Musical Notes Quotient

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ABSTRACT

Author worked for three years on resolution of human ear. The resolution was defined as “just noticeable difference” detected at a given base frequency. Large numbers of observations (10299 no of observations of 522 persons) were segregated into two groups, musicians and non-musicians. Statistical analysis showed ‘significant’ difference between the two groups. This gave the clue to define, formulate, and establish a quotient – Musical Notes Quotient (MNQ). Later, after defining MNQ author identified a method of training, which improved this MNQ considerably, in a very short period. The subjective opinion that participants (116 & 3079 no of observations) started singing better after the training programme was tested objectively. The statistical analysis confirmed the subjective opinion of better singing. The MNQ showed ‘significant’ improvement, which established the usefulness of MNQ as a measure of progress in music.

INTRODUCTION

Harmonium which is very popular in India is tuned to equitempered scale, which is not natural. Still it is popular and enjoyable. This deliberate ill tuning has the advantage of selecting any ‘key’ as the starting note for singer. And this mistuning is so small that common man is unaware of it. Technically it is ill tuned. Probable reason for the acceptance can be poor frequency resolution of ear. The research work was started to confirm this. The author found that frequency resolution of human ear has not been studied with its ***implications to music***. Knudsen in 1920 and later Zwicker-Flotter & Steven in 1957 did work on this topic but no implications to music were investigated. They had only physics in mind. The implication of this topic to music was left untouched. The author repeated the work with latest digital techniques. The author gave emphasis on the frequencies used in singing. The implications of the findings on music were studied in depth.

COMMUNICATION APPROACH

If frequency is represented by a line, the image perceived by brain can be a line of certain width.

- This width will decide what is the nearest frequency (lower or higher) that is perceived as different by the person. It has been observed by the author that non-musicians have broad image while musicians have relatively sharper image.

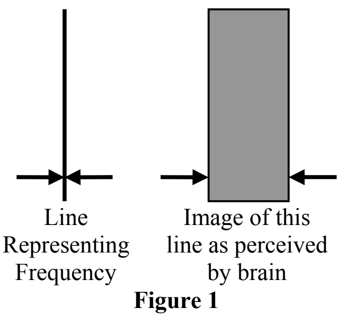


Figure 1

Unless the frequency is beyond this shadow it will not be perceived as different. This is true both sides, higher & lower of the base frequency. The method to assess the width of this ‘shadow’ is to find out the lowest higher frequency and the highest lower frequency, which the person perceives as different.

- The author has further observed that the width of this perceived image can be reduced by training indicating progress in musical acumen.

DESIGNING EXPERIMENT -

Frequency: Audio range of frequency extends upto 20 kHz. The study is being restricted only to singing range, which is only upto 1000 Hz. In that also with more emphasis on the middle octave from 240Hz to 480Hz

Resolution: Physics states that it is the smallest measurable interval by a scientific instrument. It is the resolving power. It can also be described as the minimum interval of separation between two points or entities that can be identified as distinct, or separate.

Least count of a measuring instrument is also its power to distinguish between two measurements - with a reasonable accuracy.

The instrument: Audio frequency generator with attached amplifier was used in the experiment. The experimenter and the participant sat across the table. They could see each other but the movement of hand which is operating the frequency control was not visible to the participant. Sitting across the table had the advantage of reliable communication and no misunderstandings. The volume was kept at approx 60db. The instrument had a least count 0. 1 Hz below 400 Hz &1 Hz above 400Hz.

Read out of the instrument was digital.

Procedure: Now take a concrete example. Let us produce a note of frequency 400 Hz. Let us call this the ‘base frequency’. Let us increase the frequency ***slowly*** making it 401, 402, 403 Hz. and so on, the speed being one Hz per second. Suppose the participant in the experiment is requested to tell the experimenter immediately whenever he perceives “the change” in the note. Suppose the participant perceives the change when the frequency was changed to 404 Hz

Similarly we decrease the frequency slowly from 400 Hz to 399,398,397Hz.... and so on. Suppose the participant perceives the change in the note when the frequency was 397 Hz.

The experimenter has noted three values of frequency

400 Hz	the base frequency
404 Hz	higher frequency when the change is perceived.
397 Hz	lower frequency when the change is perceived.

We will denote various quantities derived as follows

400 as the base frequency	Bf = 400 Hz
404 - 400 = 4	Ei = 4
400 - 397 = 3	Ed = 3

The percentage frequency resolution of ear can be calculated as follows –

Percentage error $= = \frac{\mathbf{Ed + Er}}{\mathbf{Bf}} \times 100$ **......** **1**

Substituting the particular values we get

Percentage error at Bf = 400 Hz

$= \frac{3+4}{400} \times 100 = 1.75\%$

Similar percentage errors are calculated at various selected base frequencies for every participant. Resolution at a particular base frequency can be considered as an error in the perception.

Selection of 'Sample': Observations were noted for number of persons. Selection of persons was done randomly.

The only criterion for acceptance was that the person should have normal hearing. Persons of all ages, of either sex and any social background or musical training were welcome. Those who were conducting music classes for at least ten years, performing artists of repute, professional reed tuners were considered as musicians.

EXPERIMENTS

- Two experiments were planned.

  In the general experiment the error readings were noted for number of persons. The data obtained was analyzed separately for common man and musician and used for defining CQ and MNQ. This newly defined quotient was used to test the effectiveness of a training method.

- For testing the effectiveness of the training camp, the "error" readings at various frequencies were taken before and after the camp. All 116 trainees for voice culture & therapy participated in the experiment.

Table: - 1
Composition of data –

	Persons		Total	obser vation
	M	F		
Musicians	46	15	61	1429
layman	279	182	461	8870
5 Days camp	44	72	116	3076
Total	369	269	638	13375

DEFINING CQ / MNQ

Average percentage error (equation-1) for all frequencies & all number of persons was calculated.

Comparison of error (just noticeable difference) between common man & musician showed that –

For Common man

overall average error is = 2.35 %

For Musician overall average error is = 1.53 %

The significant difference between these two errors indicates that musicians have less error in recognizing the change in the given note. This is due to the training they have undergone during their musical career. It logically follows that an index or quotient can be formulated to indicate the "progress" status of a person, on a scale of "zero to hundred points". This formulation was essential so that common man' who is familiar with the marks being given out of hundred, easily understands the quotient.

The potential usefulness of these measurements of errors helped in defining a parameter of progress status at foundation level of music. This research work is an attempt in this direction to discover ***objective measurable parameter for music easily understandable to common man.***

It was named as closeness quotient 'CQ'. This indicates how "close" one's judgment is to the actual base frequency.

This CQ becomes a useful tool in assessing one's progress at the foundation level of "pure notes". After this foundation level, the music becomes system specific. Eastern or Western or any other system of music in the world can be built up from this identical foundation level.

The 'scale' was formulated to allocate **0** to **100** marks for the performance.

- Deciding 100 point mark on the scale was easy. When the percentage error of (Just Noticeable difference) is "zero" the formula should give 100 points.
- For deciding "zero point" marking we took into consideration the maximum percentage error that occurs in two scales, equitempered and natural and our observations.

i) In equitempered scale the maximum error **6.14 %** (max. distance between two notes)

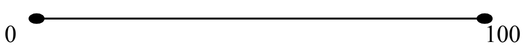
ii) In natural scale the maximum error is

6.90 % (max. distance between two notes)

iii) The maximum error, occurred during the experimental observations is **6.96%.**

We took maximum allowable percentage error as **7%** (round figure) which should give "zero" point.

Performance on zero to hundred scales is as shown



100 - (7 x 14.2854) = 0.0022 =approx. zero

100 – (0 x 14.2854) = 100

(The figure 14.2854 comes from the fact that, when multiplied by 7 it gives 99.9978 and when this product is subtracted from 100 it gives 0.0022, which is zero at two decimal accuracy)

CALCULATION OF CQ

Equation 1 gives the % error as

$$\textbf{The \% error} = \frac{\textbf{Ed + Ei}}{\textbf{bf}} \textbf{ x 100} \ldots\ldots\ldots \qquad \textbf{2}$$

CQ =100 – (percentage error × 14.2854)

Example-

If the error in detecting the change is 1.98 @ Bf = 360

Then % error = = $\frac{1.98}{360}$ x 100 = 0.55

& CQ = 100 – (14.2854 × 0.55) = 92.14

∴ CQ = 92.14 at Bf =360

METHOD FOR DEFINING MNQ

(Musical Notes Quotient)–

Since, the value of percentage error decreases with increase in frequency, the value of CQ will be different for different frequencies. MNQ was defined as the average of CQ's for ten selected frequencies, so that it is representative. The frequencies chosen were in the singing range and related to each other with 240 c/s as the key note.

The frequencies chosen are as follows –

120	**180**	**240**	**300**	**360**
450	**480**	**540**	**600**	**720**

Average of these ten values of CQ is defined as MNQ or Musical Notes Quotient.

$$\textbf{MNQ} = \sum \textbf{CQ / 10} \ldots\ldots\ldots\ldots\ldots\ldots \qquad \textbf{3}$$

Value of "CQ" is related to individual frequency while MNQ is a comprehensive value for group of frequencies.

ESTABLISHING CQ /MNQ

The general experiment was used to establish the two parameters CQ & MNQ.

As previously shown the average percentage error of musicians was less than that of non-musicians.

For musicians the error was 1.53% with corresponding CQ = 100 – 1.53 x 14.2854

= 100 - 21.85

= 78.15 (for musicians)

For non musicians the error was 2.35% with corresponding CQ = 100 – 2.35 x 14.2854

= 100 – 33.57

= 66.43 (for non musicians)

This shows that 'progress' in music is related to the value of CQ & increase in the value of CQ signifies 'progress' in music.

The fact that values of CQ and the resultant value of MNQ, increase with training was established by another experiment.

TRAINING COURSE

The experiment was in the form of a training camp of residential nature & of five days duration. A 'drone' instrument Tambora was kept continuously 'on' during the hours of training. This drone instrument produced 12 notes of natural scale. These notes get engraved in the memory of the participants. They were supposed to chant various pronunciations during the training. They naturally chanted in tune with the notes of the natural scale of the drone. This improved their sense of differentiation between two notes of nearby frequencies.

At the end of the training it was found that they were singing better after the camp. But this was only a personal guess. The significant increase in the value of MNQ confirmed this guess. This established that the value of MNQ is a measure of musical ability at the foundation level.

After attaining a certain value of MNQ at this foundation level, one is better equipped for learning system specific music – eastern or western or any other system in the world.

METHOD OF ANALYSIS -----'t' TEST

There is only one variable involved. It is the error averages in recognizing the change in the musical note of a given frequency i.e. the smallest decrease or increase in frequency necessary for the ear to perceive change in the musical note. This error was measured for various reference frequencies and for number of people.

Basic analysis work involved is 'averages' and 'standard deviations'. These errors will be objective and independent of the method and the operator who takes the readings. They will be different for different groups of persons; General public will have different average error. Accomplished musicians will have different average error, which will be less than that of general public. Similarly for studying effectiveness of a training method it will be group average before the training and similar average after the training for comparative study.

STATISTICAL TESTING OF GENERAL DATA-

Testing the difference for significance – by't'- test

Table 2 gives CQ values for Common man and Musicians at various base frequencies. This difference between these two groups must be examined for statistical significance. The examination will show whether the difference is by chance or alternatively it is on account of the "training of the musician." Since the number of observation is finite we will use t-test for examining the significance.

Table: - 2
CQ -values of common man & musician.

Bf	CQ Comn. Man.	CQ Musi -cian	Diff in CQ	Di-sqr
60	44.17	61.44	17.27	298.25
100	43.31	59.73	16.42	269.62
120	67.01	83.72	16.7	278.89
150	67.01	74.15	7.14	50.98
200	59	76.72	17.72	314.00
210	61	87.72	26.72	713.96
300	67	85.72	18.72	350.44
400	51	65.3	14.3	204.49
600	58	75.58	17.58	309.06
800	71.30	77.15	5.85	34.22
1200	75.01	80.15	5.14	26.42
1600	82.44	85.43	2.99	8.94
2000	82.30	85.58	3.28	10.76
2500	84.44	87.58	3.14	9.86
3000	81.58	85.86	4.28	18.32
	994.57	1171.83	177.25	2892.20
	66.30	78.12	11.82	

Data from **Table 2** was used to calculate t by formula

$$t = \frac{\overline{D} - 0}{\sigma_{difference} / \sqrt{n}}$$

$$\overline{D} = \frac{\sum Di}{n} \qquad \text{............} \qquad \mathbf{4}$$

and

$$\sigma_{difference} = \sqrt{\frac{\sum Di^2 - (\overline{D})^2 \times n}{n-1}}$$

Here $\overline{D}$ = 11.82

$\sum$ Di sqr. = 2892. 2

& n = 15

Substituting these values we get t = 6. 06

From the standard statistical tables value of

t = 1.71 at 14 degrees of freedom & 5% level of significance.

The difference in the two values of t confirms that the higher value of CQ for musician is significantly different from the CQ value of non musician.

STATISTICAL TESTING OF DATA OF 5 DAYS TRAINING CAMP.

Observations on 116 persons who participated in the 5 days training camp are shown in table - 3. Overall difference in averages was used for testing the null hypothesis Ho

Formula for calculating the value of CQ at different base frequencies was equation – 1 viz.

CQ = 100 – (%error x 14.2854)

Average values of CQ are shown in table 3 against various base frequencies.

This categorically rejects the null hypothesis and proves beyond doubt that the training has made significant difference.

Statistical testing of the above null hypothesis individual frequency wise.

The null hypothesis was tested for individual frequencies by using the formula – 5

Observed errors were converted into the closeness quotient (CQ). The basis being "less the error" in judging the change in the note "better the performance - higher the closeness quotient CQ."

As mentioned earlier the formula to convert error into CQ was -

CQ = 100 - (percentage error with base frequency X 14.2854)

Using Data from this table 3 the value of't' based on these observation can be calculated as follows -

Observed value of t = 4.76 @ 11 degrees of freedom

value from standard table @ 5% level of significance and 11 degrees of freedom t = 1.796

Δ We define null hypothesis as "the five days residential camp of training has made no significant difference between the

CQ values before training

CQ values after training

The observed value of t = 4.76 is much higher than the table value of 1.796. Hence observed value falls in the rejection region & null hypothesis is rejected.

We conclude that this difference in CQ is due to the training received during the session.

Testing null hypothesis for significance for individual "frequencies".

Ho - The five days training has not made any difference;

The formula used is –

$$t = \frac{X_1 - X_2}{\sqrt{\frac{(n_1-1)\sigma_{x1}^2 + (n_2-1)\sigma_{x2}^2}{n_1+n_2-2}} \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \qquad \text{...............} \ \mathbf{5}$$

From standard tables

At 5% level of significance

t= 1.323 @ 21degrees of freedom

t= 1.311 @ 29 degrees of freedom

t= 1.282 Infinite degrees of freedom

Since the values of 'n' are different for different frequencies. Values of t from standard statistical tables were chosen for comparison. They were at 5% significance level as follows: -

for 21 degrees of freedom t = 1.323

for29 degrees of freedom t = 1.311

for infinite degrees of freedom t = 1.282

Table 4
Values of't' statistic

Freq. in C /S	n	t	Remark
240	86	3.64	Ho rejected
270	86	2.62	Ho rejected
300	86	3.67	Ho rejected
320	86	0.26	Ho can not be rejected
360	86	2.38	Ho rejected
450	22	1.52	Ho rejected
480	22	2.39	Ho rejected
500	30	2.5	Ho rejected
600	30	4.82	Ho rejected
700	30	2.92	Ho rejected
800	30	3.92	Ho rejected
900	30	3.92	Ho rejected

n is number observations

Table 4 gives the observed values of t against various base frequencies. Null hypothesis gets rejected for all frequencies except for one frequency.

Conclusions are that "t" statistic testing frequency wise strongly confirms the rejection of Ho. The difference is certainly due to training and nothing else.

FOLLOWING TWO DIAGRAMS EXPLAIN THE OVERALL LOGICAL FLOW OF THE RESEARCH WORK

Logical flow diagram no: **1**

Defining musical notes quotient.

Problem	Keyboard instruments are tuned to equitempered scale which is not natural scale. But they are still popular. Why? Probably average ear has poor resolution.

↓

Solution	Data of 10299 observations on 522 persons was collected for studying frequency resolution of human ear.

↓

Analysis	Data for common man & musician was separately analyzed; resolution of musician was much better Statistical tests of significance group wise as well as, frequency wise confirmed the finding. This segregation confirmed that the improvement is due to training in music

↓

Implication	A number/ quotient can be formulated to indicate status of musical ability of a person on the scale of 0 to 100

↓

CQ – Closeness Quotient for each frequency defined MNQ – overall quotient for singing range defined.

These newly defined parameters CQ / MNQ were used for investigating a case which established their validity. The logical flow diagram is as follows –

Logical flow diagram no. 2

establishing CQ / MNQ

Case Study	5 days residential training Camp for voice culture and voice therapy

↓

Subjective Observation	Persons Sing better after the training camp

↓

Objective Investigation	Frequency resolution of 116 persons who had undergone training was noted down twice, once before the training second time after the training

↓

Results	Analysis showed CQ and MNQ improved Considerably, statistical tests of significance for group average as well as frequency wise confirmed the subjective observations.

↓

CQ MNQ established

CONCLUSION: -

For the first time objective & meaningful parameter is made available in the field of music. All the data and statistical analysis confirms that--

1. There exists an objectively measurable parameter indicating musical 'ability' of a person at foundation level.

2. This parameter is better for musicians than for non-musicians.

3. There exists a training method – which is fast and effective for improvement of this parameter.

Future direction of work

Author intends to work on the training program and create different versions for specific purpose. All this will be based on strong foundation of statistical analysis.

Also in the planning is a ‘ Do – it – your self C.D.’, Website etc.

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