EXPERIMENTAL STUDY OF RAGA SCALES OF INDIAN MUSIC— SANKARABHARANA RAGA*

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ABSTRACT: Systematic experiments conducted to examine the feasability of frequency measurments pertaining to Raga *scales of Indian Music are decribed and discussed. The data obtained regarding the* swaras *of the* Melakarta Raga Sankarabharana *are presented together with statistically computed probable errors.*

Stringed instruments have a great role in researches because the experimenter not only hears the variations in pitch but sees them too, as changes in the speaking length or tension of the strings. Bharata and Sarngadeva (13th cent.) employed the *vina* for their famous *sruti* experiments. The discovery and study of the twenty-two *srutis* which denote suitable points of musical value in an octave is evidence of their keen sense of observation. The developments in musicology went hand in hand with the development of the *vina* from the ancient harp-like instrument to the modern four-stringed version of Govinda Dikshitar, the author of *Sangita Sudha* (1629).

Ragas and Raga Scales

The concept of *raga* is a great and unique contribution of India to world music. We owe it to Matanga (9th cent.) the author of *Brihaddesi*. He interpreted *jati* as *raga* though the term '*raga*' had a different connotation in earlier times. He attempted an intelligent classification of *ragas*, introduced *vikrita svaras* as apart from the *suddha svaras* of *samagana* scale and listed a few *ragas* with *svaras*; the names of some of his *ragas* like *Ravichandrika* and *Lalita* are familiar even to-day. Even prior to Matanga, Illango's Tamil classic *Silappadikaram* (2nd cent.) had given the idea of '*pann*' having a definite musical form. Sarngadeva's *Sangitaratnakara* (13th cent.) mentions

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twelve *vikrita svaras* and *seven suddha svaras* based on *srutis* and lists 250 *ragas.*

Each *raga* has, in course of time, acquired its own musical form and personality. The names of many *ragas* and *svaras* have changed and, with the coming of Govinda Dikshitar's vina, even the number of *svaras* (*svarasthanas* to be particular) decreased from 19 to 12. Venkatamakhi, a son of Govinda Dikshitar, accepted the number as 12 and evolved his famous scheme of 72 *melakarta ragas.* Sometimes this scheme is criticised but, in fairness to him, it must be said that he recognised the scheme only as ' .... a honey-comb Cabinet to provide a niche for all *ragas,* past, present and future' and did not claim that every one of the *melakartas* were of immediate musical value.[2]

The Twelve Svarasthanas

Veena playing is facilitated by the provision of 12 *svarasthanas* but the exact *svaras* are to be produced by the skill of the player. It is most unfortunate for us that the ancient musicologists had no means of accurate measurement of string lengths. As a result we do not have a definite knowledge of the *samagana* scale (*shadja grama*) or of the *srutis*; this has led to endless conjectures, discussions and controversies. Some authors[1] seem[7] to have a fairly good idea of the scale and the *srutis* while some[14] appear to find difficulties in this regard. The frequencies of even the 12 *svarasthanas* are not known for certain as table 1 below indicates:

TABLE 1

Frequencies of the twelve swarasthanas

	Swara	Ahobala[3]	Samba-murthy[7]	Rama-nathan[8]	Samba-murthy[4] Deva[9] Mukund[12]	Equally tempered scale
1.	*S*	240.0	240.0	240.0	C 240.0	240.0
2.	*Suddha R*	259.4	256.0	256.0	D_b 256.8	254.3
3.	*Chatu. R*	270.0	270.0	270.0	D 270.0	269.4
4.	*Sadha. G*	288.0	288.0	284.4	Eb 287.2	285.4
5.	*Anta. G*	303.2	300.0	300.0	E 300.0	302.4
6.	*Suddha M*	320.0	320.0	320.0	F 320.0	320.4
7.	*Prati M*	345.6	337.5	341.3	F 335.3	339.4
8.	*P.*	360.0	360.0	360.0	G 360.0	359.6
9.	*Suddha D*	388.8	384.0	384.0	A_b 384.1	381.0
10.	*Chatu. D*	405.0	405.0	400.0	A 400.0	403.6
11.	*Kai. N*	432.0	432.0	426.7	B_b 429.2	427.6
12.	*Kakali N*	454.7	450.0	450.0	B 450.0	453.1

In the above table the frequencies have been calculated from the data and assignments in comparison to the Western scale as given by the references cited using for *Shadja* the standard value of 240.0 Hz. Ahobala (17th cent.) has given measured string lengths. Sambamurthy[7] has used the cycle of fourths and fifths. Mukund[12] has explained that D_b, E_b, $F\sharp$ A_b and B_b are the 'black keys' of the harmonium (equally tempered scale). Ramanathan ([8]) is a well known *veena* maker of Tiruchi. It is clear from the table that equally tempered scale does not fit in. Some authors believe that the tempered scale is used in Indian music.[12, 13, 15]

It is not known if *veena* makers go by any definite standards in fixing the frets. Thus Indian musicology suffers from a serious drawback viz., the non-availability of frequency standards for the *svarasthanas*. Such standards would be even more important for the *raga* scales. The gradual disappearance of the *guru-kula* system further emphasises this point and references to the equally tempered scale have already done much harm. Impelled by these considerations an attempt has been made in the present work to measure the frequencies of *Sankarabharana raga* of the Karnatak system of Indian music.

Frequencies of Svaras

It is well known that an essential feature of Karnataka music is the *gamaka*. *Gamaka* may be regarded as graces and embellishments which lend beauty and charm to this music. In physical terms they are rather complex and elude accurate description; generally speaking, they involve slight oscillatory variations of frequency and downward or upward sliding of frequency extending over time durations of varied amounts and these are often accompanied by changes in tone quality (vocal or instrumental). Under these circumstances one is faced with the question whether a *svara* may at all be represented by a frequency and, if one seeks such a representation, what would be a reasonable method to find it.

One approach is to examine the *raga* scales as expressed by its *arohana* and *avarohana* for they constitute 'the briefest description of a *raga* and are like a theorem in geometry'[5] Another approach is to observe the notes sung or played steadily during a performance. These two methods have been used in the present series of experiments to examine the feasibility of frequency measurements of *svaras*. When a *svara* is sung or played, the fundamental frequency as well as its overtones are produced. In the present context the term 'frequency of a *svara*' denotes the fundamental frequency.

Pioneering work in this field was done by Deva[10] who measured the frequencies of the ragas *Sankarabharana* and *Bhup* by using cathode ray oscillograph patterns corresponding to vocal rendering of these *ragas*. Modak *et al*[16] have measured the frequencies of a few *ragas* of Hindustani music; their work was of an exploratory nature and the error of measurement is

placed around two per cent which would mean an error of ±5 Hz in a value of 250 Hz.

Experimental Set-up

As in ancient musicology, so in the present work, the *vina* plays an important role. A '*sruti-veena*' manufactured by S. Ramanathan (Ramji & Co., of Tiruchi, Tamilnadu State) is used.[17] It has twenty-three strings of gradually varying length from 51.7 cm to 70.5 cm; each string is provided with a microtuning arrangement for fine adjustment of string tension and frequency. There is an additional string whose length as well as tension may be varied. The instrument is also provided with a four stringed *vina* set-up with frets. An in-built magnetic pick up feeds the signals from the *vina* to an audio-amplifier; this has the important advantage that the *vina* sound can be heard for several seconds. This helps in precision tuning of the strings to bring them into unison with the desired *svaras* by eliminating beats during an interval of several seconds. The block diagram given below shows the experimental set-up:

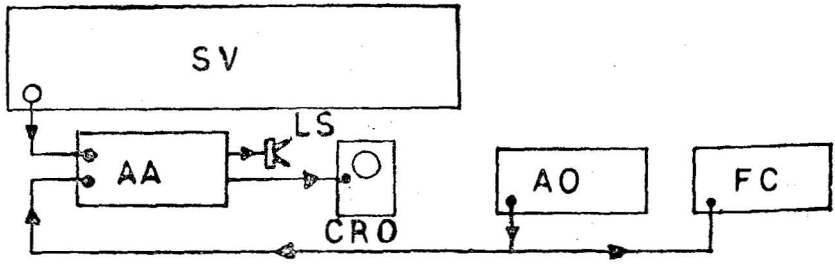

Figure showing the experimental arrangement. SV : *Sruti-vina*, AA : Audio-amplifier, LS: Loudspeaker, CRO: Cathode-ray oscillograph, AO : Audio-oscillator, FC : Frequency counter

The frequency of *sruti-vina* strings is measured by an electronic frequency counter (Electronics Corporation of India Ltd.) which counts to an accuracy of 0.1 Hz when the counting is performed over a time interval of ten seconds. However, the *sruti-vina* vibrations do not last that long nor can they have a constant amplitude. To get over this difficulty, an electronic audio-oscillator is first tuned to be in unison with the *vina*; this is done very carefully by listening to beats and observing the patterns on an oscillograph. The frequency of the audio-oscillatory is then measured with the frequency counter. Obviously, this value is also the frequency of the *vina*. Preliminary experiments performed to determine the frequencies of standard tuning forks with this method showed that the method is reliable. The error of measurement is 0.1 Hz in so far as the frequency of the *vina* is concerned; this would correspond to 0.04 per cent in a value of 250 Hz. (cf. B.C. Deva, *Res.* Rep. *I.* Sangeet Natak Akademi, New Delhi).

Procedure of Experiments

I. Tuning the sruti-vina to arohana and avarohana svaras : In this part a musician first tunes the *adhara Shadja* (S), *Panchama* (P) and *tara sthayi Shadja* (S') strings by consonances. He then proceeds to tune the strings for the other *svaras* viz., *Rishabha* (R), *Gandhara* (G), *Madhyama* (M), *Dhaivata* (D) and *Nishada* (N) with reference to the *S-P-S* already fixed. For this purpose he depends only on his knowledge of the *svaras* and he is requested not to use any other technique such as consonances amongst the *svaras*. The final adjustments are checked by him, to his satisfaction, by playing the strings in the *arohana* and *avarohana* sequences. The frequency of each *svara* is then counted by the electronic arrangement repeatedly. The musician then disturbs the tuning and the whole procedure is repeated a few times. This is essential to check the reproducibility of the observations and to compute the probable errors as indicated below.

II. Use of a musician's performance : (a) The musician sings (or plays) freely the *alapana* of the *raga* to *tambura* accompaniment. He then takes up a composition, say a *pallavi*, and sings it in *vilambakala* and *madhyamakala* (slow and fast speeds). This is followed by a rendering of *kalpana svaras* in *vilambakala* and *madhyamakala*. He is requested to render *vilambakala svaras* as and when it is convenient to him during the singing. The whole programme is recorded on a tape-recorder. The reproducibility of frequencies by the recorder was tested and found to be satisfactory within experimental errors of the other instruments in this work.

As a preliminary part of the procedure, the experimenter listens to the recording a few times to get thoroughly familiar with the programme. The recording is then replayed and *sruti-vina* strings are tuned one by one to be in unison with the *svaras* of the recording. For this purpose it is more convenient to work with the *vilambakala svaras*. It is usually necessary to replay a number of times to get a satisfactory adjustment for all the *svaras*. Finally the tuning is checked with reference to the recording by using the tuned strings as accompaniment to the recorded programme. This is facilitated by feeding the sound from the recording as well as the sound from the *sruti-vina* to the same amplifier and listening to the combined musical effect of the two. Once the tuning is thus checked, the tuned strings are found to represent the *raga* quite well since they can convey to a considerable extent the characteristic personality of the *raga* when they are played in the *arohana* and *avarohana* sequence.

The frequency of the tuned strings is then measured by the electronic equipment. The whole procedure is repeated several times for the same recording. On average about twenty-five measurements of frequency have been made for each *svara* in the programme recorded by a single musician

and their mean value taken. A large number of measurements is necessary to check the reproducibility of the values and also to compute the probable errors as shown below.

The probable error of each average frequency value F in the case of a particular artiste is calculated from the formula

$$\text{Probable error } e = 0.6745 \sqrt{\frac{R^2 i}{n(n-1)}}$$

where n = number of measurements

R_i = the difference between the average frequency F and each individual frequency f_i

$= F - f_i$

The probable error is indicated along with the average frequency F by means of a $\pm$sign e.g., 270.4 ± 0.09 Hz. The average frequency values for a given *svara* obtained from the performance of different artistes are then combined to obtain the weighted mean value which then shows the final result as derived from the whole series of experiments. In this computation 'weights' are first assigned to the mean values of frequency using the relation

$$\text{Weight } w_j \propto \frac{1}{e_j^2}$$

where Wj is the weight assigned to the average value Fj of a *svara* from the programme of an artiste 'j'. and ej is the probable error of Fj. The weighted mean value of the frequency is

$$F_{w.m.} = \frac{\Sigma w_j F_j}{\Sigma w_j}$$

The probable error of the weighted mean is calculated using the relation

$$\text{Probable error of the weighted mean } e_{w.m.} = 0.6745 \sqrt{\frac{\Sigma w_j z^2_j}{(m-1)\Sigma w_j}}$$

where zj is the difference between the weighted mean value and the value Fj i.e., $z_j = F_{w.m.} - F_j$

and m is the number of artistes who participated.

TABLE 2

Experimental frequencies of the swaras of the raga *Sankarabharana*

Swara	R.K.R. Vocal	R.K.R. **	H.R.R. **	H.R.R. Vocal	K.I. **	T.S.T. Violin	A.S.R. Violin	S.S.R. Vocal	C.B. Veena	Weighted Mean	Major Diatonic Scale
S	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
R	269.7 ±0.18	270.6 ±0.06	270.7 ±0.15	271.3 ±0.25	271.4 ±0.22	269.4 ±0.09	270.7 ±0.-0	269.7 ±0.18	270.4 ±0.09	270.27 ±0.14	270.0
G	300.7 ±0.32	302.3 ±0.06	301.8 ±0.07	302.6 ±0.20	302.4 ±0.20	299.2 ±0.40	302.5 ±0.19	301.3 ±0.30	301.5 ±0.33	302.02 ±0.04	300.0
M	321.0 ±0.24	318.2 ±0.05	321.1 ±0.08	320.8 ±0.26	321.5 ±0.23	320.9 ±0.16	321.3 ±0.21	319.0 ±0.20	320.2 ±0.20	320.08 ±0.31	320.0
P	360.0	360.0	360.0	360.0	360.0	360.0	360.0	360.0	360.0	360.0	360.0
D	404.6 ±0.20	403.6 ±0.09	403.6 ±0.05	403.5 ±0.16	403.4 ±0.25	404.8 ±0.13	403.6 ±0.39	402.2 ±0.24	401.1 ±0.43	403.35 ±0.14	400.0
N	459.6 ±0.15	456.6 ±0.09	460.6 ±0.09	460.1 ±0.82	458.0 ±0.25	459.1 ±0.16	459.4 ±0.16	456.3 ±0.25	459.4 ±0.12	458.78 ±0.38	450.0
S	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0	480.0

**In these experiments the *Sruti Vina* was tuned to the various *svaras* by the artist himself.

Results of Experiments

The following musicians participated in the experiments on the *raga Sankarabharana:*

(i) R.K. Ramanathan, musicologist and vocalist, Lecturer in music, Bangalore University (R.K.R.).
(ii) H. Ramachandra Rao, vocalist and music teacher (H.R.R.).
(iii) K. Indira, M.A. (Music) (K.I.).
(iv) T.S. Tatachar, violinist, All India Radio, Bangalore, (T.S.T.).
(v) Anoor S. Ramakrishna, violinist, Lecturer in Music, Bangalore University (A.S.R.).
(vi) Sandhyavandanam Srinivasa Rao, vocalist, Principal, Government College of Music, Madras (S.S.R.).

Measurements were also made using a tape-recording of the broadcast performance of Chitti Babu on *vina* (C.B.).

The measured frequencies were converted to a common *adhara Shadja* value of 240 Hz as is the common practice. The mean frequencies of each experiment, together with the statistically computed probable errors, are given in Table 2. The results for each *svara* are combined to calculate the weighted mean. The values of the weighted mean are also given in the table and these may be taken to represent the results of the whole series of experiments on the *raga Sankarabharana.* The frequencies of the Major Diatonic Scale are given in the same table for comparison.

Discussion

The present series of experiments have shown that it is possible to measure the frequencies of the *svaras* of scales of Karnataka *ragas* if one fixes attention on the *arohana* and *avarohana* renderings or on *vilambakala svaras* in a musical performance.

There is reasonable agreement in the values obtained in experiments in which different musicians participated. Sambamurthy[6] has worked out the frequencies of the twenty-two *srutis* and identified them with reference to current *ragas*; the 5th *sruti* of 270 Hz is identified as the R, the 8th *sruti* of 300 Hz as the G and the 21st sruti of 450 Hz as the N of *Sankarabharana.* The results of the present work are in good agreement with his R, in fair agreement with his G but not with his N. Dr. S. Ramanathan[16] of Madurai has also identified the *sruti* with frequency 270 Hz as R of *Sankarabharana.* The identification of the *sruti* of frequency 405 Hz as the D or *Sankarabharana* by Rangaramanuja Ayyangar[1] agrees well with the present results (the reference does not give the actual frequency assignment — this has been calculated by Sambamurthy's method). Modak *et al*[16] have measured the

frequency of the N of *Bilaval raga* of Hindustani Music as 457.6 Hz which compares well with the value of 458.8 in the present work.

It is commonly stated that the Major Diatonic Scale resembles *Sankarabharana* closely. However, table 2 shows that there is significant disagreement in the case of G, D and N. It is interesting that there is better agreement with the equally tempered scale which is itself admittedly of limited value in western music. The frequencies of the equally tempered scale are : 240, 269.4, 302.4, 320.4, 359.6, 403.6, 453.1 and 480 Hz. It may be for this reason that *Sankarabharana* is assumed to be close to the 'major diatonic scale'.

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