AN OBJECTIVE METHOD OF LOCATING OPTIMUM PITCH

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A review of literature, on the methods of locating optimum pitch which is an important step in most of the voice therapies, shows that all of them are subjective and differ from each other. The present study attempted to locate the optimum pitch, objectively, using the resonance of vocal tract, which is a common factor in all the present definitions of optimum pitch. Experiments were conducted to find out the natural frequency of vocal tract, using an external sound source, in the frequency range of 80 Hz-300 Hz and 750 Hz—1050 Hz. It was possible to determine the natural frequency of vocal tract, only by using the frequency range of 750 Hz—1050 Hz. It was also found there was a consistent and constant relationship between the fundamental frequency of voice and the natural frequency of vocal tract in case of superior male speakers age ranging 20-25 years who were, presumably, using their optimum pitch. The relationship was 1:8. Using this relationship it was possible to predict either the fundamental frequency of voice or the natural frequency of vocal tract in case of other superior male speakers, when one of these frequencies were known. Thus this method was used to locate optimum pitch in dysphonics also, by finding out the natural frequency of their vocal tract.

'It is accepted that each person in accordance with his unique physical vocal equipment, has a pitch level at which the greatest 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, p. 94. Fisher (1966) lists the following as the characteristics of optimum pitch. This permits voice to function most efficiently. Hence it has three practical characteristics:

1. Optimum pitch is the easiest to phonate.

2. Optimum pitch 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 or extremely thickened. Being more elastic they are more responsive to the force of subglottic breath pressure. They can swing more widely apart

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and pull back together more quickly. Intensity of the vocal tone depends on amplitude of the vibration and the duration of glottic closure.

3. Optimum pitch is so located within the total range of voice as to permit effective variation in pitch for intonations. Total range means all the frequencies at which a person can produce a vocal tone (pp. 168-170).

In most of the voice disorders it is found that the pitch is not appropriate for the person, that is for the vocal tract or cords of the person. Pitch disorders are mainly because of the improper vibration of the vocal cords—may be too high or too low or monotonous or the pitch breaks. Whatever may be the cause, the therapy will be almost the same, except in a few organic conditions.

Loudness disorders are mainly too loud, too soft or monotonous. In all these cases either the vocal cords will not be functioning at their natural or optimum level. In other words the pitch or the tone complex tone produced by the vocal cords may not be coinciding with the frequencies of the resonators to give the maximum intensity or normal voice with minimum use of energy.

Quality disorders can also be explained on the same basis, as the quality of the voice mainly depends upon the relative intensities of the partials; which is determined by the vocal cord vibration (the fundamental pitch and its partials) and resonance which intensifies some of the partials and damps out certain other partials. Thus the production of voice, normal one, mainly depends on the mode and rate of vocal cord vibration and the physiological conditions, shape and size of the resonators.

'Fundamental to many procedures employed in vocal training is the belief that for each person there is an optimum or natural pitch level at which an human vocal apparatus operates with greatest efficiency' (Thurman, 1958). A review of literature on voice therapies also shows that almost in all kinds of voice therapies the therapist locates 'optimum' or 'efficient' or 'natural' pitch level for the case and makes the case to use that pitch in his speech. Thus there is a great need for locating the optimum pitch.

Almost all definitions tell only of greatest efficiency, least effort and maximum intensity. There are several methods of locating optimum pitch and none of them have been found to be satisfactory and objective. This has been discussed elsewhere (Nataraja, 1973). Hence, an attempt has been made to locate this optimum pitch objectively.

For the purpose of the study optimum frequency was defined as the frequency range of vocal cords at which maximum resonance occurs in the vocal tract of that particular individual. This optimum frequency when resonated through the vocal tract it will be perceived as optimum pitch.

It was hypothesized that it would be possible to stimulate the vocal tract with an external sound source and at the natural frequency of the vocal tract there will be maximum resonance. It was further hypothesized that:

1. It would be possible to find out the maximum increase in intensity using the fundamental frequency range of voice (80 Hz—300 Hz).

2. It Would be possible to find out the maximum increase in intensity using the natural frequency range of vocal tract (750 Hz—1050 Hz).

3. It would be possible to find a definite relationship between the frequency where such increase in intensity occurs and optimum pitch.

4. Relationship determined in such a way can be used to predict the optimum frequency using the natural frequency of vocal tract.

5. When this optimum coincides with the fundamental frequency of voice, the optimum frequency will be perceived as 'optimum pitch'.

To test these hypotheses the following experiments were conducted.

Methodology

One of the rooms which are tentatively being used for audiometric testing was used for the experiments. It is acoustically treated.

Experiment 1

Finding the Optimum frequency range using the fundamental frequency range

Subjects

Twenty subjects were randomly selected from the population of the institute. They were examined by the experimenter for any (gross) oropharyngeal deformities. There was no subject with any observable deformity. Fifty males and five females of age range 20 to 30 years were taken, mean age being 25 years.

Instruments Used

1. A. F. Generator (Philips GM 230890).
2. Frequency counter (Type 702).
3. Frequency analyzer (Type 2107 B & K) with condenser Microphone.
4. Speaker (ear phone) (S.H. 264).

These instruments were arranged as shown in block diagram 1. The speaker and the microphone were fixed on an acoustic tile, 3 cms. apart from each other. The acoustic tile was fixed to a transverse microphone stand. The instruments were calibrated.

Validating the equipmental set up

To test whether the principle or method planned in the study works with known resonators, that is, whether it is possible to find out the natural frequency, it was tested with known resonators (Kundt's tube). It was possible to locate the natural frequency of these known resonators.

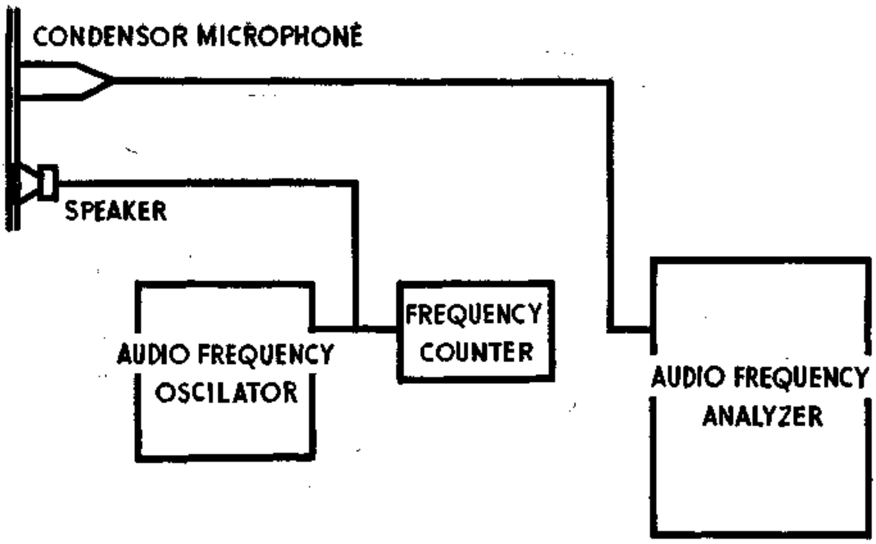

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DIAGRAM NO. 1. Showing the apparatus for the measurement of natural frequency of vocal tract

Procedure

Step 1. Keeping the speaker and the microphone facing the open field, the intensity levels at different frequency levels, in steps of 10 Hz., starting from 80 Hz were taken. These readings give the variations in intensity level without resonator or the output of the speaker. The intensity levels at the various frequencies were taken as the base line.

Step 2. The subject was asked to sit on an easy chair in a comfortable position. The subject was instructed to say vowel /a/ and to observe the positions of his tongue and lips. The subject was also instructed to keep his tongue and lips in the same position without phonation and without any extra effort, and to maintain his head, tongue and lips positions constant.

Step 3. Then the microphone and the speaker were adjusted at a distance of 3 cms. from the lips of the subject. The subject was asked to keep his mouth in vowel /a/ (central) position, putting in no additional effort.

The tones were given starting from 80 Hz up to 300 Hz in 10 Hz steps. At each frequency level, their intensity level was observed on A. F. Analyzer.

Step 4. These were plotted on a graph sheet. The time taken for these readings was determined approximately as 2 minutes for each subject. The same steps were followed to measure frequency response of the vocal tract in vowel /i/, and /u/ positions.

Variation check

As check against possible variations in the vocal tract that could affect the resonance characteristics and therefore intensity readings some cases were subjected to variation check.

1. The subject was asked to keep his mouth in /a/ position, as before.

2. A tone of 200 Hz at 65 dB was given through the speaker which was adjusted near his mouth as before. The same frequency tone was presented for five minutes.

3. The intensity level of the tone and starting time were noted down. A change in intensity was observed at the end of second minute, which was approximately 0.5 dB and again at the end of fourth minute a change in intensity of approximately 1 dB was observed. This was consistent and constant for all the 5 subjects.

This shows that there were no apparent significant changes, in shape, size and physiological conditions of the vocal tract which might have affected the resonance factor during the experiment. Therefore, it was assumed that intensity changes during the experiment were in fact due to resonance.

Experiment 2

Locating the optimum frequency range using the natural frequency range of the vocal tract

This was conducted to see whether there would be maximum resonance (increase in intensity) at the natural frequency of vocal tract of the subject.

Subjects and the equipment were same as in the Experiment 1. The procedure was also same as in experiment 1, except that in this experiment frequency range of tone given was from 750 Hz—1050 Hz and tried only with vowel /a/.

Experiment 3

Locating the optimum frequency range using the natural frequency of vocal tract in good speakers and also fundamental frequency of their voice. It was expected that there would be a relationship between the natural frequency of vocal tract, that is, optimum frequency of the vocal tract and the fundamental frequency of voice in case of superior breakers, as they presumably, were using their optimum pitch.

Subjects

Fifteen superior speakers were selected with th e help of ten judges, who were trained speech pathologists. Some of these subjects were in expt. I also. Age range 20 years to 30 years, mean age being 25 years. Five of these subjects were used for this experiment.

Instruments

A. Same as in Experiment 1.

B. 1. Microphone connected to an SPL Meter with an octave filter circuit.
   2. Stroboscope.
   3. Tacho Meter.

These instruments were arranged as shown in block diagram 2.

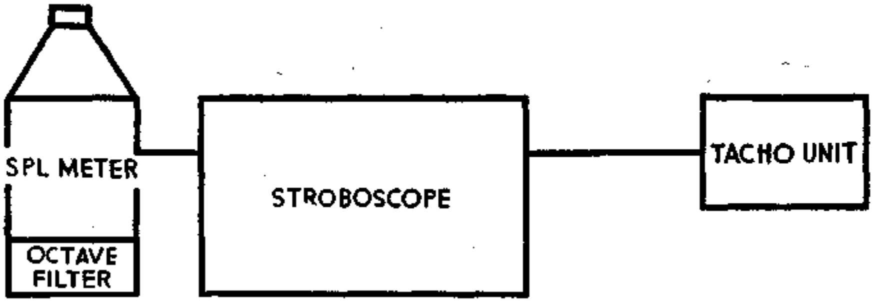

DIAGRAM No. 2. Showing the apparatus for the measurement of fundamental frequency of voice

Procedure

A. Same as in Experiment 1.

B. Step 1. The subject was asked to say /a/ continuously for few minutes until the needle of the tacho meter showed no more deflections.

Step 2. The reading on the meter directly gave the fundamental frequency of voice for vowel /a/. Three readings were taken for each individual.

Experiment 4

This was conducted to see the predictive validity of the test and the relationship, that was developed, between natural frequency and fundamental frequency, in experiment 3.

The remaining ten subjects out of fifteen were selected for this experiment. Age range being 20-30 years, with mean age 25 years.

Part A

Instruments and Procedure

Same as in Experiment 3 Part—A.
Same as in Experiment 3 Part—B.

Part B

Instruments and procedure

Same as in Experiment 3 Part—B.
Same as in Experiment 3 Part—A.

Experiment 5

To find out the validity of Experiment 4, two cases of dysphonia (who were diagnosed as high pitched voice with breaks in pitch clinically by speech pathologists) were taken. Both were males, age 18 years and 22 years. Their fundamental frequencies Were measured using stroboscope, as described in expt. 3 part B. They were 220 Hz and 240 Hz respectively.

Then their optimum frequencies (for vocal cords) were determined by using the relationship, developed, and the natural frequencies of their vocal tract. They were 120 Hz and 110 Hz.

Using stroboscope the model pitches were given by the experimenter and they Were asked to vary their pitch and to approximate the model pitches that were given by the experimenter. They were able to phonate or say vowel /a,' (with which the model pitch was given) at the optimum frequencies that Were determined by the experiment with few trials and errors. Then the speech pathologists, who previously diagnosed the eases as high pitched, were asked to re-evaluate the cases. The speech pathologists considered or evaluated the voices as 'good' or 'normal' or 'effective'. The pitches were stabilized and follow ups were done after one month and it was found that they were using the pitches that were given as 'optimum pitch' and there was no difficulty in using those pitches.

Results and Discussion

Experiment 7. Locating the optimum frequency using fundamental frequency range (80 Hz—300 Hz).

Increase in intensity (peaks) were observed at different frequency ranges for vowel /a/ for each individual. In most of the subjects peaks were observed at following four frequency ranges:

	For vowel /a/	
1.	90 Hz	120 Hz
2.	140 Hz	170 Hz
3.	210 Hz	250 Hz
4.	270 Hz	300 Hz

Similarly, for vowels /i/ and /u/ also such increase in intensity (peaks) were observed at different frequency regions, for each individual. In most of the subjects peaks were observed at the following five frequency regions:

	For vowel /i/			For vowel /u/	
1.	80 Hz	100 Hz	1.	110 Hz	130 Hz
2.	140 Hz	160 Hz	2.	140 Hz	160 Hz
3.	180 Hz	200 Hz	3.	190 Hz	210 Hz
4.	220 Hz	240 Hz	4.	220 Hz	240 Hz
5.	270 Hz	300 Hz	5.	270 Hz	300 Hz

Each peak was consistent within ±10 Hz for each subject on several readings. Peaks ranged from 3 dB to -9 dB. They were found at the same frequency ranges for all the subjects irrespective of their age, sex, size and shape of the oral

Cavity. In fact for one male subject and one female subject ail the peaks were at identical frequencies.

The fact that the intensity increases were similar for all subjects indicated that the resonance was not determined by shape, size of the vocal tract, not even the age and sex. The intensity changes were not discriminative and therefore stimulating the vocal tract with fundamental frequency range does not seem to be a useful technique for locating 'optimum frequency'. The non-discriminative nature of increase in intensities supports Thwman's study (1958).

Experiment 2: Locating optimum frequency using natural frequency range of vocal tract (750 Hz—1050 Hz).

Results

Clearly observable increments in intensity (peaks) were observed for all the subjects at different frequencies varying from individual to individual. There were other peaks which were less prominent.

The hypothesis (1) that when an external sound of variable frequency impinges upon the vocal tract it will show observable increases intensity—was supported when the variable frequency range was from 750 Hz-1050 Hz, where natural frequency range of the vocal tract also lies. It is assumed that maximum intensity increases came about when the stimulating frequency was near the natural frequency because the instrument was able to produce resonance with known resonators.

Experiment 3: Locating the natural and fundamental frequency to see the relationship between them in superior speakers.

Again, discriminative and consistent increments in intensity at a particular frequency range for each subject were observed when the natural frequency range was used.

The stroboscopic measurement gave the fundamental frequency of voice, when the subjects phonated /a/. The following table shows the natural frequency (N.F.), fundamental frequency (F.F.) and their relationship (R).

	N.F.	F.F.	N.F.R(F.F.)
1.	960 Hz	120 Hz	8
2.	1010 Hz	125 Hz	8
3.	860 Hz	110 Hz	8
4.	1040 Hz	130 Hz	8
5.	940 Hz	115 Hz	8

1. The frequency, between 750 Hz—1050 Hz, at which the maximum resonance occurred was considered as the Natural frequency of vocal tract for that position.

2. The fundamental frequency of voice in superior speakers was accepted as the optimum frequency.

Hypothesis (III) that there is a constant relationship between **natural frequency ranges, where the** significant increases in **intensity** were noticed, **and optimum frequency of vocal** cords is supported by the results of this experiment. The relationship is 8:1. In other words, the optimum frequency of vocal cords is 1/8 of the natural frequency of the vocal tract.

Experiment 4: Predicting the optimum frequency using the natural frequency of vocal tract and predicting the natural frequency of vocal traci tying the fundamental frequency of voice in case of superior speakers.

Predictions using optimum frequencies of vocal cords and natural frequency range were found to be true. The following tables show the expected0 and obtained frequencies using the relationship between the natural and fundamental frequency ranges that was established in experiment 3.

Predicted optimum frequency of vocal cords using the natural frequency of vocal tract:

No.	*Expected Optimum frequency*	*Obtained Optimum frequency*
1.	115 Hz	114 Hz=(910/8)
2.	120 Hz	118 Hz =–(940/8)
3.	100 HZ	97 Hz= (780/8)
4.	95 Hz	95 Hz=(760/8)
5.	100 Hz	100 Hz=(800/8)

Predicted natural frequency of vocal truer using the fundamental frequency of voice:

No.	*Expected Natural frequency*	*Obtained Natural frequency*
1.	960=(120x8)	960 Hz
2.	1080=(135x8)	1040 Hz
3.	880=(110x8)	880 Hz
4.	1000=(125x8)	1000 Hz
5.	840=(105x8)	800 Hz

Experiment 5: Predicting the optimum frequency of vocal cords for dysphonics.

By experiment 4 and the relation that was established between optimum frequency of vocal tract and fundamental frequency of voice, the optimum frequencies were obtained for two cases of dysphonia, who were diagnosed as puberphonics. They were made to use those frequencies as their fundamental frequencies, that is, as optimum frequencies. They were re-evaluated by the speech pathologists and identified the new pitch of their voice as optimum. The results of this experiment supports the hypothesis IV and V.

General Discussion

It is interesting to note the response of the vocal tract for pure tones, from 80 Hz—300 Hz. The response of the vocal tract is almost same for different vocal tracts. That is the response of the vocal tract (resonance effect measured in terms of increase in intensity) is the same for different ages, sex, size and shape of the cavity. (Fant. G. 1968, pp. 206-208, in Manual of Phonetics ed. by Malmberg) while discussing the vocal tract transfer function says that:

> 'It is a remarkable fact that in the frequency range of phonetic interests the vocal tract transfer function is a sum of smooth elementary resonance curves independent of irregularities and peculiarities of cavity shapes'.

Further he cites an experimental proof of this theme, which was done by Fujimura and Lindquist (1964 a, b, c,).

> 'A vibrator fed from a gliding frequency source attached externally to the throat at the level of the larynx and the subject retains a steady soundless articulation with his glottis closed. The sine wave transmitted through the vocal tract air system is picked up by a microphone at the lips and registered on an automatic sound level recorder . . . the responses have the general characteristics and specific shape features predicted from the theory of frequency domain synthesis from the elementary resonance curves. Minor irregularities are due to the subject's difficulty in maintaining an exact, constant position of the articulators during the 5-10 seconds needed for the sweep through a 40000/s range'.

When the vocal tract response curve obtained by the present experiment 1 was compared with the response curves of Fujimura and Lindquist (1964 a, b, c) between the frequency range of 80 Hz to 300 Hz, it was found that they were similar.

Experiment 1 refuted the hypothesis that when an external sound source of variable frequency (ranging from 80Hz to 300 Hz) impinges upon the vocal tract shows observable increases, such a significant increase in intensity can be considered as at the optimum frequency. The fundamental tone did not produce clear intensity increases.

This would imply that the fundamental frequency is not amplified or resonated observably in the vocal tract.

Probably the tone presented at the fundamental frequency range was not strong enough to drive the vocal tract into forced vibration.

However, Boone (1970) has found the vocal sound to be weak and unhuman before resonance. This sound is amplified and resonated by the vocal tract or speech would also have been weak. This difference is perhaps due to the fact that vocal cords are producing not only the fundamental tone but also the partials as pointed out by Judson and Weaver (1966, pp. 115-116).

However, when the natural frequency range was used as a stimulating tone it was found that there were observable increments in intensity which were related to the optimum frequency of the vocal cords in a consistent manner. It was also found that when this frequency was used as the fundamental frequency by the cases of dysphonia optimum pitch resulted.

This would lead to the assumption that when the vocal cords vibrate at optimum frequency they also produce the necessary partials.

However, the objective of the study has been satisfied as it has been possible to obtain 'an objective method of locating the optimum pitch'.

The procedure for obtaining the optimum pitch using the equipment recommended by the present investigator is as follows:

1. Find out the base line, (the output of the speaker without the resonator).

2. Make the subject to sit in a comfortable chair and ask him to keep his mouth in /a/ position without phonation. Adjust the speaker and microphone in front of his mouth (as near as possible).

3. Give tone ranging from 750 Hz to 1050 Hz and note down the intensity level at each 10 Hz step.

4. Find out the frequency at which the maximum increase in intensity is observed.

5. Divide it by 8 (for males, age range 20-30 yrs. only). It will give optimum frequency for the vocal cords of that individual.

This frequency can be established in a speaker with the help of a stroboscope.

Summary

A review of literature on the methods of locating the optimum pitch, which is an important step in most of the voice therapies, shows that all of them are subjective and differ from each other. This raises the need for finding an objective method of locating optimum pitch.

The common factor in all the present definitions of optimum pitch is that there will be a pitch range, for each individual, at which maximum resonance occurs resulting in greatest loudness and good quality with least expense of energy.

To locate such a frequency of vocal cords the following experiments were conducted using an A. F. Generator to give tone with variable frequency and A. F. Analyzer to measure intensity. A speaker and condenser microphone were kept close to the mouth of the subject which was in *la!* position (Central). The tones of different frequencies ranging from 80 Hz to 300 Hz (fundamental frequency) were given and the increase in intensity at each 10 Hz step were noted. In the same Way for /i/ and /u/ vowel positions the increases in intensity were noted.

There were no discriminative increases in intensity either between individuals or between different vowels. Thus the hypothesis (1) was refuted. Similarly, another experiment was conducted with the natural frequency range of vocal tract

(750 Hz—1050 Hz) and it was found that there were discriminative peaks for all individuals at different frequencies. This supports the hypothesis (2). The experiment was repeated with good speakers and the fundamental frequency of their voice were measured using stroboscope. (It was presumed that they were using their optimum pitch). A definite and consistent relationship of 8:1 was found between the optimum frequency and natural frequency of vocal tract (where the maximum increase in intensity was observed), which supports the hypothesis (3). Further, to test the validity of relationship, fundamental frequencies of some speakers and natural frequencies of vocal tracts were predicted. The predictions were found to be true.

Further, this method of determining optimum frequency for vocal cords was used therapeutically with two cases of dysphonia (puberphonia) and they were helped to use the frequencies as their fundamental frequencies using the stroboscope.

Conclusions

1. Stimulating the vocal tract with fundamenal frequency range of vocal cords (80 Hz—300 Hz) was found to be not useful in determining the optimum frequency.

2.. Stimulating the vocal tract with natural frequency range of vocal tract (750Hz—1050 Hz) gave clearly discriminative and observable increases in intensity.

3. Such increases in intensity that were observed by stimulating the vocal tract by natural frequency of the vocal tract had a definite and consistent relationship with the frequency of vocal cords. The relationship was 1:8.

Optimum frequency_______Natural frequency of vocal tract
of vocal cords 8

4. The relationship thus determined can be used to predict optimum frequency of vocal cords.

5. When this optimum frequency is used as the fundamental frequency of voice, it will be perceived as having optimum pitch.

6. This method provides for objective identification and classification of voice disorders.

7. The technique of treating dysphonics given by the investigator is simpler and more objective than FLORIDA, as the needle of the tachometer can be used as visual reinforcer. The therapist can also explain to make variation in a better way than a machine.

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