically acceptable too.

The hygienic criterion can be applied psychologically and acoustically. Psychologically, it is stated as the ratio of loudness to vocal effort. In the more acoustical form, it is the Vanden Berg (1956) ratio of glottal efficiency : acoustic power compared to subglottic power.

Implicit in the hygienic criterion is the idea that the farther the voice production is from the optimum on any dimension, the more it contributes to vocal abuse (Perkins, 1971).

Most of the disorders of pitch, loudness and quality reveal that the vocal mechanism is not functioning a! the optimum pitch level or natural level. Berry and Eisenson (1962) consider that the asymmetry in coupling between mouth and pharynx and nose would probably affect the adduction of vocal cords. And further the rigidity of the face and neck would also play an equal strain on larynx because they inhibit free laryngeal movements.

According to Nataraja and Jayaram (1982) "it is possible to objectively categorize voice into normal and abnormal by taking optimum frequency as the criterion. It is possible to treat a number of vocal disorders, irrespective of ' labels and causes' by training patients to use their optimum frequency " and thus possible to provide good voice to the cases of voice disorders.

While discussing the general principles of voice therapy, Berry and Eisenson (1962) consider that the " Development of Kinesthesia of the proper muscle synergy, the proper tensing and timing in the larynx and the pharynx " as an important part of therapy.

The principles of voice therapy, ' MIDVAS ', include ' Approximation ' towards the modal pitch, as a step in voice therapy (Van Riper and Irwin, 1958).

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) emphasizes 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 an important phase in therapy.

A review of literature on voice therapies thus indicates that almost in all kinds of voice therapies, the therapist 'locates' 'optimum' or 'eficient' or ' natural' pitch level for the case and makes thecase to use that pitch in his speech. In other words/most of the therapies of voice disorders are based on the assumption that each individual has an optimum pitch at which the voice will be of good quality and will have maximum intensity with least expense of energy. Most of the therapies aim to alter the habitual pitch level of the patients or make the patient to use his optimum pitch (Cowan, 1966;Strother.1946; West et al, 1957; Thurman, 1958 ; Anderson, 1961; Greene,1964; Murphy, 1946; Van Riper and Irwin, 1958). It is apparent that irrespective of the label and caues the clinician is training the patient to. use his optimum pitch on the assumption that this would result in ' good ' voice. The charaterstices of optimum pitch suggest that if the patient is trained to use his optimum pitch it will result in good voice. Thus it is evident that finding out optimum pitch has been Considered as an important step in voice therapy.

There are several methods of locating optimum pitch. Wentworth (1940) in her study of fourteen texts found the that there were eight different methods. Pronovost (1942) described and experimented with nine such methods. Basically, these methods can be classified into four groups.

1. By finding out the total pitch range that a person can use.
2. By locating the 'swelling of loudness'.
3. And other methods like 'Coughing and laughing' or 'locating the pitch at which the person can produce voice with greatest ease '
4. By finding out the 'natural frequency of vocal tract'.

1. *Methods using the total pitch* range.

There are several methods locating optimum pitch, using the total pitch range. As a first step total pitch range that tha person can produce is determined. That is, the lowest and highest note, including the falsetto, that the person can produce will be determined either by using the musical scale or a piano. And then, some locate optimum pitch as a frequency one- fourth above the lower limit of the pitch range that a person can produce (Pronovost, 1942 ; Fisher, 1966 ; Fairbanks, 1966 ; Berry and Eisenson, 1962).

Some others recommend optimum pitch as the frequency one-third from the basal tone of the pitch range (Berry and Eisenson, 1962). Still others consider this as one-fifth from the lower limit of the total pitch range than a person can produce (Brownstein and Jacoby 196 7).And also some others suggest the mode of the pitch range that a person can , produce falsetto, which Still others

locate the optimum pitch at the median of the pitch range that a person can produce (Gray and Wise, 1959).

Promovost (1942) located median pitch levels in six superior male voices and found that they approximated the level that was also one-fourth of the total pitch range. Linke (1953) in a similar study found that median pitch levels comprised one-fifth of the total pitch range, in case of female voices.

Johnson *et al.* (1967) while discussing the methods of finding optimum pitch consider the method given by Fairbanks (1966) as the most satisfactory method yet devised, for estimating a person's natural pitch level. While discussing the limitation of the method, they say that ' the procedure 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.

Even though 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 none of them have any experimental evidences. In general, these methods cannot be used with cases who do not have a concept of pitch or pitch range.

In a study Sheela (1974) has found that there is no consistency in terms of location of the pitch within the pitch range which was identified as optimum.

2. ***Locating the swelling of loudness*** :

These methods are also recommended and advocated by several people (Wentworth, 1940 ; Berry and Eisenson, 1962; Murphy, 1964; Fisher, 1966 ; West *et al.,* 1957 ; Van Riper and Irwin, 1958). Basically, these methods assume that when the subject produces voice at several pitch levels covering the total pitch range, at particular pitch level there will be maximum increase in resonance and as such there will be maximum increase in intensity. " These usual procedures of locating optimum pitch by a resonance reinforcement in a fixed region was not supported by Thurman's study (1958). But clinically it has been found to be useful to establish the 'optimum pitch level' (Johnson *et al.,* 1967). West *et al.* (1957) state that for male speakers there are two such swellings. But they do not provide any exeprimental evidence in support of their statement.

It may not be possible to locate the swelling of loudness as each individual monitors the loudness (voice) by auditory feedback involuntarily, and thus may not show any variation in loudness. Further, the increase in loudness cannot be simply attributed to resonance, as the increase in loudness can also occur due to increase in subglottal air pressure or involuntary variations. Apart from this",

these methods are purely subjective as eitherthe experimenter or the subject has to locate the swelling of loudness.

House (1959) discusses the vocal swell method of estimating natural frequency and demonstrates that presumably perceptible changes in overall voice level would result when a hcrmonic of the fundemental frequency coincides with the centre of vocal tract resonance. Thprecetible increases in loudness will reflect this match rather than reflecting an increased laryageal efficiency. He concludes that the vocal swell method .is of little value..

3. ***Methods employing 'coughing and laughing and other methods:***

These methods are advocated by many people (Wentworth 1940 ; Pronovost, 1942). These methods consider the optimum pitch as the pitch at which person coughs and laughs or the note at which the speaker experiences, greatest ease (Fisher, 1966). There are no expermental evidences in support of the above methods and it is obvious from the study of these methods that they are subjective. Therefore it will not be possible to get a reliable and valid pitch which can be called as optimum pitch.

4. ***Method using the natural frequency of vocal tract :***

In order to overcome the drawbacksin locating optimum pitch (*i.e.,* as stated . under Methods 1, 2 and 3) an experiment was conducted by Nataraja (1972).

From the definitions of optimum pitch is clear that optimum pitch is one at which maximum resonance occurs in the vocal tract of a particular individual. Nataraja (1972) has developed an objective method of locating optimum pitch by measuring the natural frequency of the vocal tract.In this experiment the - vocal tract of good speakers was stimulated using an external sound source frequency ranging from 100 Hz to 5 KHz, with a constant intensity. 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 vocal tract. Fundamental frequency of voice of the same good speakers was determined using the stroboscope..

A definite and consistent relationship of 8:1 was found between the natural frequency of vocal tract (NFVT) and the fundemental frequency of the voice (FFV) in case of goGd speaer, males age ranging 20-25 years. The predictive validity was also tested and it was found that this method was valid. Hence optimum frequency (pitch) = $\frac{NFVT}{8}$ (in case of males 20-25 years).

Further, this method was used therapeitically with dysphcnics and they were helped to use this frequency as their fundamental frequency of voice using stroboscope. Follow-up of these subjects has shown that they were using the optimum frequency as the fundamental frequency of their voice and the voice was considered as ' good '.

Thus the review of these methods shows that the methods, 1, 2 and 3 are subjective and have severe limitations theoretically as well as practically. The new method (method 4) of locating optimum pitch was found to be free from these limitations. It is objective as it does net involve any sort of judgement on the part of the subject or experimenter.

To extend this technique, the objective method of locating optimum frequency (Nataraja, 1972, 1975), to other age groups and for females, it was necessary to find out the relationship between NFVT and FFV in superior speakers. In an attempt to find out this relationship in adult females, Shantha (1973) conducted an experiment with the experimental set-up and procedure, as described by Nataraja (1972). She found a consistent relationship between NFVT and FFV in adult female superior speakers as 5:1 and even she used this relationship to provide optimum frequency to adult female dysphonics in therapy. She has demonstrated that it is possible to provide ' good ' voice by training the patients to use this ' optimum frequency', as habitual frequency or modal frequency.

Further, a similar attempt was made by Samuel (1973) to find out the relationship between the NFVT and FFV in male and female subjects, age ranging from 7 to 16 years and 20 to 25 years, from normal population using the same experimental set-up and procedure. He concluded that the relationship between NFVT and FFV was not a stable phenomenon between ages and within the age groups. Average speakers do not use their 'optimum pitch'. This may be because of the fact that the normal population was studied and not the superior speakeis at any age group. Samuel (1973) based on his finding that the average normal voice is not optimal, argued that "the validity of all therapies trying to provide the optimum frequency (pitch) to all cases may be questioned. The question is whether poor voice must be necessarily be made good voice using optimum or whether it is enough if they become average voice, not necessarily optimum".

Perkins (1971) writes that " the specification of optimal functioning is quite different from specification of normal functioning. Designation of optimum is designation of the best. Designation of normal is designation of the average. Ideally the normal for vocal functioning would be optimal functioning... The more stressful the conditions for vocal production the closer to optimal will be the voice need to function if hygiene is to be maintained. But always aiming for optimal functioning, therapy can be terminated at whatever distance from this objective is deemed adequate ".

With reference to Samuel's (1973) criticisms and Perkin's (1971) view , Nataraja and Jayaram (1975) write that we must remember that the speech pathologist's responsibility is to correct the deviant vocal behaviour (Perkins 1971) and not only to give socially acceptable aesthetic 'voice'.

In order to extend this technique of finding out optimum frequency, it was necessary to carry out a study with larger and varied group, good speakers to be selected from various age groups and relationships to be found between " natural and fundamental frequencies'". This was also one of the recommendations made by Samuel (1973) based on his study.

A study was conducted to find out the relationship between NFVT and FFV in a total of 1,100 subjects, consisting of both males and females, from the ages of 7 to 25 years. Further, this relationship was also studied in subjects who were rated as superior, average and poor speakers by judges, by Gopal (1982).

In this study, a probe speaker was introduced into mouth of the subject, which was in a position to produce vowel /a / in such a way that no part of the mouth came in contact with the probe speaker. The subject then phonated vowel /a/. This signal was recorded using a tape recorder and analyzed using stroboscope to obtain FFV which was considered as the habitual frequency for that subject.

To find out the NFVT, with the mouth being held in the same position, frequencies, ranging from 50 Hz to 10 KHz with constant intensity, were presented through the probe speaker, which was produced by scaning the frequency range on a BFO. The response of the vocal tract was recorded using a graphic level recorder. The frequency with the greatest increase in intensity when compared against the frequency response of the probe speaker (base line) was taken as the NFVT, for that speaker. The recorded voice of each subject was rated as being superior average and poor by speech pathologists. From this study Gopal (1982) has concluded that

" There is a constant and consistent relationship in all the superior speakers of the same age and sex. This- relationship between NFVT and FFV :

(a) in superior female speakers in the age range 7-25 years is 5-00,

(b) in superior male speakers in the age range 7-10 years is 5-0,

(c) in superior male speakers in the age range 10-25 years is 8-0 and therefore

(i) Optimum frequency $= \frac{NFVT}{5}$ for females in the age range of 7-25 years.

(ii) $O.F. = \frac{NFVT}{5}$ for males in the age range of 7-10 years.

(iii) $O.F. = \frac{NFVT}{5}$ for males in the age range of 10-25 years.

This relationship can be used to predict the optimum frequency by finding out the NFVT in both males and females in the age range of 7 to 25 years.

This objective method of locating optimum frequency has been validated by Shashikala (1979). She measured intensity range, maximum phonation duration and mean air flow rate, in normal males and females, at optimum pitch and + 50 Hz + 100 Hz + 200 Hz and — 50 Hz away from the optimum pitch. It was found that both the males and females showed greater intensity range, longer phonation duration and lower mean air flow rate at optimum frequency when compared with other frequency levels of voice.

Further studies by Nataraja (1984) to find out the physio-acoustic economy at optimum frequency in terms of maximum phonation duration and mean air flow rate also show that at optimum frequency, the longer maximum phonation duration and lesser mean air flow rate are seen when compared with other frequencies produced by the same individuals.

Nataraja and Jagadeesh (1984) conducted a study to find out the relationship between fundamental frequency and vowel duration. In this study, 60 subjects, both males and females, were made to utter three meaningful sentences, with a VCV word (idu) occurring in the beginning of each sentence at their optimum pitch, at a lower and at higher pitch than optimum. All the utterances were normal, intelligible and meaningful. The duration of the vowel /i / in all the 3 sentences (occurring in the initial word) under all the conditions were measured. The results indicated that the duration of the vowel / i /, occurring in all the 3 sentences, uttered at optimum pitch, as determined by an objective method of locating optimum pitch, was minimum or less when compared to the duration of / i / produced using a lower and higher fundamental frequency than the optimum. This indicates that the subjects use minimum duration cr energy to produce. the same sentence at optimum pitch than at other frequencies available within the pitch range of the individual. Thus the results of studies by Shashikala (1979), Nataraja (1984) and Nataraja and Jagadeesh (1984) indicate that at the optimum frequency as located by an objective method (Nataraja, 1972), there is maximum physio-acoustic economy, *i.e.*, maximum acoustic realization with minimum energy is seen when voice is produced at the frequency located as ' optimum' by the objective method (Nataraja, 1972).

Geetha (1974) utilizing Nataraja's (1972) technique of locating the NFVT found that the natural frequency does not coincide with any of the formant frequencies and the formant frequencies are independent cf the fundamental frequencies. She concluded that there was no correlation between the FFV and the NFVT in normal . Thus the measurement of NFVT as measured in this study is the response of the whole of the vocal tract and not the individual cavities. Further, questions were also raised regarding the participation of the infraglottal area during the measurement cf NFVT. As Judson and Weaver (1967) state the

participation of the infraglottal resonators in the production of voice is negligible- In order to note the contribution of the infraglottal resonators, an experiment was conducted. In this experiment the NFVT was measured, using the technique described by Nataraja (1975), by asking the subject to held the breath (during which the glottis is closed) and by asking the subject to breathe a usual. No significant difference in NFVT was found between the two conditions Thu; the contribution of infraglottal resonators in determing tne N.F.V.T. was ruled out.

This technique of locating optimum frequency is in use at AIISH. The optimum frequency as located by this technique has been found to be useful in diagnosis and treatment of voice disorders.

Nataraja and Jayaram (1975) while discussing the classifications of voice disorders that are presently in use conclude that " thus we come to inescapable conclusion that these classifications do not serve any purpose " and t hey continue by stating that " we propose to define ' good ' voice operationally The ' good ' voice is one which has optimum freqrency as its fundamental frequency". According to them the comparison of the habitual frequency or modal frequency used by the case and his optimum frequency would help in classifying the voice into normal and abnormal. This would also provide a goal for the therapist in treating the voice disorders, *i.e.*. the direction in which the habitual frequency should be changed to achieve the optimum pitch.

It has been reported by Shantha (1973), Jayaram (1975) and Asthana (1976) that the cases of voice disorders, that they had studied, had shown deviation in habitual frequency from their optimum. Shantha (1973) has shown that it is possible to achieve 'good' voice by training the patient to use his optimum frequency, she has demonstrated this with patients having ' hoarseness' nasality, breathiness, puberphonia, 'spastic dysphonia ' high pitch due to hearing loss', 'hysterical aphonia', vocal cord paralysis, etc. She has also reported that she was not able to achieve 'socially acceptable aesthetic' voices with two patients having 'hoarseness', even when they were trained to use their optimum frequencies as determined by the objective method. The reasons for this failure are not known. Whether the failure can be attributed to the method of locating optimum pitch or to the method of treatment oi to the systems of the cases itself is not known. Nataraja and Veena (1982) have reported a case of vocal cord paralysis, who could use aesthetic, socially acceptable voice after providing optimum frequency. Thus there are a number of clinical reports lending support to the contention that the op'.imum frequency as located by this technique is not only economical both physiologically and acoustically, but also provide socially acceptable acosthetic voice to the cases; with voice disorders. This pitch is physiologically economical, as it uses minimum mean air flow rate, and acoustically economical since it permits longer phonation duration and greater intensity range. Thus it is justified that it is useful and objective. Most of the times 'maximum realization of the acoustical and aesthetic goals are achieved when voice is produced efficiently, therefore effortlessly, therefore hygienically ' (Perkins, 1971).

Questions have also come up regarding the usefulness of this method since the optimum frequency is measured, with reference to only one position of the vocal tract and as it will be applicable to that particular vowel. In voice therapy, the therapist locates the ' good voice ' or ' optimum pitch' (by some method) and makes the case to use that particular pitch to produce that particular vowel. Once it is achieved, then the therapist tries to generalize the pitch to other vowels. Slight changes in the pitch with vowels are expected and do occur while generalizing the ' optimum ' to other vowels. This is possible, as Judson and Weaver (1966) put it, there is coupling between the grenerator and resonator, *i.e.*. any change in the resonator would bring about a change in the generator. The generalization of pitch over to other vowels that takes place can be explained on the basis of these principles. Further the studies by Shantha (1973), Nataraja and Veena (1982) and Asthana (1976) have indicated that even when such generalization takes place, the voice still remains as acceptable and within the vicinity of optimum frequency located for / a / position of the vocal tract. As it is time consuming, to find out optimum frequency for different vowel positions, only one vowel position is considered and used. Since it has been found that the generalization from this can be achieved this cannot be considered as a limitation. Thus the concept of optimum frequency (pitch) is, important in the study of vocal physiology and pathology. This will be useful in diagnosis and treatment of voice disorders. Further, as this discussion shows, it is possible to measure the optimum frequency, objectively. The discussion has also shown that there is maximum physio-acoustic economy at this frequency. Therefore achieving the optimum pitch as located by this method must become the goal of voice therapy.

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