OBJECTIVE ANALYSIS OF CONSONANCE (VADITYA) IN INDIAN CLASSICAL MUSIC

Ranjan Sengupta

Sir C V Raman Centre for Physics and Music
Jadavpur University, Kolkata 700 032, India
sgranjan@gmail.com

and

Asoke Kumar Datta, and Nityananda Dey

Scientific Research Department
ITC Sangeet Research Academy
Tollygunge, Kolkata 700 040, India
srd_itcsra@rediffmail.com

Abstract

The sense of vaditya in Indian music is examined in relation to the psychophysical concept of consonance and dissonance. A theoretical model based on vaditya for Indian musical scale including the shruti structure and the relationship of the representative pitch ratios with respect to the shruti intervals is summarised. The experimental results of investigations on signals taken from recorded performances of maestroes and senior music scholars vis-a-vis the theoretical model are presented. The notion of a personal scale embedded in the general scale used by four maestroes as a consequence of the concepts of global vaditya with its experimental verification is also presented. The nature of local vaditya is examined with respect to the splitting of steady notes into two or more steady pitches in aalap of raga for senior musicians.

Key Words: Indian Classical Music, Consonance, Dissonance, Pitch ratios, Vaditya

Introduction

Oral expression and aural cognition form the core of intelligent human communication. The physical reality of sound forms the material element of transfer and the neuro-physiological processes of production and reception from the interfaces for these communications. The major load of the total communication including ideas, feelings and emotions is, however, primarily borne by the cognitive functions of the human brain. This is primarily the subject matter of psychology, which embodies the development of human mind since the origin of the specie. In fact, it is believed that human brain embodies the history of development of intelligence since the origin of living organisms and all basic neurological processes of each stage of evolution are embedded in rudimentary form in human brain. Music, speech and language involve the human psyche most deeply. The advances in the sciences of physics, chemistry, neuro-physiology and psychology during the last four centuries, though spectacular, have been able only to peck at the outer shell of the vast and complex processes involved in human cognition.

The interaction between music and science is a logical corollary that is capable of furthering the cause of both music and science. Scientific researches of musical acoustics had been initiated long before. Pythagorous in Greece, Bharata in India, speculated on the rational or scientific basis of music to elucidate its fundamental structures. Music was first given numbers (the simple ratios of octave, ‘perfect’ fifth and ‘perfect’ fourth) by Archimedes.

Music is a phenomenon in the ideational world of man and hence has its primary basis in the psychology of perception of sound. The ancient Indian approach for understanding and production of music was metaphysical and was given the aura of divinity. There may be good reasons to believe that such an approach is more meaningful than the modern mechanical approach of explaining or understanding music in terms of physics of vibration only or the approach of forcing unnecessary numerical manipulation as Tagore put it "(which) mystifies the subject by enveloping it in a cloud of mathematicism"[1].

Though some measurements are available on the basis of comparison of string lengths these are of quite recent in origin (17^{th} Century A D) [2] and are believed by the Indian theorists to be less accurate and practical than the perception on the basis of feelings [3]. Though there exists a physical reality of music, that is the reality of the physical phenomena which is interpreted by the mind as music, this reality is transformed into ideational entities by the perceptual and cognitive mechanism which are often arbitrary [4].

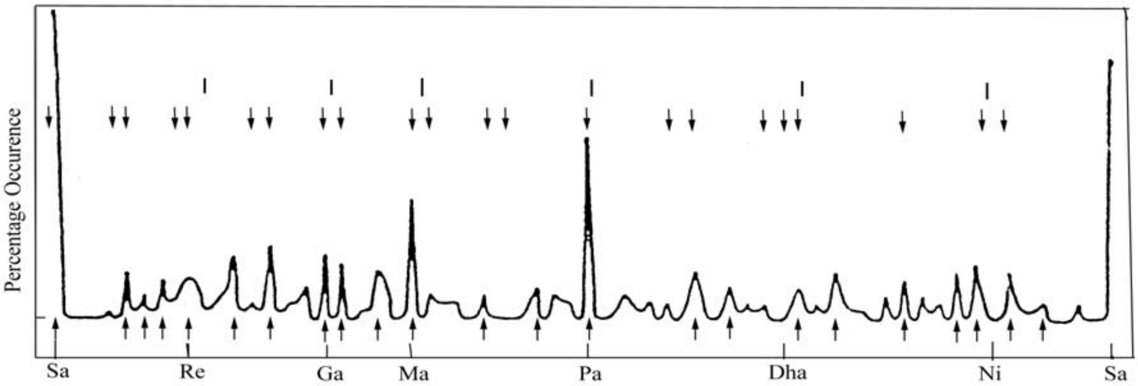
A systematic scientific investigation into the perception and production of music, requires a multidisciplinary approach, involving acoustics, phonetics, psychology, physiology, musicology to name a few. Even if one puts aside aesthetic appreciation, the task is formidable. The four aspects - the purity of tune, the purity of phonation, the beauty of voice and rhythm each in itself opens up a vast area of study. Through the ages experts, teachers and fastidious listeners are assessing these aspects merely by listening. Modern science has just made an entrance through the physiology of voice production, acoustic theories of production and transmission mechanism, theories on auditory perception, and above all, technology aids and instrumentation.

While the studies on cognitive aspects here cover voice quality[5], phonetic quality [6], quality of sound of musical instrument[7], etc., the main thrust have been on *vaditya* which forms the backbone of appreciation of musicality in Indian classical tradition. The present paper concentrates on giving a consolidated view on objective analysis of the role of *vaditya* in cognition of various aspects of musicality in north Indian classical music. The physical and neuro-physical aspects underlying the cognition of *vaditya* are discussed. These are seen to be the fundamental basis of Indian music and intrinsically related to the development of its shruti structure. The Indian musical system is modal as opposed to the western which is harmonic. In a modal system relations between successive sounds as well as those between any sound and a fixed tonic are of paramount importance. Whereas in a harmonic system it is the relationship between the simultaneous sounds which is important. In the Indian musical system, even in the absence of the tonic, an isolated sound can convey an expression, of course with respect to a memorised tonic or a previous sound. Here each sound leaves an impression in the mind and the idea is revealed through the cumulative effect of successive sound [8].

It is believed that as the musical scale has strong physical and neuro-physical basis they may have a sort of universal applicability. In fact, investigation reveals the existence of the same scale even in songbirds' repertoire [9]. The discussion includes the classical structure of Indian musical scales and their theoretical positions [10]. The consistent departure in performances from some of classical theoretical positions led to a comparison of these ratios and those deduced from the scientific premises of *vaditya* with the ratios observed from recorded performances in north Indian classical singing. The theory of *vaditya* enabled fixing the position of representative shruti position with the shruti intervals at the mean of each interval [11].

Analysis of recorded performances of some maestro both male and female of north Indian classical vocal music on a number of ragas reveal the existence of personal shruti structure embedded in the general scale of major notes. This is again in consonance with the theory of *vaditya* [12]. A detailed analysis of recorded performances of raga Yaman of a number of students and maestro revealed a splitting of a steady note into two or three steady states of separate pitches differing by a few Hz only. Such splitting were found to be not arbitrary but to follow strict demand of vaditya between successive notes[13].

In 1983 first experimental evidences of 22 shrutis surfaced unexpectedly in a study conducted on objective assessment of music scholars at ITC Sangeet Research Academy[14]. Fig.1 below



represents the histogram distribution of F_0 for 8 senior research scholars (skilled musicians of both sexes in Hindustani Music) in singing the pure notes of an octave both in ascending and descending modes on the 3 vowels /a/, /e/ and /o/. The vertical bars at the base of the figure give the note position according to Bhatkhande [15]. The downward arrows at the top of the figure give the shruti positions according to the formulations of Lentz [16]. The note positions where prominent peaks should have occurred to account for all the rendered samples, are occupied by sharp, though small peaks, but adjoining to it there are well separated sharp peaks distributed over a length. The upward arrows at the bottom of Fig.1 indicate the position of the 22 clear, unambiguous and significant peaks in each of the calculated intervals. It may be observed that 14 of the 22 significant peaks indicated by the arrows at the bottom are almost in full agreement with the defined shruti positions.

Vaditya

Consonance is generally said to be the absence of dissonance, which is caused by rapid beats [17]. These rapid beats cause subjective feeling of roughness, which is found to be strongly correlated to dissonance. With simultaneous sounding of two complex tones roughness may be produced by the production of beats for a large number of adjacent overtones. It has been suggested for a complex-tone-pair with a given structure of partial amplitudes the number of beating partials is smallest when the fundamental frequencies are related by a ratio of small integers [18]. On this basis Terhardt defines psycho-acoustic consonance, as the undisturbed simultaneous sounding of pure tones, the disturbing elements destroying consonance is roughness. However he also asserts that 'roughness principle' is not a sufficient basis of consonance and harmony [19]. It is an experimental fact that when musical notes, which are in simple integral ratios, are sounded together they sound pleasant. Musical sounds are generally complex in nature and as such contain a large number of upper partials. One theory is that when some upper partials of the two tones match consonance results. When these two sounds are not simultaneous but in succession same effects are observed. A complex wave gives rise to a series of active groups of nerve fibres separated by the groups of inactive fibres. The active fibres correspond to partials [20]. These patterns are imprinted in the auditory cortex at the learning stage. The other theory of preference of pair of tones relies on the similarity of the temporal patterns of neural discharge for tones having simple frequency ratios [21].

For the purpose of studying *vaditya* in the context of Indian classical music we consider consonance even when there is no simultaneous sounding. We believe that the remnant of the previous note, through some short-term memory, can psychologically interact with the current note and the musical sense of consonance remains still active. More over we consider consonance in a positive sense, i.e., we define consonance as the matching of a large number of higher partials rather than the absence of a non-matching that causes roughness. It has been shown that this also requires the fundamental frequencies to be related by a ratio of small integers [22]. In fact this definition appears to be relevant more in the cognitive domain rather than the physio-acoustical domain of inner ear. It seems that before the activated pattern for the earlier partial structure in the cortex die out if the new activation is such that some of the earlier regions are rejuvenated and a pleasing sensation is generated. We postulate that musicality, in Hindusthani music, requires two consecutive notes to be consonating in the aforesaid sense and that in turn requires the two pitch values to bear a simple ratio of small numbers. This will be referred to as *local consonance* later.

Musical Scale

Sensation of pitch which corresponds primarily to that of fundamental frequency of vibration is the most important property of musical sounds. The average human ear has a frequency range from 10 Hz to 20kHz. Of this region the ear is most sensitive in the neighbourhood of 5kHz. The range of frequencies over which the human voice spectra has relevance is approximately up to 8 kHz. Ear is most sensitive to frequency discrimination, generally referred to as difference limen (DL), near 2 kHz. There is a sudden decrease in the discrimination capability in the region 5 to 6.3 kHz. The whole audible range of pitch is available for musical expression and it is therefore necessary to have a scale suited to a particular musical system for interpreting, analysing as well as expressing musical ideas. Like all other musical systems octave (pitch ratio 2:1) is the most fundamental unit in Indian system. It also happens to be the most consistent interval (keeping aside the small amount of perceptual stretching of octave under certain constraints [15]). A very long period of development of Indian music (over four millennium) [23] gave rise to a unique scale based on a large number of basic intervals called shrutis.

According to ancient definition shruti is perceived as an interval of sound [24]. Again the music is similarly defined as a particular arrangement of sounds, which is pleasing. Thus shruti may be defined as the separately identifiable intervals of pleasing sounds. There had been various opinions about the number of shrutis during the span of development. References are found for the number to be 66, 53 [24]. In recent times it seems the number of shrutis are broadly agreed upon as 22 [25]. All shrutis are by no means equal. According to the size of the intervals three different shrutis are mentioned, pramana, nyuna and purana shruti [16]. There is confusion regarding the measures of these intervals.

Table 1. Comprehensive chart for different sets of shrutis

Sl. No	Ratio	Freq. (Hz)	Cents	MA	Name of Shruti	Support Swara	Sl No	Ratio	Freq. (Hz)	Cents	MA	Name of Shruti	Support Swara
1	24/23	104.3	73.7	0.15		rishava	34	23/17	135.3	523.3	0.14		madhyam
2	**21/20**	105.0	84.5	0.22	atikom		35	15/11	136.4	536.9	0.23		
3	19/18	105.6	93.6	0.20			36	11/8	137.5	551.3	0.18		
4	17/16	106.3	104.9	0.15			37	**25/18**	138.9	568.7	0.28	eksruti	
5	15/14	107.1	119.4	0.26			38	**7/5**	140.0	582.5	0.32	tivra	
6	14/13	107.7	128.3	0.15			39	24/17	141.1	596.9	0.18		
7	**13/12**	108.3	138.6	0.25	komal		40	27/19	142.1	608.3	0.14		
8	12/11	109.1	150.6	0.23			41	10/7	142.9	617.4	0.32		
9	11/10	110.0	165.0	0.22			42	**13/9**	144.4	636.6	0.28	tivratar	
10	**10/9**	111.1	182.4	0.29	suddha		43	19/13	146.1	656.9	0.14		
11	19/17	111.8	192.5	0.12			44	25/17	147.0	667.6	0.17		
12	**9/8**	112.5	203.9	0.26	tivra		45	**3/2**	150.0	701.9	0.72		pancham
13	25/22	113.6	221.3	0.18			46	23/15	153.3	740.0	0.22		
14	8/7	114.2	231.2	0.31			47	17/11	154.5	753.6	0.17		
15	23/20	115.0	241.9	0.17			48	**14/9**	155.6	764.9	0.26	atikom	dhaibat
16	22/19	115.8	253.8	0.09			49	19/12	148.3	795.5	0.20		
17	**7/6**	116.7	266.9	0.30	atikom	gandhar	50	**8/5**	160.0	813.6	0.38	komal	
18	27/23	117.4	277.6	0.12			51	13/8	162.5	840.5	0.23		
19	13/11	118.2	289.2	0.22			52	23/14	164.3	859.4	0.25		
20	25/21	119.0	301.8	0.22			53	**5/3**	166.7	884.3	0.55	suddha	
21	**6/5**	120.0	315.6	0.43	komal		54	17/10	170.0	918.6	0.23		
22	17/14	121.4	336.1	0.23			55	12/7	171.4	933.1	0.32		
23	11/9	122.2	347.4	0.22			56	**26/15**	173.3	952.2	0.26	tivra	
24	16/13	123.1	359.4	0.12			57	**7/4**	175.0	968.8	0.34	atikom	nishada
25	26/21	123.8	369.7	0.22			58	23/13	176.9	987.7	0.15		
26	**5/4**	125.0	386.3	0.45	suddha		59	25/14	178.6	1003.7	0.29		
27	19/15	126.7	409.2	0.20			60	**9/5**	180.0	1017.5	0.40	komal	
28	23/18	127.8	424.3	0.22			61	20/11	181.8	1034.9	0.22		
29	9/7	128.6	435.1	0.28			62	13/7	185.7	1071.6	0.29		
30	**13/10**	130.0	454.2	0.28	tivra		63	**15/8**	187.5	1088.2	0.32	suddha	
31	17/13	130.8	464.4	0.14			64	**21/11**	190.9	1119.4	0.23	tivra	
32	25/19	131.6	475.1	0.15			65	27/14	192.9	1137.0	0.23		
33	**4/3**	133.3	498.0	0.54	suddha	madham							

The psychophysical hypothesis [22] for explaining the shrutis and the consequent Indian musical scale contains four basic postulates: 1) shrutis are perceptually differentiable and 2) they are pleasant. Furthermore we include two more assumptions 3) shruti should be distributed over the saptak as evenly as possible and 4) they should be pleasant among themselves as numerously as possible. As for 2) the pleasantness of two sounds determined by vaditya requires small integral ratios. To answer the question how small it should be we might fall back upon the consonance theory, which requires some of the upper partials of the two sounds to match. If the fundamental of the two sounds are in the ratio of m : n where m and n are prime to each other and m>n then the first matching would be for the mth partial of the lower note with nth partial of the higher note. Taking 100 Hz as the tonic at best only two partials of the pair of tones would match within the sensitive range of human ear if m lies between 25 and 30.

A computation of all ratios m/n for m<30 shows that there exists only 138 ratios and the note corresponding to all of which (with 100 Hz as the tonic) are not perceptually separable. The ratios of each pair of these notes, 18906 in number, are computed to the form m/n. For each of these 138 notes the number of other notes with which these ratios have m<30 is then computed. This number divided by the number of notes less one (137 in this case) shall be referred to as the measure of acceptability (MA). Thus MA for a note can be used to determine how extensively this particular note can produce a pleasant pair in combination with the other note of the set.

To weed out notes those are perceptually not separable, avoiding well acceptable notes being filtered out, it is decided to select all notes having MA>0.2 first and then use DP (frequency discrimination of the ear expressed in percentage) in the descending order from the already selected notes at the end of the list and work upwards. The resulting selection indicated clearly that the upper value of m could be fixed at 27 without any significant adverse effect. Table I shows a list of all ratios having m> 27 and hence consonant with the tonic. The perceptually differentiable ratios are marked underlining the serial number. These notes are also pleasant in conjunction with other notes to the extent indicated by the corresponding MA given in column 3. The number is 65 and including the tonic this number fully conforms to the number of Shrutis, i.e. 66, referred to in the ancient literatures. The selection of subsets from this should be done in such a manner that while rejecting notes with least MA care is taken to reject notes from intervals which are more crowded. It may be noted here that MA refers to the acceptability only with reference to the notes in the current set. Therefore if a large number of notes are discarded at a single step there is a risk of those notes being discarded which are more acceptable with respect to new set than the less acceptable once. Thus in forming a subset of this set of 66 Shrutis not more than 10% of these ratios are filtered out in each iteration by selecting an appropriate threshold. After only two iterations the numbers of two Shrutis are reduced to 53 (including the tonic). If this iteration is continued 8 times we get the Shrutis given in bold ratios in Table I. The number of these is 22 including the tonic, which conforms to number of Shrutis at present in use [22].

Fig.2 shows the distribution of all the 138 notes along with the consonance coefficients taking all the 138 notes into consideration. This coefficient for a particular note is obtained by dividing the number of other notes, excluding tonic, which consonates with this note, by 138. The figure shows some discernible gaps in the ratio axis often followed by high consonance coefficients. Since each musical interval should be clearly differentiated one would like to place the interval boundaries at the end of a gap, preferably when such an end has a high consonance coefficient. According to this principle the shruti boundaries could be set [22] to 27/26, 14/13, 10/9 and 8/7 for the four shrutis in *Rishav*, 7/6, 6/5, 5/4, and 9/7 for *Gandhar*, 4/3, 7/5, 10/7 and 13/9 for *Madhyama*, 3/2 for the fifth pure note 'Pa', 26/17, 19/12, 5/3 and 12/7 for *Dhaibat* and 7/4, 9/5, 15/8 and 25/13 for *Nishad*.

The lengths of shruti intervals are expectedly non-uniform, the minimum being 19.2 cents for *tivra maddhyam*. *Atikomal gandhar* also has small interval 28.7. A large number interval is found having the size 70.7 cents conforming to the value of pramana shruti of 70 cents. The largest interval is found to be of 84.2 cents a value close to the theoretical value of 90 cents for purna shruti.

Experimental Verification

Four senior scholars of ITC Sangeet Research Academy rendered Kheyal in raga *yaman* in vilambit laya without any drone. The duration of each rendering was approximately 6 mins. A special PDA was developed to continuously track pitch of the signal. The pitch thus obtained was pre-processed and pitch values of steady notes were obtained therefrom [22]. The tonic for each singer was determined manually from the part of the signal where he sang the base note. This value was used to normalise the pitch values for all singers so that the tonic for each of the singers become 100 and notes in the higher and lower octaves are mapped onto appropriate values in the middle octave. A scale is formed by dividing the octave into 120 bins close to the theoretical value of 90 cents for purna shruti. The results reveal that the performers used notes very close to the theoretical values. There are only six outliers having deviations more than 8 cents mostly either in *panchama* or in the uppermost range of *trivatatra madhyam*. Excluding the outliers the average deviation comes within 4 cents.

In another experiment [11] 6 senior music students were asked to render the alap part of the raga *yaman* which was recorded in a noise-proof laboratory. Alap part of the same raga of the four maestros were re-recorded from their performance recordings. Only the part where the background music was less was recorded. These were sampled at the rate of 10kHz and the individual pitch periods were extracted by a PDA developed for the purpose. The steady state pitch and their durations were found out. A steady pitch was defined if it remains constant for ≥ 50 ms.. The tonic (Sa) of the singer was found out by a particular algorithm considering the longest-duration-pitch to be a valid note and comparing it with the interval ratios. The raga *yaman* contains all pure notes except Ma. Also there is a preponderance of Ga and Ni (vadi and samvadi). On this frame our approach was to analyse

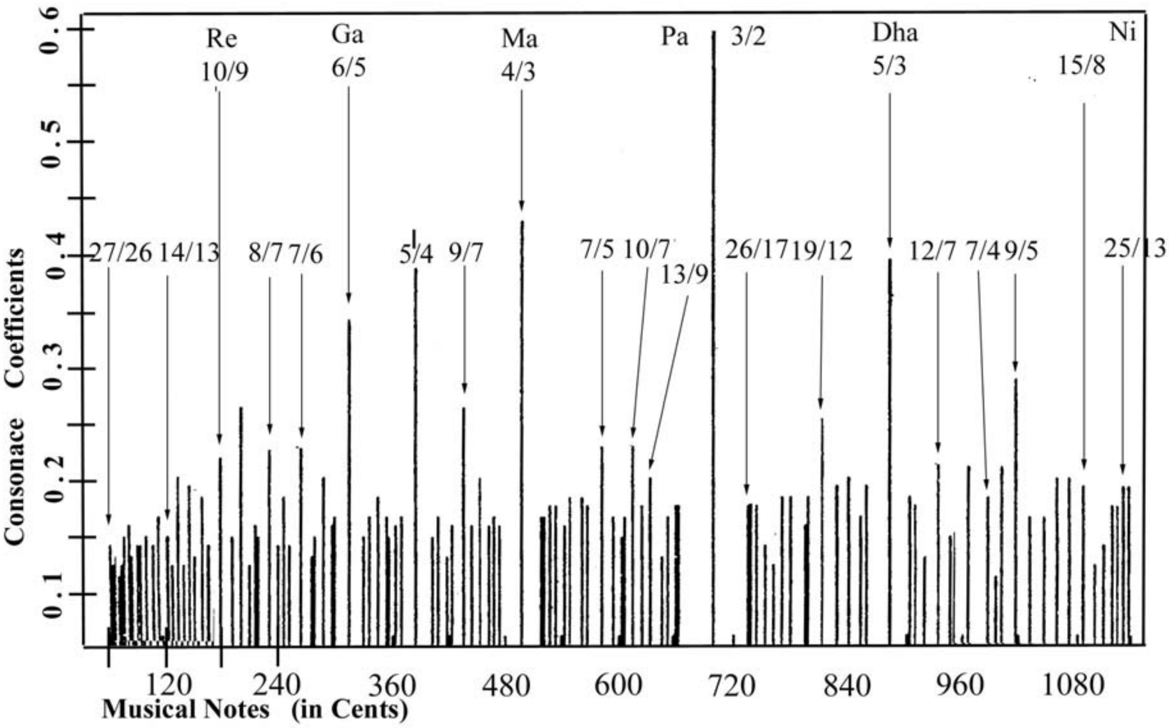


Fig 2. Intervals Based on Properties of Consonace

Table 2. Shruti intervals in three models

Sl. No.	Western Source	Consonance Model	Altered Consonance Model	Sl. No.	Western Source	Consonance Model	Altered Consonance Model
1	1/1	1/1	1/1	12	45/32	10/7	10/7
2	256/243	27/26	27/26	13	64/45	13/9	13/9
3	16/15	14/13	14/13	14	3/2	3/2	3/2
4	10/9	10/9	10/9	15	128/81	26/17	26/17
5	9/8	8/7	8/7	16	8/5	19/12	19/12
6	32/27	7/6	7/6	17	5/3	5/3	5/3
7	6/5	6/5	6/5	18	27/16	12/7	26/15
8	5/4	5/4	5/4	19	16/9	7/4	25/14
9	81/64	9/7	9/7	20	9/5	9/5	9/5
10	4/3	4/3	4/3	21	15/8	15/8	15/8
11	27/20	7/5	7/5	22	243/128	25/13	25/13

the position of the ratios representing the intervals with respect to the interval itself and to find out which of the three sets (mentioned below) of ratios are being used. Three different ratio sets (table 2) were compared with the pitch data and their duration, they are ratios from: 1) the western source [3], 2) the consonance model [22] and 3) ratios slightly altered from the consonance model. The shruti nos. 18 and 19 were altered in the ratios obtained from the consonance model, since it was found that the consonance coefficients of the new values were little high. Error was calculated from the pure note ratio values.

Four different representations of the intervals by the representative ratios were considered. They are:
1) $r \geq r_1$ where r belongs to Ir_1 (left boundary)
2) $r \leq r_2$ where r belongs to Ir_2 (right boundary),
3) $r \geq (r_1 + r_2)/2 < (r_2 + r_3)/2$ where r belongs to Ir_i (AM)
4) $r \geq \sqrt{(r_1 r_2)} < \sqrt{(r_2 r_3)}$ where r belongs to Ir_i (GM)
Where r_1, r_2 and r_3 are the three successive ratios and r is the ratio of any pitch with respect to the tonic. Ir_i represents the interval corresponding to r_i. Conditions 1 to 4 shown above define the belongingness of r to an interval.

Error δ was defined as the ratio of the sum of total durations of all the komal notes with respect to the total duration of the song excluding those for Sa, Pa and Ma. Though it is prescribed that Ma should be tivra in *yaman* it was observed that the singers used both Tivra and suddha Ma, so we have excluded Ma in error calculation. Theoretically δ should be zero in all cases for the scale used by the singer. The *vaditya* or the consonance factor τ was defined as the ratio of the sum of the total duration of Ga and Ni with respect to the total duration of all the 22 notes. A high τ value will indicate a greater duration of Ga and Ni in the song. The values of δ and τ were obtained for all the four conditions as mentioned earlier. In these calculations 3 different ratio sets were used in two different shruti intervals i.e. Bhatkhande's proposition (4,3,2,4,4,3,2) [26] and that obtained from the compilations of Danielou (1,4,4,4,1,4,4) [3]. Table 2 shows the shruti ratios of three scale distributions. Table 3 shows the average error $<\delta>$ in rendering the notes and the average consonance factor $<\tau>$ in rendering vadi – samvadi notes i.e. Ga and Ni, in all the four conditions for four maestros and six senior students. The legend used in column one has the following meaning: M – maestros; S – senior students; B – Bhatkhande's distribution; D – Danielou's and A – altered scale. Each row is the average of error value in each condition. It is observed from the table that MBA shows the minimum value of $<\delta>$ and an appreciably high value of $<\tau>$ in the scale obtained from the consonance model in AM position. Also $<\delta>$ in AM of SBA shows an appreciably low value and $<\tau>$ shows an appreciably high value.

Table 3. Average values of δ and τ for all the experimental sets

CODE	Ratios from Western Source								Ratios from Consonance Model							
	Interval Boundary								Interval Boundary							
	Left		Right		A M		G M		Left		Right		A M		G M	
	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>	<δ>	<τ>
MB	0.03	0.50	0.04	0.18	**0.01**	0.43	**0.01**	0.42	0.03	0.50	0.15	0.35	**0.01**	0.45	**0.01**	0.45
MD	0.04	0.50	0.03	0.25	0.08	0.45	0.12	0.44	0.14	0.51	0.38	0.38	0.18	0.47	0.21	0.47
MDA	0.04	0.50	0.03	0.25	0.08	0.45	0.12	0.44	0.14	0.50	0.38	0.38	0.17	0.46	0.22	0.47
MBA	0.03	0.50	0.04	0.18	0.01	0.43	0.01	0.42	0.03	0.50	0.14	0.28	**0.00**	0.45	**0.01**	0.45
SB	0.12	0.47	0.03	0.25	**0.04**	0.36	**0.04**	0.36	0.12	0.47	0.06	0.35	**0.06**	0.39	**0.06**	0.38
SD	0.13	0.48	0.45	0.41	0.11	0.40	0.12	0.41	0.15	0.48	0.23	0.39	0.12	0.41	0.15	0.41
SDA	0.13	0.48	0.45	0.41	0.11	0.40	0.12	0.41	0.15	0.48	0.23	0.39	0.12	0.41	0.15	0.41
SBA	0.12	0.47	0.03	0.25	0.04	0.36	0.04	0.36	0.12	0.47	0.04	0.34	**0.05**	0.39	**0.05**	0.38

Personal Scale

An analysis of excerpts from alap in ragas *yaman*, *malkaush*, *darbari* and *bhairabi* of some eminent maesros both male and female revealed an interesting feature. The steady states of the notes and ratios thereof determined by algorithms detailed in [12] were exhaustively listed for each performance.

The best fit of these real values of the steady states to simple ratios of the form m/n where 200 >m > n and m and n are integers are determined by exhaustive search. This fitting is done for each of the songs separately. As will be discussed later the best fit for all songs of one singer had a single value for m. The absolute value of error for each of the steady states are then computed and used for analysis.

Table 4 taken from [12] provides one of the examples of the data collected from four performers.

Table 4. Normalised pitch ratio for one performer and corresponding error for 3 ragas

Ratio	Error (x e^{-7})			Ratio	Error (x e^{-7})		
	Yaman	Malkaus	Darbari		Yaman	Malkaus	Darbari
134/122	10		10	134/90	5		
134/120	5		5	134/88		3	
134/118	40		40	134/86		7	
134/116		8		134/84		9	
134/114		10		134/80	20		
134/112		20		134/79		50	
134/108	60			134/78		30	
134/106	8			134/77		20	
134/104	20			134/76		8	8
134/100		20	20	134/74			40
134/98	7	7	7	134/72	60		
134/96	40	30	30	134/71	70		
134/94	40		40	134/70	10		
134/92	2			134/69	1		

This reveal that the deviations of the ratio of the note used by the performer to the tonic used by him from the ratios given in the first column is surprisingly small. The average error is of the order of 10^{-6} which is 1000th part of a cent. In some cases the error for individual ratios are 10,000th part of a cent. It may, therefore, be held that the pitches rendered by the performer follows the ratios of column 1 exactly. The most important to note is that the numerator of the ratio is same for a single performer for different performances for which time, place and raga all are different. Apparently a singer divides the octave into a number of harmonically equal divisions, the number being personal to the singer, and uses the notes having exactly the pitches determined by these ratios. This ensures any two notes will bear a simple ratio, which in turn ensures matching of some of the upper partials in the audible range, the condition required by *vaditya*. Thus in effect a singer uses a personal scale consisting of his personal set of pitches which are embedded in the shruti-intervals belonging to the general scale. In a particular raga only a small subset of these ratios is used. As expected these subsets are different for different ragas. In general the sizes of these subsets are larger for male singers. This personal scale is again determined by the pitch of the tonic of the singer and is given by the relation F M = T, where F is the tonic in Hz., M is the value of the numerator and T is the upper audible range which was found to be near 19 kHz.

Local Relevance of Vaditya

These studies reported in the last section more or less reflected the global nature of the relevance of *vaditya* of notes and the tonic. We shall now consider the local nature of this relevance, i.e., the relevance of consonance in determining the infrastructure in melody management with particular references to consecutive notes. It has been noticed that quite often a steady state of note contains more than one steady fundamental frequency, all of them lying in the same micro-tonal interval but having discrete and firm existence. The existence of the multiple frequencies in a micro-tonal interval could be a random bio-phenomenon or may be due to some melodic requirement. These frequencies in an interval sometimes differ by a significant amount, 5 to 6 Hz. It is hard to believe such an uncontrolled behaviour from singers with rigorous practice and performances extending over thirty to fifty years, particularly when studies reveal an accuracy of less than one Hz for all such singers whose performances have been studied [12]. . It is interesting to examine whether such multiplicity has any relevance to consonance. Some earlier studies revealed the existence of personal scales for experienced classical singers with the possibility of dividing the octave into large number of discrete usable frequencies [12] indicating the availability of a fixed number of usable frequencies in a shruti interval and indicated extreme accuracy in pitch production.

In a singing the intervals of a note may not always bear small ratios to those on either side and therefore may not be locally consonant by themselves. In such cases the pitch contour of the central note can be usefully split up into different pitch contours such that all the pitch values still remain in the same interval but each can bear small ratios with the corresponding adjacent note. Categoricity of pitch perception in music mode would keep intact the grammatical and other musical requirements dependent on perception of notes whereas the requirement of local vaditya would then be fulfilled.

The basic approach undertaken here to test whether multiple states are required for better consonance between consecutive notes is to examine analytically the degree of this consonance in actually sung sequences and properly altered sequences. Let us consider sequences $\{a, b_1, b_2, c\}$ of the pitch values in notes {A, B, C} in the originally sung phrases. We conjecture that when B do not have a good consonance with either A or C or both, the note B would be split into two steady states of pitch values b_1 and b_2 which would be in consonance with the two consecutive notes on either sides. That is $\{a, b_1\}$ and $\{b_2, c\}$ will consonate. If we change the sequence to $\{a, b_2, b_1, c\}$ then both the sequences $\{a, b_2\}$ and $\{b_1, c\}$ will not consonate. To test this, sequences of the types $\{a, b_1, b_2, c\}$ and $\{a, b_1, b_2, c_1, c_2, d\}$ are selected and the set {O} is formed. An altered set {R} is also formed by interchanging the split notes of the set {O}. The degree of the consonance of the two sets is then compared.

The analysis indicates good correlation of the splitting of the steady state of a note in more than one positively defined different steady pitch-states with the need for local consonances between consecutive notes.

Discussion

As we have already noted in the introduction, scientific investigation in Indian Classical Music opens up a vast area of multi-disciplinary research. The terms and concept used by musicologists and exponents of Indian Music are primarily ideational and though real are yet to find expression in the objectivity of modern science. As such their interpretation become subject to and is apt to lead to ambiguity and even confusion. Primarily because of this the transmission of this art has been through the tradition of what is normally termed as *guru-shishya parampara* and almost completely dependent on aural propagation also known as shruti in classical literature. This study on vaditya exemplifies the possibilities of establishing some objectivity to musical concepts in general is also exemplified through work on musicality of voice/instrument, assessment of progress of musical trainees, etc. Studies in the west on the universality of *vadi, samvadi and vivadi* relation in Indian *thata* system lends credence to this belief to this belief. It is possible that vaditya at the local level may lead to the interpretation of the semantic and cognitive aspects of musical phrases in raga leading to the understanding of the emotional ambience created by a raga. It may also be interesting to study the role of vaditya in the decay of some of the old ragas.

So far, whatever preliminary studies we have made are on an objective basis and interpretation of the degree of vaditya. Are there also some attributes of vaditya which lead to the creation of different emotion and if so what could be the psychophysical basis of it? In this context we believe that there is a need of serious wide spread studies on the role of vaditya in modal music.

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