# Observing entrainment in music performance: Video-based observational analysis of Indian musicians' tanpura playing and beat marking

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## Abstract

Entrainment has been suggested as an important phenomenon underlying aspects of musical behaviour, and is attracting increasing attention in music psychology (see *e.g.* Large and Jones, 1999; Large, 2000), and in ethnomusicology (Clayton, Sager and Will, 2005). Approaches to its study in ethnomusicology must address a significant methodological problem: how to study entrainment phenomena in an ecologically valid manner, and to integrate this process into a programme of ethnographic research. Video recordings contain important data regarding the physical movements of participants in musical events (as well as their audible results), and through the application of observational analysis software these recordings can form the basis of studies of entrainment between different quasi-periodic musical processes as manifested in movement patterns. For the present study a short video clip of an Indian raga performance was selected (taken from a performance of Shree Rag by the singer Veena Sahasrabuddhe). Observational analysis was carried out using The Observer Video-Pro software, configured to record the plucking of tanpura strings and performers' beat markers (hand or finger taps). Time series data thus generated were analysed using calculations of phase relationships, revealing several instances of both self- and interpersonal entrainment (the stated intention of the performers is, on the contrary, that the tanpura rhythms

should each proceed independently). Entrainment between these behaviours points to a complex, but unintended form of emergent order. This unexpected result demonstrates the usefulness of this method in revealing otherwise unnoticed phenomena in musical performance, and raises important questions for future research.

## Introduction

Entrainment - the process by which two or more independent rhythmic processes interact, leading in some cases to synchronisation - is proving a fruitful concept in a variety of fields in the sciences and social sciences (*e.g.* Strogatz, 1994, 2003, Bluedorn 2002). In music psychology research it forms an important element of Jones's theory of attentional periodicity (*e.g.* Jones, 1976; Jones and Boltz, 1989; Drake, Jones and Baruch, 2000; McAuley and Jones, 2003), which in turn underpins the most powerful current theories of musical metre (*e.g.* Large and Kolen, 1994; Large and Jones, 1999; Large, 2000; London, 2004). Its significance extends beyond what is normally thought of as the metrical domain: I have previously suggested its application to the study of apparently unmetred music (see Clayton, 2006).[1]

Clayton, Sager and Will (2005) argue for this breadth of applicability to music research and also introduce to an ethnomusicological readership the study of phase relationships between different musical rhythms, as an analytical tool for the study of entrainment (pp. 49-75). They also suggest that the analysis of video recordings of musical performances might form the basis of entrainment studies, through the medium of established techniques of behavioural analysis (pp. 46-7). There are clearly many forms of musically significant behaviour which are impossible to extract from audio recordings but may nonetheless be accessible via video recordings. This visual data is particularly relevant in an ethnomusicological context, where researchers are concerned with studying real-life musical practices in situ, without the intervention of intrusive data-capture methods such as EMG monitors. Although there are aspects of entrainment that can only be investigated in a laboratory setting, the relevance of ecologically valid studies extends beyond ethnomusicology and impacts on all disciplines: it is important that musical entrainment studies consider how people actually behave in a variety of environments and contexts, as well as studying their performance in experimentally-determined tasks.

The use of film and video recording in academic research on interpersonal interaction has a long history. The present research builds on the work of many researchers, from Condon's and Birdwhistell's pioneering studies of interpersonal interaction in the 1960s (*e.g.* Condon, 1985; Birdwhistell, 1970) through to more recent studies of gesture (eg. McNeill, 1992, 2004; Kendon, 2004) and child development (*e.g.* Trevarthen, 1999-200). Observational analysis techniques have moved on from the manual coding of filmed behaviour on a frame-by-frame basis, and are now facilitated by a number of specialist software packages, used in a wide range of ethological and psychological research.

Perhaps the most significant precursors of this study in the musicological literature are Qureshi's 'contextual input' model, employing audio-visual transcription and applied to Sufi ceremonies in India and Pakistan (1986, 1987); examples of film- or video-assisted transcription by Baily, Kubik and others (*e.g.* Baily, 1985; Kubik, 1961); and recent studies by Davidson and colleagues into performers' gestures (*e.g.* Davidson, 1993, 2001, 2005; Williamon and Davidson, 2002). This is a rapidly expanding field, however, as evidenced by the successful "Music and Gesture" conference held at the University of East Anglia in August 2003, and it is not possible to list all of the emerging approaches here.

Moran has proposed the use of video transcription and coding as a tool for the analysis of interaction in Indian music performance:

> a video recording of a multiplayer performance, analysed with attention to both musical and non-verbal, musically 'unnecessary' communicative behaviours, can potentially provide a temporally structured method for examining musical processes as physically dynamic situations […] the

> findings of such an analysis might include evidence [of] synchrony in individuals' movements between hand, eye and head movements, and a constant relationship in time of gestures such as head tilting and hand movements intra-individually. (Moran, 2002, p. 53).

Using a clip from an Indian vocal performance and a manual coding technique, Moran demonstrated a relationship between the time structure of the 'global gesture phrases' (McNeill, 1992, pp. 83f) of the singer Veena Sahasrabuddhe and one of her tanpura players. [2] These gesture phrases last between 4 and 8 seconds and could perhaps be described as quasi-periodic processes: although strictly speaking, entrainment is hard to prove in this case, the two musicians' gestures seem to evidence a consistent mutual relationship.

Although informed by many of the same concerns, the present study follows a different route in several respects: it concentrates on the precise coding of clearly-defined events rather than on the partially subjective interpretation of gesture phrases; it uses observational analysis software to assist the coding and analysis processes; and it attempts to uncover evidence of entrainment processes on the basis of rigorous analysis of the coding data. The method described below outlines (a) the process of coding video clips of music performances in order to extract time series data relating to defined events, many of them quasi-periodic (*e.g.* tapping of hands or feet), and (b) the analysis of these time series to search for evidence of mutual interaction that may point to self- or inter-personal entrainment. I do not discuss methods for sampling performances (*i.e.* the selection of clips), and although the results of this study are highly suggestive of unsuspected aspects of entrainment, my intention is not to draw conclusions about Indian raga performance in general, merely to introduce a method that should enable such conclusions to be drawn in the future. The main aim of this study, then, is to demonstrate the applicability of a method for entrainment studies: in the course of demonstrating this method, I also report on some preliminary but nonetheless potentially significant results.

## Method

In order to code video clips, it is necessary first to design suitable coding configurations within observational analysis software (in the case of this example, The Observer Video-Pro 5.0 was used), assigning key codes to represent salient observable events (*e.g.* the plucking or striking of instruments, foot- or hand-tapping) or changes of state (*e.g.* someone starts or stops singing, opens or closes their eyes). In The Observer, at least, the hierarchy established at this stage in the coding configuration is important, in that it sets limitations on the formats in which data can be displayed and output. I do not discuss these issues in detail here, although the significant parts of the present configuration can be found in an online Appendix.[3] Using this configuration, salient events and states can be coded while viewing the video clip.

The timing of events in each individual stream can be output to any spreadsheet or statistical analysis program. In addition to basic statistical information such as the average period and variability of any rhythm, particular techniques are needed for entrainment studies. Most importantly, plots of phase relationships between pairs of time series prove an effective tool in uncovering instances of entrainment between the different series (and thus, entrainment between independent rhythmic processes); for more detail see Clayton, Sager and Will (2005, pp. 66-72). The case described below represents a pilot study, using a short clip of an Indian raga performance, and is intended to demonstrate the practicality and effectiveness of this procedure.

## Tanpura playing and beat marking in Indian raga performance

This case study describes analysis of the playing of the tanpura - a type of plucked lute used to produce a drone for pitch reference - and of beat marking gestures, in an Indian vocal raga performance. The performance extract considered here is taken from a video recording of a performance of Shree Rag by Veena Sahasrabuddhe, made as part of a pilot study for the research project “Experience and meaning in music performance” in Mumbai, India in April 2003. The aim of the pilot project was to produce video recordings suitable for studies of specific issues in musical performance, including entrainment and gestural communication (Clayton, 2005).

The well-known khyal singer Veena Sahasrabuddhe was accompanied for this concert by Seema Shirodkar (harmonium) and Viswanath Shirodkar (tabla - who was however not playing on this clip, which comes from the unmetred alap portion of the performance). The tanpuras were played by Veena Sahasrabuddhe herself and by two of her students, Bageshree Vaze and Madhuchhanda Sanyal. The performance of Shree Rag was divided into three sections: the alap, then sections in two different talas (metres), jhaptal and teental respectively. This study focuses on an extract from the alap, thus there is no explicit metrical framework to take into account. The extract chosen (12’35” - 13’21”) covers the change from the slow alap (in which most listeners do not seem to experience a clear pulse) to the jor or madhya alap (in which a pulse is much more easily apparent).[4]

Two unambiguous and observable markers of the music’s pulse as perceived by the performers take the form of (a) Veena Sahasrabuddhe striking her thigh with her left hand, and (b) Seema Shirodkar tapping the bellows of her harmonium with the index finger of her left hand. Logging of the occurrence of these ‘beat markers’, and analysis of their relationship, forms one part of this study: the second part comprises the study of tanpura rhythms.

FIGURE 1 NEAR HERE

The tanpura is a plucked, long-necked fretless lute (see Figure 1), used to produce a drone emphasizing the Sa (ground note or tonic) and Pa (fifth).[5] The tanpura provides a constant reminder of these pitches for the singer - and, due to the particular timbral characteristics of the instrument, even with a basic 1-5 tuning several other important pitches can be heard clearly in the sound produced. The instrument’s four or five strings are not meant to be heard rhythmically: however, in order to optimise the sound of each string and their blending, the instrument tends to be played in a quasi-periodic rhythm, with lower pitched strings (the first and last) sounding for longer than those of higher pitch (see detailed measurements below). Even if performers employ fairly regular rhythms, since (a) the characteristics of the instrument itself mean that each string's volume can swell long after the plucking, and (b) several instruments are used, each employing independent rhythms, this regularity of plucking can not generally be perceived by the listener or extracted from the audio recording, and can only be recovered using video data.[6]

As for the performers' understanding of tanpura playing, the following comments are taken from Veena Sahasrabuddhe's own description:

> Plucking should be such as not to produce pronounced attack. The complete cycle takes 2 to 2½ seconds. An even volume is heard all through the cycle when the tanpura is plucked well. Beginners often unconsciously adjust the plucking rate to tempi of singing - they have to be told to break the connection. Tanpura should be plucked at an even rate not connected with singing. (Veena Sahasrabuddhe, pers. comm., 12 Sept 2004)

Since the performers try to keep the rhythm of the tanpura independent of the rest of the music, any correlations between the tanpuras and other rhythms are not intentional. Thus, any significant correlations between the timing of different tanpura players' strokes, or adjustments of the tanpura timing to other events, constitute prima facie evidence of entrainment processes that players do not intend, and in fact consciously try to avoid.

This case study, then, involves the use of the video recording, and observational analysis software, to extract timing data for the plucking of the tanpura strings and the beat markers; and the analysis of this data for evidence of correlations between the rhythms within and between players (*i.e.* both self- and interpersonal entrainment),[7] and for phase adjustments which might correlate to other musical features.

**Video extract and coding configuration**

The extract chosen for this study is 46 seconds long (12'35" to 13'21"), and is taken from the transition between the two major portions of the alap or exposition of the raga: effectively, this transition marks the emergence of a clearly perceivable pulse in the music. In this performance the soloist takes a short break between the two sections, allowing her harmonium accompanist Seema Shirodkar to take a short solo. The extract begins in the middle of this harmonium solo: it includes two cadential patterns (known as mukhra), which are used to mark the end of each short episode of the extempore development: the second of these appears to be stronger and to conclude the whole clip, while the first is more provisional, marking an interim ‘resting place’.

The video recording allows us to extract the timing data for each tanpura string for almost the whole clip; it also allows the coding of the singer’s beat markers (left hand on thigh) as she establishes the pulse, and finger taps of the harmonium player on her instrument’s bellows. The same video also affords the coding of the occurrence of the singer’s breaths, and marking of the focal point of each of the two cadences (in this case only, the coding relied on aural evidence and contextual knowledge). The coding data from this extract therefore allow us (1) to consider the possibility of mutual entrainment between the different tanpura players; (2) to quantify the process of entrainment between the singer’s and harmonium player’s beat markers; and (3) to examine the relationship between the tanpura rhythms, the emerging beat in the music and the cadential figures.

The Observer was configured to allow coders to log the playing of each of the three players; the physical ‘beat markers’ performed by the singer and harmonium player; other salient features such as when the singer started and stopped singing, when she took breaths, and where the cadences fell; and miscellaneous gestures such as head shakes. Relevant parts of the Observer configuration can be found in an online Appendix, and instructions followed by each coder are reproduced as the Appendix of this paper. The Observer’s facilities for graphical display were used to get a quick visual impression of the results, and then the timing data were exported to Excel, SPSS and Oriana for further analysis. The key analytical method employed here involved the calculation of phase relationships between the different rhythms in order to identify entrainment phenomena.

**Data reliability**

The data reliability figures in Tables 1 and 2 (inter- and intra-coder reliability respectively) are based on data from the beat markers and the plucking of string one only. They show more than 80% agreement between coders with a tolerance of +/- 1 frame (0.04 secs);[8] agreements reached 100% in virtually all cases with a tolerance of 2 frames (0.08 seconds). Using data from the most consistent coder (B) - as I have done below - it seems reasonable to take the error in measurement as +/- 0.04 seconds. In terms of the phase plots, with a period of 1.35 secs this would translate into an error of about +/- 11°.

TABLE 1 NEAR HERE

TABLE 2 NEAR HERE

## Results

### 1. Tanpura playing: periodicity

The three tanpuras are distinguishable morphologically, and this has an effect on the periodicity of their playing (the figures for the periodicity of the patterns are derived from coding of the plucking of string one in each case). Singer Veena Sahasrabuddhe’s own tanpura is significantly smaller than the other two, and has five strings; that of the player on the left of the video image (referred to below as Tanpura L) is a larger instrument with 5 strings, while the third instrument (Tanpura R) is also a large instrument but with only 4 strings. The average lengths of the pucking patterns reflect the difference in the instruments' relative size, with the singer's (smaller) instrument being played significantly faster (Table 3). This is because the longer (and lower-pitched) strings tend to vibrate for longer than the shorter, higher pitched strings of the singer's instrument, and players tend to wait until the sound of one string is noticeably decaying before striking the next. It is also clear from this data that the pattern of Tanpura L shows more variation than the other two.

TABLE 3 NEAR HERE

Figure 2 is the plot of period length against time (the striking of string one) for the three patterns. An unexpected feature shown up in this chart is the sudden increase, towards the end of the clip, of Tanpura L's period from 2.44 to 3.48 seconds, that could also be described as a delay of about a one second before the striking of the first string: this will be examined further below (see Figure 2 at around 40 secs).

FIGURE 2 NEAR HERE

## 2. Tanpura playing: internal rhythms

As noted above, tanpura players tend to produce patterns with their own distinctive rhythms - inter-onset intervals (IOIs) are not equal, since the lower-pitched strings tend to be allowed to sound for longer before the next string is played (the strings are never damped, so the instrument's sound presents a blend of all the pitches at all times). These lower-pitched strings will generally be the first (usually tuned to the fifth scale degreee, Pa) and last (tuned to the tonic or Sa in the lower octave). The measurements for this clip (Table 4) confirm this general tendency for the two larger instruments (Tanpuras L and R), whereas the singer rests longer on the second and fifth strings, and by no more than a ratio of 3:2 (0.52 secs to 0.34 secs, on average). Figure 3 plots the IOIs for Tanpura R's pattern for a short part of the clip: although it is possible to pick out a periodic grouping of four intervals, the plot demonstrates that this is far from regular. Comparison with Figure 2 shows that the duration of the overall pattern seems to be more stable than the internal rhythm of the pattern. Autocorrelation plots of the tanpura time series do however clearly show the temporal patterns to be periodic, with significant positive correlations at multiples of the number of strings on the respective instruments (Fig. 4a-c).[9]

TABLE 4 NEAR HERE

FIGURE 3 NEAR HERE

FIGURE 4 NEAR HERE

## 3. Tanpura playing: phase relationships between players

The relative phase of the tanpuras was calculated between each pair of players (abbreviated as Tan L vs Tan S, Tan R vs Tan S, and Tar R vs Tan L, where S refers to the singer and L and R to the players on the left and right of the video image, see Figure 5a-c), in order to look for evidence of interaction between the different patterns (which one would expect to find if they were playing ‘in time’ with one another, but not if they were playing truly independently).[10] Two of the three relative phase plots (Tan L vs Tan S, Tan R vs Tan L) seem to show a continuous drift in phase relationships, illustrated in the diagonal trends of the data points, as one would predict for players who are plucking independently. The third however, that for Tan R vs Tan S, seems to show a bimodal distribution, with alternate points aligned just below 0° and on or just below 180° (Fig. 5b). The distributions of the relative phase measurements of these three pairs of players are presented as circular plots in Figure 6. Figures 5b and 6b together suggest an alternation between two phase regions in Tan R vs Tan S (between the bottom right and top left of Fig. 6b). This alternation (roughly speaking, in-phase/ anti-phase) tallies with the 3:2 relationship between their average periods, although the durations are much longer than one would expect of 3:2 polyrhythms (3.00 and 2.03 secs).

FIGURE 5 NEAR HERE

FIGURE 6 NEAR HERE

In order to test the hypothesis of a bimodal distribution with equal and opposite modes, the following method was used, as described by Batchelet (1981, pp. 21ff) and by Fisher (1993, pp. 37, 98-99).[11] All of the phase angles are doubled and the resultant angles reduced modulo 360°: a unimodal distribution in the doubled data is consistent with a bimodal distribution with opposite modes, but not with a uniform distribution, in the original data. In the case of the Tan R vs Tan S data (Fig. 6b), Rayleigh's test discounts a uniform distribution for the doubled angles ($p = 0.017$), thus supporting the hypothesis of a bimodal distribution for the original phase angles. The mean vector of the doubled phase angles $\mu_2$ = 302° - indicating mean angles for the two modes at 151° and 331° - with a length $r_2$ = 0.51. These mean vectors differ significantly from 0°/180°: the 95% confidence interval for $\mu_2$ is 262°-340°.

This finding is supported by another, *ad hoc* procedure. The phase angles were split into two streams, comprising the odd and even data points. The mean vectors of the resulting data sets are μ = 153°, r = 0.63 (odd) and μ = 337°, r = 0.61 (even). These procedures confirm the interpretation above, of a stable 3:2 relationship between these two two tanpura rhythms. Summary statistics are presented in Table 6 below.

## 4. Beat markers: phase relationships between singer and harmonium player

Similar procedures were used to investigate the relationship between the singer's hand beating and the harmonium player's finger tapping. The Observer plot (Fig. 7) shows that the two musicians follow a similar pattern, starting and ending at a faster rate, and dropping to a slower rate in the middle portion of the extract (c. 18.7-32.4 secs). A significant (and expected) alignment between the two series of beat markers is also easy to see on this plot. The plot of IOI against time (Fig. 8) illustrates the same data in a different format, on which the two tapping rates can easily be seen - the ratio of the two rates is 2:1, with average IOIs of 0.67 and 1.35 secs.

FIGURE 7 NEAR HERE

FIGURE 8 NEAR HERE

The relative phase plot (Fig. 9) shows clearly that the harmonium player starts slightly behind the singer's beat, then runs ahead slightly (c. 6-10 secs) before returning to phase alignment: they continue to fluctuate around 0° for the remainder of the extract (from the relative phase plot it is not possible, however, to say who is adjusting to whom). This type of continuous correction process is typical of entrainment phenomena, and clearly indicates interaction between the two series of beat markers, and therefore a significant degree of entrainment between the two musicians. Statistical tests confirm the relationship between the two beats (Rayleigh's test gives $p < 0.01$). Figure 10 presents the relative phase distribution as a circular plot: the arrow illustrates the vector ($\mu = 6°$, $r = 0.69$), suggesting that the phase attractor may have a small positive value (the harmonium player slightly behind the singer). The deviation from 0° is not significant however: the 95% confidence interval is 348° - 23°.

FIGURE 9 NEAR HERE

FIGURE 10 NEAR HERE

## 5. Correlations between beats and tanpura playing

Figure 11 presents plots of the relative phase of each tanpura pattern with respect to the singer's marking of the beat. Again, one of the plots - Fig. 11a, that of the singer herself - seems to show a clustering of points around the 0° and 180° lines. The circular phase distribution plot in Figure 12a in fact shows more clearly that 5 out of 18 data points fall exactly on 0° or 180°, although the pattern overall is not as clear as that in Figures 5b and 6b above. The angle-doubling procedure described above gives a significant unimodal distribution (Rayleigh's test gives $p = 0.034$) with a mean vector $\mu_2 = 334°$, consistent with a bimodal distribution in the original data with mean vectors at 167° and 347°. The procedure of separating out odd and even data points gives mean vectors at $\mu = 155°$, $r = 0.26$ (odd), and $\mu = 7°$, $r = 0.38$ (even).

Close inspection of the relative phase plot (Fig. 11a) suggests that the relative phase may in fact stabilise in the middle part of the extract: this coincides with the period when the slower (1.35 sec) beat predominates (see above). Rayleigh's test gives $p = 0.001$ for the portion 18.7-32.4 secs, but $p = 0.562$ for the remainder of the extract, confirming this impression. Whether this is because the phase relationship between the two rhythms only stabilises during this period, or is a statistical artefact related to the change in the period of the beat and the pattern of 'missed' beats, is not clear although evidence presented below suggests that the relationship also remains stable in the latter part of the extract.

FIGURE 11 NEAR HERE

FIGURE 12 NEAR HERE

## 6. Correlations between tanpura playing and cadences

I noted above the curious lengthening of period, or delay in plucking, manifested by Tanpura L just after 40 seconds in this extract. The Observer plot of all data around this point (Fig. 13) clearly illustrates that this effect correlates with the occurrence of the mukhra (cadence) just before 42 seconds (marked in black, third line from top). It is clear that at this point, two of the tanpura periods and the two ‘beats’ are very close to alignment - something which does not occur elsewhere in this clip, not even at the first cadence. My interpretation is that the emphatic nature of this cadential figure causes two of the three tanpura players to align the plucking of their first string, with Tanpura L delaying her plucking by a full second in order to do so. Thus, although there is no conclusive evidence that this player displays entrainment effects with respect to the other periodic rhythms considered above, she does perform a significant phase realignment at this important point in the performance. This same plot also reveals a clear relationship between the singer’s tanpura pattern and the beat, with three beats per tanpura period: this could indicate the emergence, at least for a few seconds, of a ternary metrical structure. It also suggests that, contrary to the impression given by Figure 11a, the singer’s tanpura playing and beat marking remain closely coordinated in the latter part of the extract. The analogous plot for the first part of the extract is not so clear cut, but seems to suggest phase stabilisation from around 13-14 secs, which is when the final phrase of the cadential figure begins (Fig. 14). In this case is we interpret the singer's beat marking and tanpura patterns as describing a 3-beat metre, the focal point of the cadence falls on beat 3, rather than on beat 1 as in the final cadence of the passage.

FIGURE 13 NEAR HERE

FIGURE 14 NEAR HERE

**7. Summary of results**

The main results of the analysis are as follows:

i. The relative length of the tanpura patterns reflects the relative size of the instruments, the larger instruments' periods being longer. In each case the IOI after the plucking of the last string, and in the larger instruments after the first string also, is longer than that following plucking of the middle strings. The internal rhythms seem to be less stable than the overall periodicity, although their quasi-periodic temporal structure clearly shows up in the autocorrelation plots. One instance of extreme variability in overall period (Tanpura L, c. 40 secs) seems to be best explained as a phase correction due to the influence of a cadential figure (mukhra).

ii. Two of the tanpura players (Singer and Tanpura R) seem to be entrained in a 3:2 relationship, with Tanpura R's phase relative to the singer alternating between modes centred around 151° and 331°. The relationship between their average periods is almost exactly 2:3 (2.03 vs 3.00 secs). The third player (Tanpura L) seems to be independent of these two, except for the phase correction noted above.

iii. The two patterns of beat markers are closely correlated. Relative phase plots reveal a process of continual adjustment typical of mutually entrained quasi-periodic systems. Two tapping rates, periods averaging 0.67 and 1.35 secs, occur consecutively, and the mutual adjustment occurs across the changes in the tapping rate.

iv. The relationship between the singer's tanpura playing (average period 2.03 secs) and her own hand beating shows phase stabilisation at least in the middle portion of the extract (where the beat averages 1.35 sec), alternating in- and anti-phase relationships. The Observer plot (Fig. 13) also suggests that the relationship resembles a stable ternary metre in the latter part of the extract, and from about 13 secs (roughly, when she starts singing the first cadential figure).

The relationhips between the various periodicites are summarised in Table 5. This table reveals a complex interrelationship between 4 of the 5 main periodic rhythms identified. This result is very surprising in light of the performers' view that these rhythms are intended to be mutually *independent*.[12] What it seems to indicate is the emergence of a complex set of relationships between different periodic rhythms due to pre- or unconscious entrainment processes. Summary statistics are presented in Table 6.

TABLE 5 NEAR HERE

TABLE 6 NEAR HERE

## Discussion

The emergent order described above is not a conscious aim of the performance, and neither performers nor audience seem to be aware that such a phenomenon can occur (although Veena Sahasrabuddhe's comment above shows an awareness that conscious effort may be required on the part of a tanpura player to *avoid* playing in time with the music). It would be misleading to term this organisation of physical behaviour 'metre', but it does have some characteristics in common with musical metre - I propose the term *proto-metrical behaviour* to describe such unintentionally entrained cooperative action involving multiple periodicities.

These results support the suggestion that entrainment phenomena pervade musical performance, and offer a strong indication of the potential of the method described above. It should be remembered, of course, that this paper describes the analyis of a single 46 second video extract: much more work needs to be done to determine the manner and the extent to which these same phenomena are manifested in other performances in this tradition, or even at other moments in this same performance. Only once this work has been done can we speculate in more general terms about the kinds of entrainment phenomena, and the varieties of unintentional emergent order that may be manifested in performances of Indian raga music. I also anticipate similar studies involving observational analysis of audience members, as well as performers.[13]

This case study has demonstrated the effectiveness of the present method in uncovering aspects of temporal order in musical performance that until now have gone largely unnoticed by performers, audiences and musicologists alike. The uncovering of emergent, unintentional pulse hierarchies of this kind in musical behaviour both supports and enriches the position described by Large in his paper “On synchronizing movements to music” (2000). Large talks in terms of listeners synchronizing their movements *in response to* a perceived pulse hierarchy (metre): this study suggests the emergence of complex hierarchies of entrained movement patterns in the course of producing music with a much simpler consciously-perceived metrical structure. Large’s description of the processes involved in movement synchronisation in terms of the properties of pattern-forming dynamical systems (2000, p. 560) is also consistent with the results presented here.

The analyses above may also indicate the importance of visual information in musical entrainment: it is very unlikely that Tanpura R can *hear* the periodicity of the singer’s tanpura pattern to which she seems to be entraining in this extract. It is more likely that she is entraining her pattern to a periodic *visual* rhythm (*e.g.* in the movement of the singer’s back and shoulder). The phenomenon of unintentional entrainment mediated through visual information has been demonstrated over a number of years by

Schmidt and colleagues (see *e.g.* Schmidt & O'Brien, 1997; Richardson et al, 2005), and the present study suggests that this can occur also in musical performance.

Although the present study is not designed for the control of variables one would hope for in a laboratory experiment or computer simulation, the results may provide an illustration of the power of ethnomusicological studies to help direct psychological enquiry into productive new areas in the future.

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## Table captions

Table 1. Inter-coder reliability figures for each pair of three coders. For each coder the second coding run was taken as representative. A tolerance of +/- 1 frame (0.04 seconds) was allowed.

Table 2. Intra-coder reliability figures for two coders. For each individual the two codings were made approximately 6 months apart, using the same set of instructions (see Appendix). A tolerance of +/- 1 frame (0.04 seconds) was allowed.

Table 3. Average periodicities of the three tanpura patterns (in seconds), and their variability (standard deviation).

Table 4. Summary of intervals between plucking (IOI) for all tanpura players. Figures given are i. AVE = Average, ii. SD = Standard Deviation. 1-2 indicates the interval between the striking of string 1 and string 2, and so on.

Table 5. Periodicities observable in performers' movements in the video clip (in sec) and relationships for which we have evidence of entrainment. Nb.

The average period of Tanpura L, at 2.72 sec is approximately double that of the slow beat (1.35 sec), but the there is insufficient evidence of phase stabilisation to include this in the summary table.

Table 6. Summary statistics for each pair of rhythms discussed. The first group of figures relate to the original data; the second to the complete set of data doubled and reduced modulo 360°; the third and fourth to the odd and even data points respectively (not doubled).

**Figure captions**

Fig. 1. From left: Bageshree Vaze (= Tanpura L), Veena Sahasrabuddhe (= Singer), Madhuchhanda Sanyal (= Tanpura R), Seema Shirodkar (Harmonium). Viswanath Shirodkar (tabla) is not pictured here. Video still: Mumbai, 9 April 2003.

Fig. 2. Periodicity (in secs) of tanpura patterns for three players. S = Singer (Veena Sahasrabuddhe); L = Tanpura L; R = Tanpura R.

Fig. 3. Plot of intervals between plucking (IOI) for all strings of Tanpura R (detail, 12’35”-12’55”). It is difficult, if not impossible, to identify a regular pattern at this level (but see Figure 4c).

Fig. 4a-c. Autocorrelation plots for all strings of the three tanpura patterns. The three charts plot the autocorrelation function (ACF) for lags 1-16. The strong correlations at multiples of 5 lags (for the singer and Tanpura L) and of 4 lags (for Tanpura R) indicate a degree of consistency in the rhythm of the plucking patters (the instruments have 5, 5 and 4 strings respectively).

Fig. 5a-c. Relative phase plots of tanpura patterns for the three players (using data for string one). In Figure 5a and Figure 5c data points line up diagonally (bottom left to top right), indicating a gradual drift in phase relationships that would be expected of unrelated quasi-periodic rhythms. In Figure 5b, however, the points seem to line up around (mainly just below) the 0° and 180° lines, indicating a consistent relationship between the two patterns (Tanpura R and the singer).

Fig. 6a-c. Circular plots of the distribution of the relative phase measurements illustrated in Figure 5. Figures 6 a-c correspond to Figures 5a-c respectively.

Fig. 7. The Observer plot of the beat marking gestures of the singer and harmonium player. Both singer ('soloist') and harmonium player start off with faster beats, slow down around 20 secs, and speed up again at around 32 secs. Although both lines have gaps (*i.e.* not every beat is physically marked), both are clearly marking approximately the same beat.

Fig. 8. Plot of intervals (IOI) between the beat markers of the singer (S) and harmonium player (H). This chart shows the data from Figure 7 in another format, with intervals between beats plotted against the time of occurrence

of each beat. The shift from a very consistent faster beat to a slightly less consistent slower beat, and back again, is even clearer than in Figure 7, although the alignment of the beats is much less apparent.

Fig. 9. Plot of the phase of the harmonium player's beats relative to the singer's beats. The phase difference of 60° at the start indicates that the harmonium player starts beating significantly behind the singer (this lag is noticeable on the video recording played at normal speed). The succeeding data points show how the harmonium player shifts to being ahead of the singer, then behind again, and so on. The plot does not indicate who is making the bigger adjustments, but it does indicate the operation of an ongoing error-correction mechanism typical of entrained quasi-periodic systems.

Fig. 10. Circular plot of the distribution of the relative phase measurements illustrated in Figure 9.

Fig. 11 a-c. Relative phase plots of the three tanpura patterns against the singer's beats. Figures 11b and 11c show no significant pattern, and therefore do not supply any evidence of entrainment. Figure 11a, however, shows a significant proportion of data points collecting around the 0° and

180° lines, which suggests that the two rhythms (the singer's beating and tanpura playing) are mutually entrained.

Fig. 12. Circular plots of the distribution of the relative phase measurements illustrated in Figure 11. Figures 12 a-c correspond to Figures 11 a-c respectively.

Fig. 13. The Observer plot of the tanpura plucks (string 1; lines 2, 5 and 6); beats (lines 3 and 4), singer's (soloist's) breaths (line 1) and the main mukhra or cadence (line 3, black line) (detail, c. 13'09"-13'17"). Data points occurring on four of the rows at or near the mukhra indicate that different processes (two sets of beat markers and two tanpura patterns) converge at this point. Comparison of rows 2 and 3 (the singer's tanpura and beats) indicates a 3:1 relationship between the two periodicities, with approximate phase alignment.

Fig. 14. The Observer plot of the tanpura plucks (string 1; lines 2, 5 and 6); beats (lines 3 and 4), singer's (soloist's) breaths (line 1) and the main mukhra or cadence (line 3, black line) (detail, c. 12'35"-12'52"). Comparison of rows 2 and 3 (the singer's tanpura and beats) seems to

indicate a 3:1 relationship between the two periodicities, with approximate phase alignment, from about 13 secs.

## Tables

Table 1.

| Measure | A vs B | A vs C | B vs C |
|---|---|---|---|
| Percentage of Agreements: | 93.28 | 82.09 | 89.31 |
| Cohen's Kappa: | 0.91 | 0.77 | 0.86 |

Table 2.

| **Measure** | **A vs A** | **B vs B** |
|---|---|---|
| Percentage of Agreements: | 91.67 | 97.73 |
| Cohen's Kappa: | 0.89 | 0.97 |

Table 3.

| | **Singer** | **Tanpura L** | **Tanpura R** |
|---|---|---|---|
| Ave Period (secs) | 2.03 | 2.72 | 3.00 |
| SD | 0.16 | 0.28 | 0.18 |

Table 4.

| | *1-2* | *2-3* | *3-4* | *4-5 (4-1)* | *5-1* |
|---|---|---|---|---|---|
| ***Singer*** | | | | | |
| AVE | 0.39 | 0.45 | 0.34 | 0.34 | 0.52 |
| SD | 0.10 | 0.13 | 0.04 | 0.05 | 0.07 |
| *Tanpura L* | | | | | |
| AVE | 0.71 | 0.46 | 0.41 | 0.35 | 0.79 |
| SD | 0.10 | 0.10 | 0.06 | 0.10 | 0.16 |
| *Tanpura R* | | | | | |
| AVE | 0.77 | 0.66 | 0.61 | 0.96 | |
| SD | 0.11 | 0.11 | 0.07 | 0.14 | |

Table 5.

| | | | | |
|---|---|---|---|---|
| Beat | 0.67 | | | |
| Beat | 1.35 | 1:2 | 1:3 | |
| Tanpura (singer) | 2.03 | | 2:3 | |
| Tanpura R | 3.00 | | | 2:3 |

Table 6.

| Variable | Tan L vs Tan S | Tan R vs Tan S | Tan R vs Tan L | Beat H vs Beat S | Tan S vs Beat S | Tan L vs Beat S | Tan R vs Beat S |
|---|---|---|---|---|---|---|---|
| Number of Observations | 17 | 15 | 14 | 30 | 18 | 15 | 12 |
| Mean Vector (µ) | 17.8° | 133.4° | 230.1° | 5.7° | 47.0° | 220.0° | 85.9° |
| Length of Mean Vector (r) | 0.076 | 0.057 | 0.11 | 0.694 | 0.104 | 0.251 | 0.201 |
| Standard Error of Mean | 129.6° | ***** | ***** | 8.9° | 91.5° | 57.94° | ***** |
| 95% Confidence Interval | | | | | | | |
| for µ | 123.8° | ***** | ***** | 348.2° | 227.6° | 106.5° | ***** |
| | 271.9° | ***** | ***** | 23.2° | 226.4° | 333.6° | ***** |
| Rayleigh Test (Z) | 0.097 | 0.049 | 0.169 | 14.466 | 0.195 | 0.942 | 0.487 |
| Rayleigh Test (p) | 0.91 | 0.954 | 0.849 | 1.23E-07 | 0.827 | 0.397 | 0.624 |
| ***Doubled Angles*** | | | | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Mean Vector ($\mu_2$) | 18.0° | 301.6° | 259.8° | | 333.6° | 207.8° | 304.1° |
| Length of Mean Vector ($r_2$) | 0.149 | 0.512 | 0.117 | | 0.43 | 0.147 | 0.181 |
| Standard Error of Mean | 65.5° | 19.9° | ***** | | 21.1° | ***** | ***** |
| 95% Confidence Interval for $\mu_2$ | 249.6° | 262.5° | ***** | | 292.2° | ***** | ***** |
| | 146.5° | 340.7° | ***** | | 15.0° | ***** | ***** |
| Rayleigh Test (Z) | 0.378 | 3.93 | 0.19 | | 3.321 | 0.325 | 0.393 |
| Rayleigh Test (p) | 0.691 | 0.017 | 0.832 | | 0.034 | 0.729 | 0.684 |
| ***Odd data points*** | | | | | | | |
| Number of Observations | 9 | 8 | 7 | | 9 | 8 | 6 |
| Mean Vector ($\mu$) | 66.8° | 152.9° | 244.6° | | 155.0° | 252.9° | 44.9° |
| Length of Mean Vector (r) | 0.085 | 0.633 | 0.195 | | 0.256 | 0.21 | 0.593 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Rayleigh Test (Z) | 0.065 | 3.206 | 0.266 | | 0.591 | 0.353 | 2.113 |
| Rayleigh Test (p) | 0.94 | 0.035 | 0.779 | | 0.567 | 0.715 | 0.12 |
| ***Even data points*** | | | | | | | |
| Number of Observations | 8 | 7 | 7 | | 9 | 7 | 6 |
| Mean Vector (μ) | 341.5° | 336.8° | 172.4° | | 6.7° | 198.8° | 182.5° |
| Length of Mean Vector (r) | 0.122 | 0.61 | 0.058 | | 0.377 | 0.36 | 0.392 |
| Rayleigh Test (Z) | 0.119 | 2.603 | 0.023 | | 1.278 | 0.905 | 0.92 |
| Rayleigh Test (p) | 0.894 | 0.069 | 0.979 | | 0.286 | 0.42 | 0.416 |

## Figures

Fig. 1.

Fig. 2.

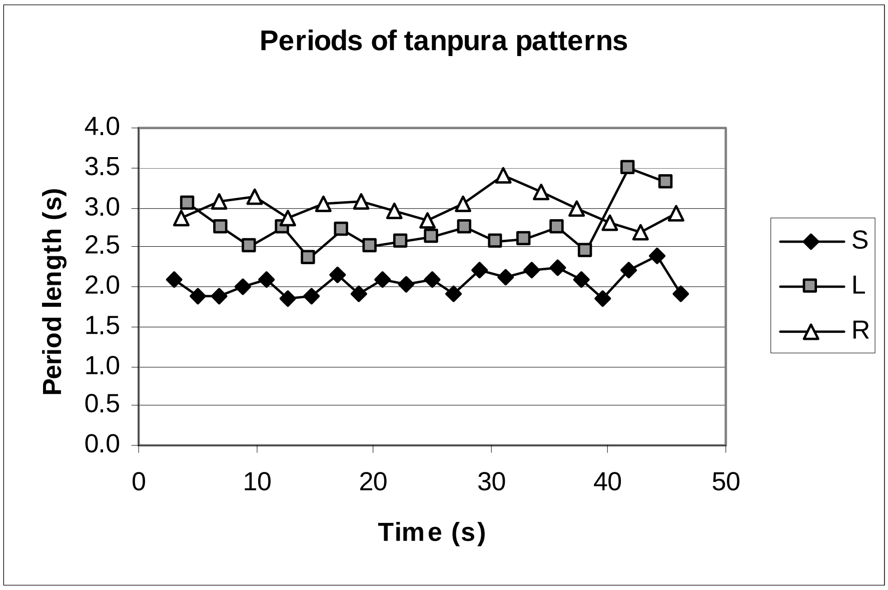

Periods of tanpura patterns
Period length (s)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
10
20
30
40
50
Time (s)
S
L
R

Fig. 3.

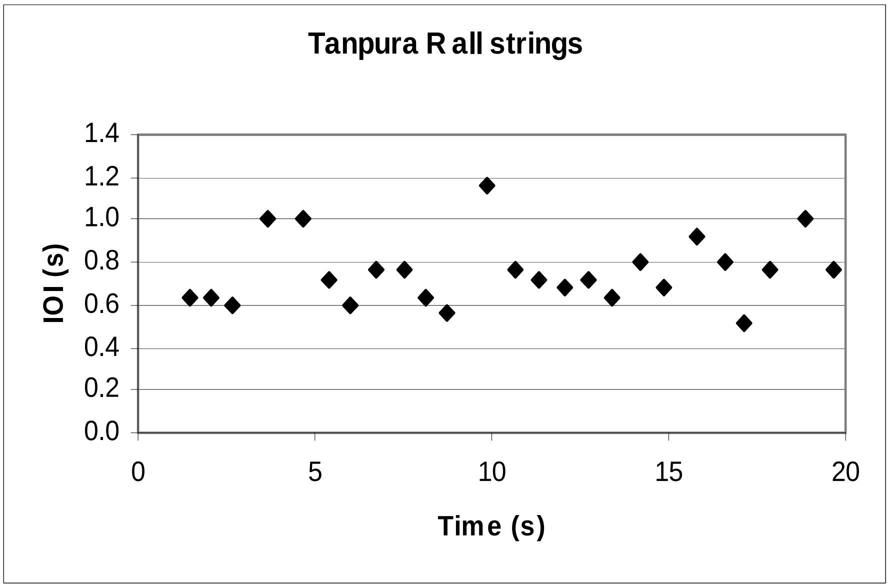

Tanpura R all strings
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
IOI (s)
0
5
10
15
20
Time (s)

Fig. 4a

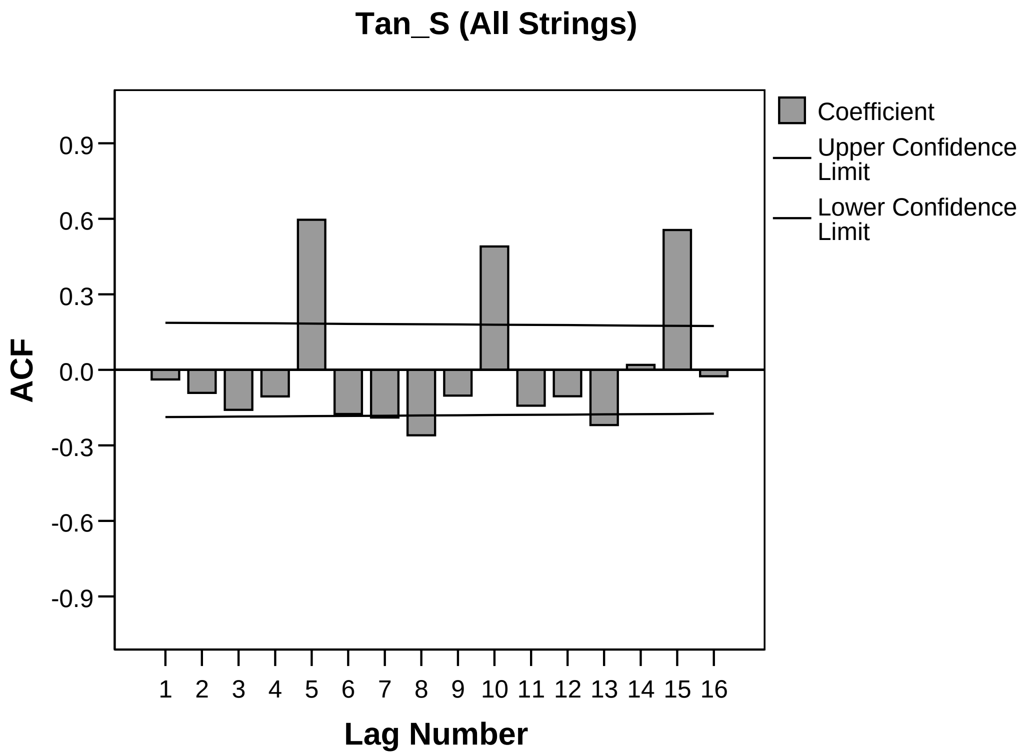

Tan_S (All Strings)
Coefficient
Upper Confidence Limit
Lower Confidence Limit
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
ACF
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Lag Number

Fig. 4b

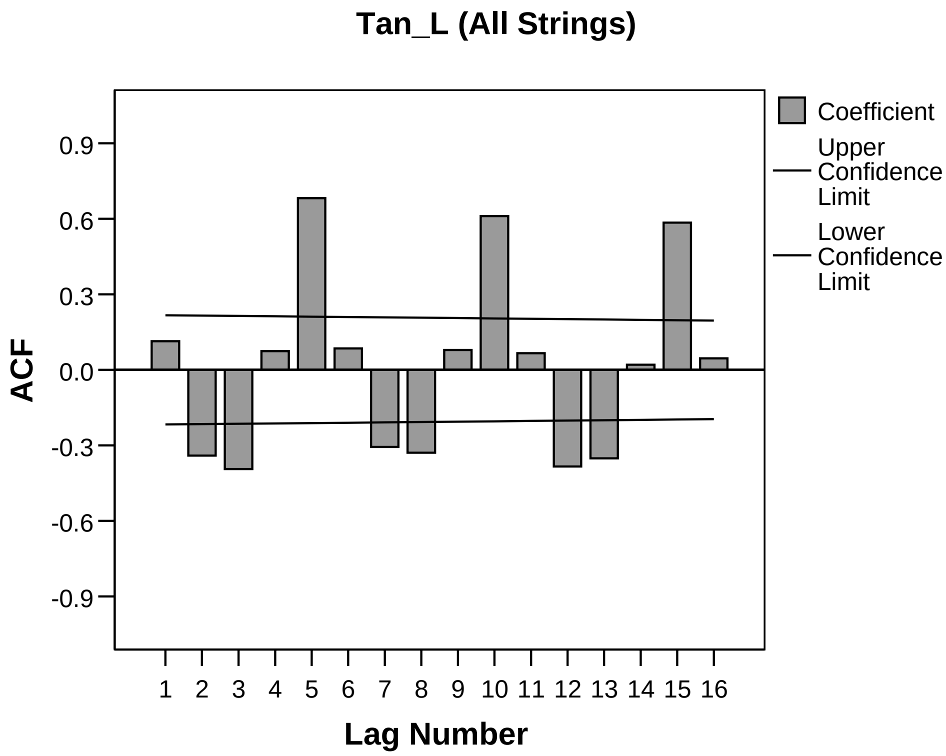
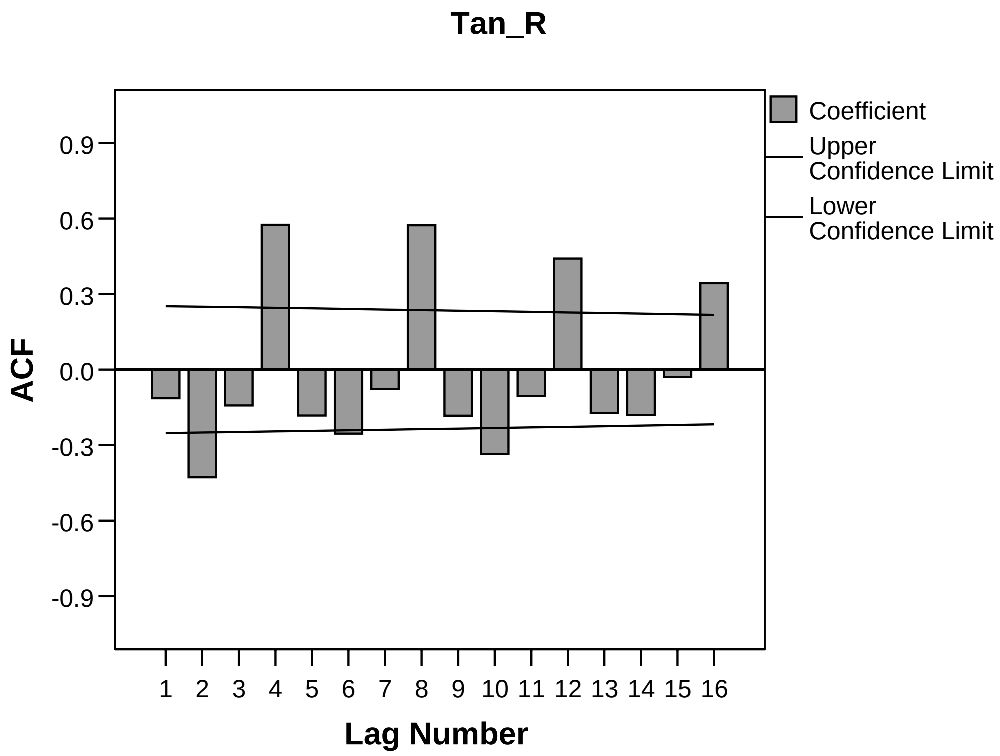
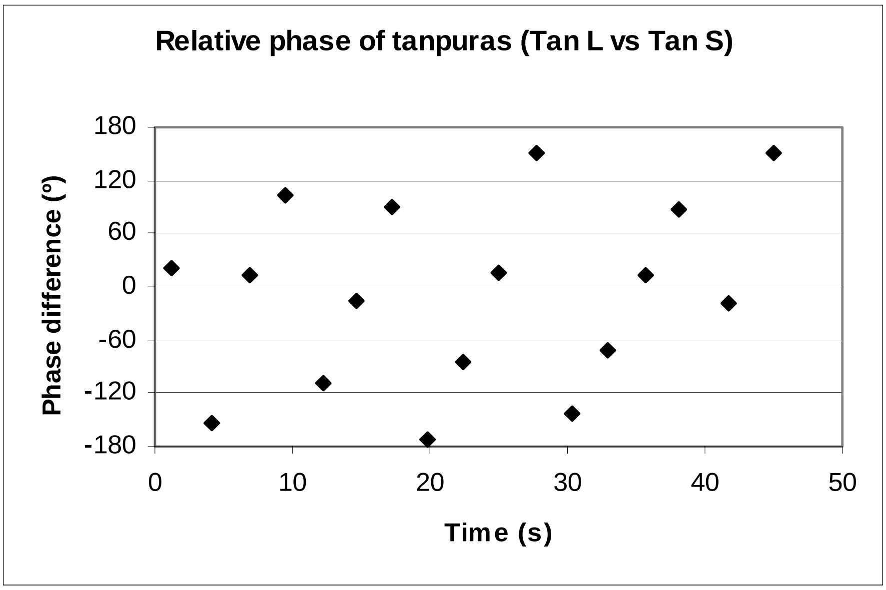

Tan_L (All Strings)
ACF
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Lag Number
Coefficient
Upper Confidence Limit
Lower Confidence Limit

Fig. 4c



Tan_R
Coefficient
Upper
Confidence Limit
Lower
Confidence Limit
0.9
0.6
0.3
0.0
-0.3
-0.6
-0.9
ACF
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
Lag Number

Fig. 5a.



Relative phase of tanpuras (Tan L vs Tan S)
Phase difference (°)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 5b.

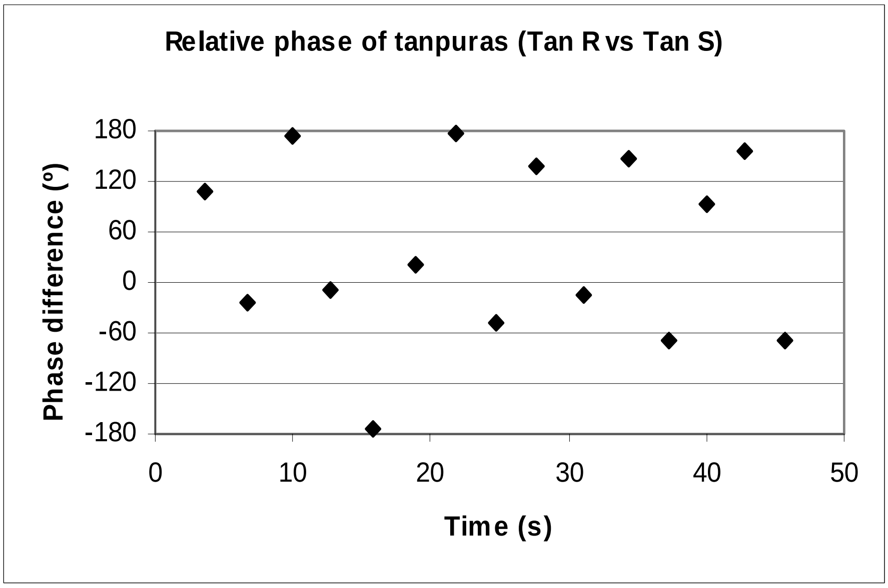

Relative phase of tanpuras (Tan R vs Tan S)
Phase difference (°)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 5c.

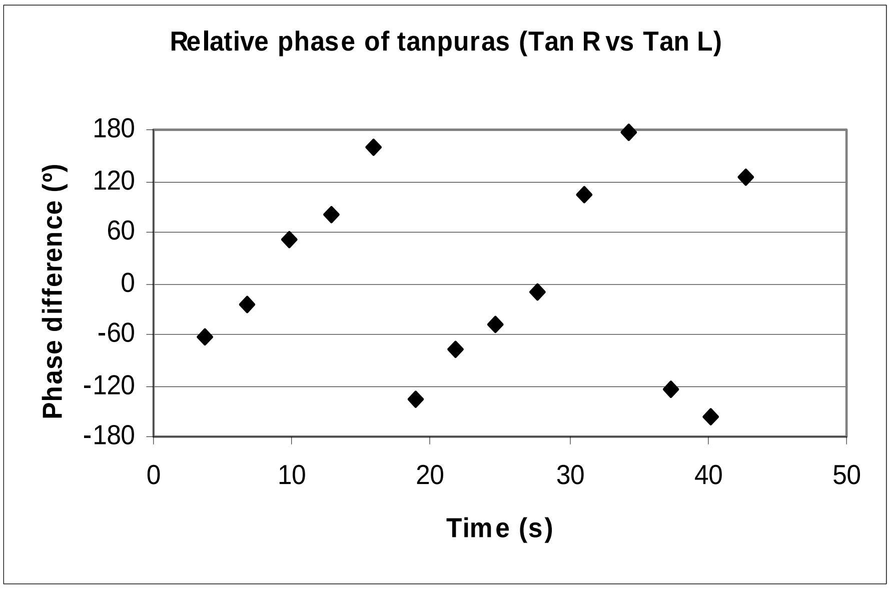

Relative phase of tanpuras (Tan R vs Tan L)
Phase difference (°)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 6a

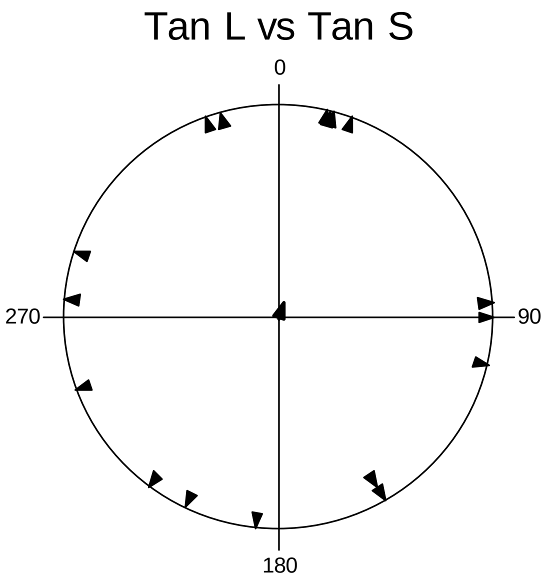


Fig. 6b

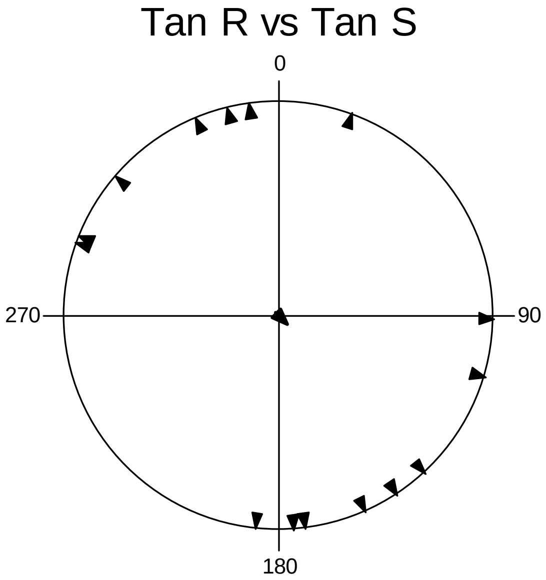


Fig. 6c

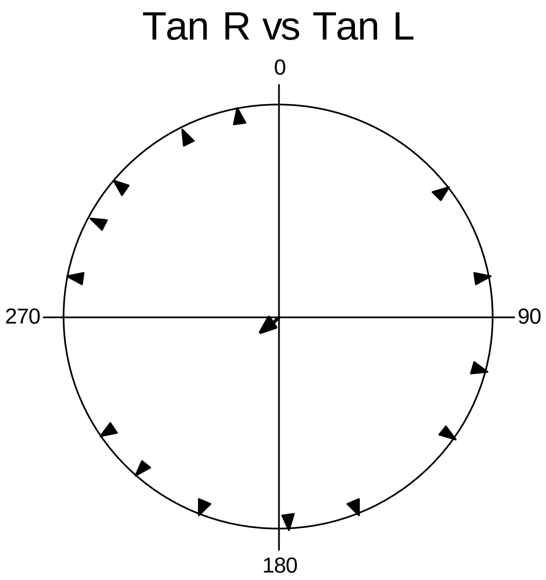


Fig. 7.

| Subject | Behavioral Class |
|---|---|
| Soloist | Beat |
| Harmonium player | Beat |

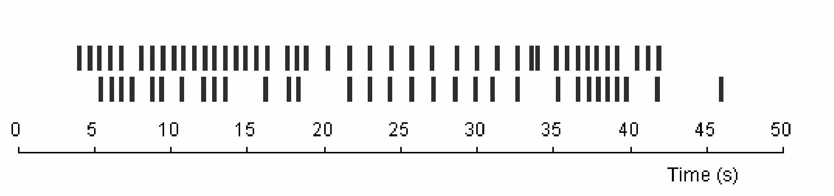


Fig. 8.

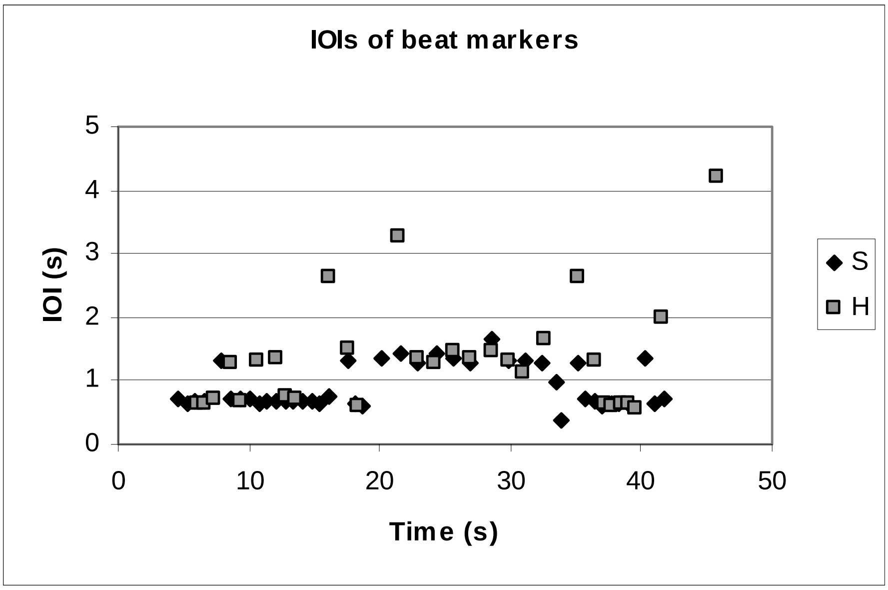
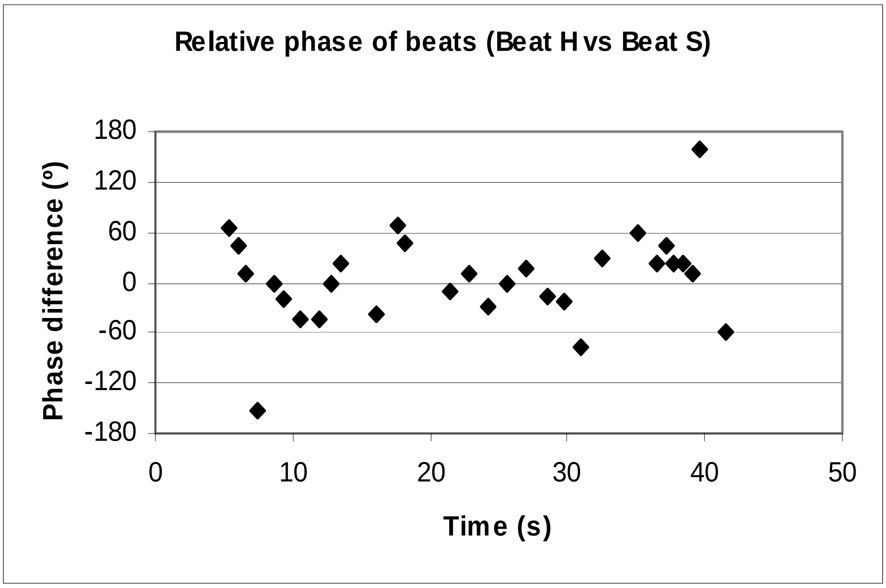


Fig. 9.



Relative phase of beats (Beat H vs Beat S)
Phase difference (º)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 10.

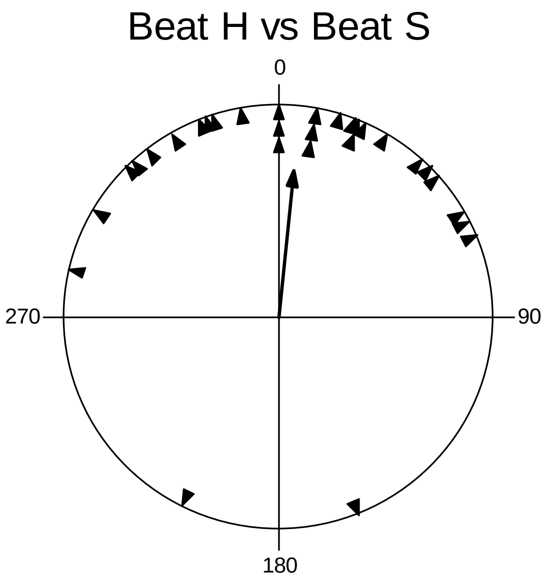
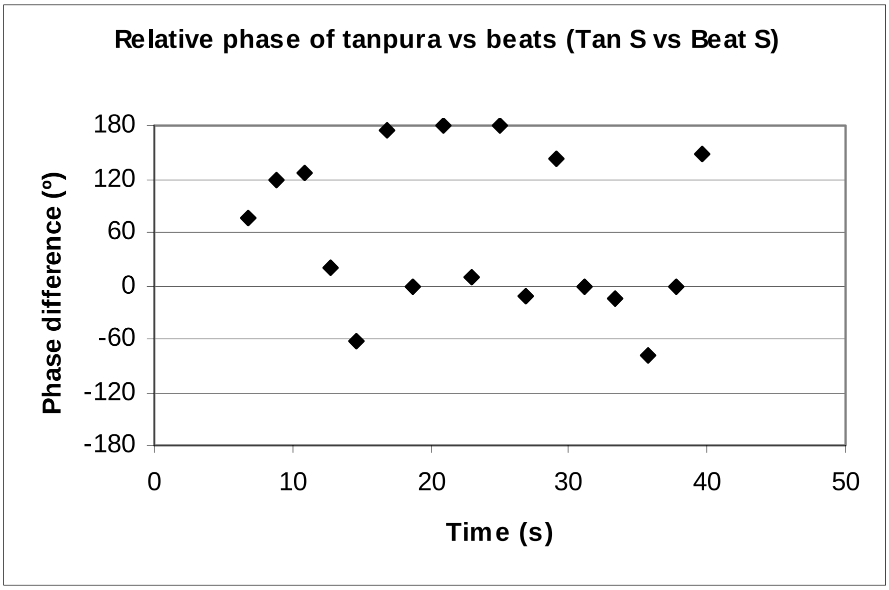
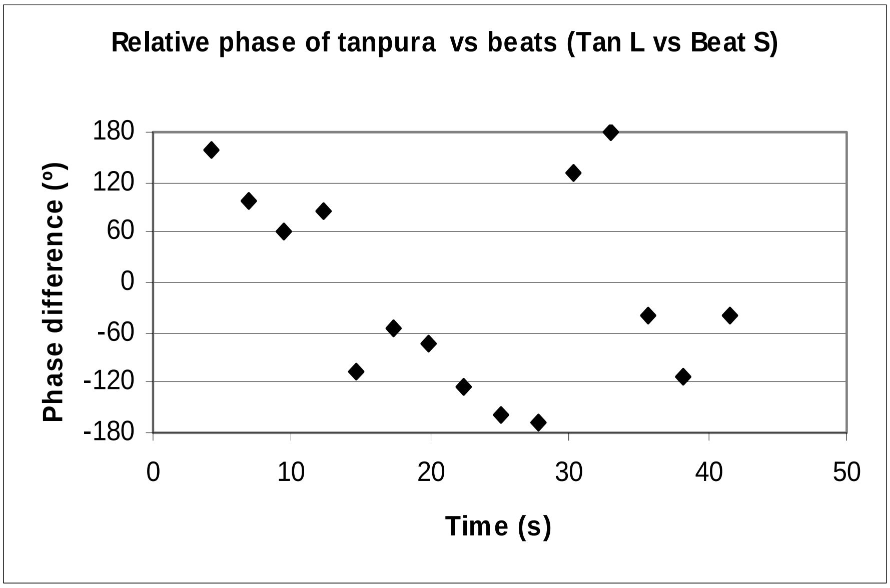


Fig. 11a.



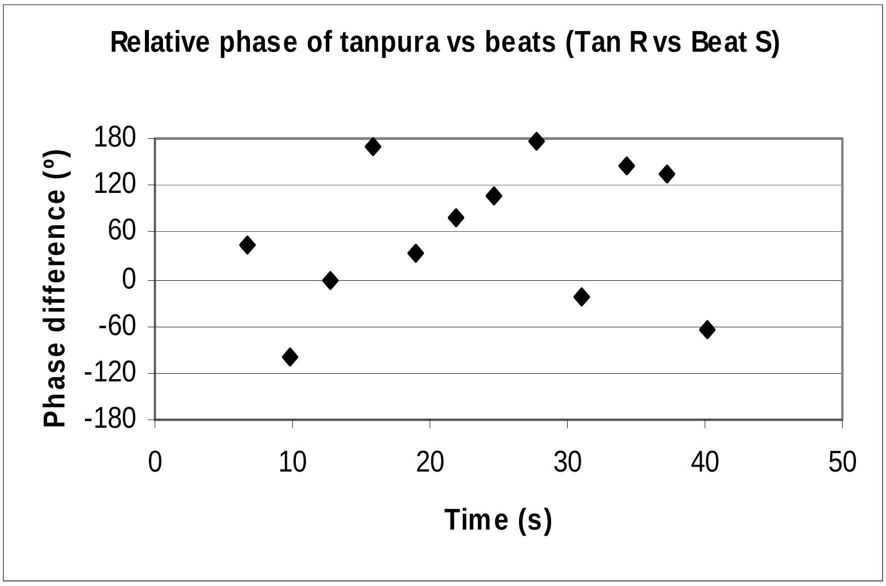
Relative phase of tanpura vs beats (Tan S vs Beat S)
Phase difference (°)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 11b.



Relative phase of tanpura vs beats (Tan L vs Beat S)
Phase difference (°)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 11c.



Relative phase of tanpura vs beats (Tan R vs Beat S)
Phase difference (º)
180
120
60
0
-60
-120
-180
0
10
20
30
40
50
Time (s)

Fig. 12a.

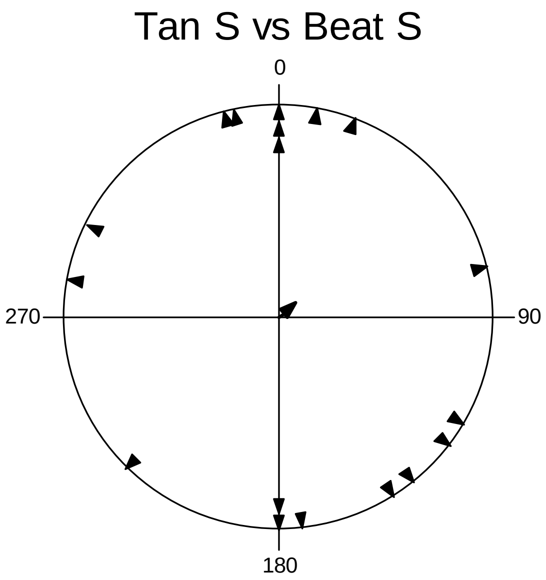


Fig. 12b.

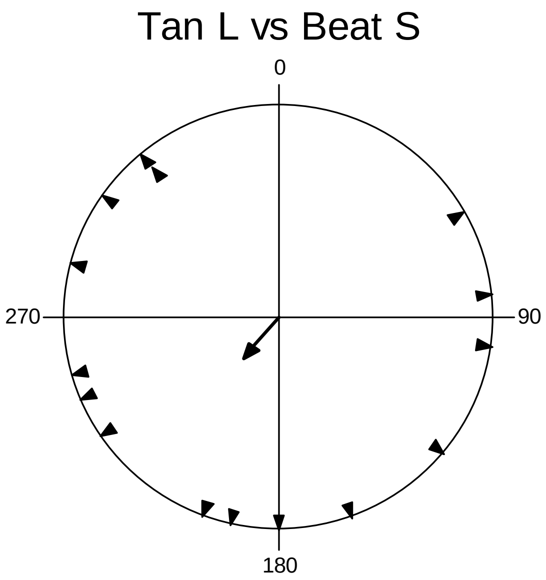


Fig. 12c.

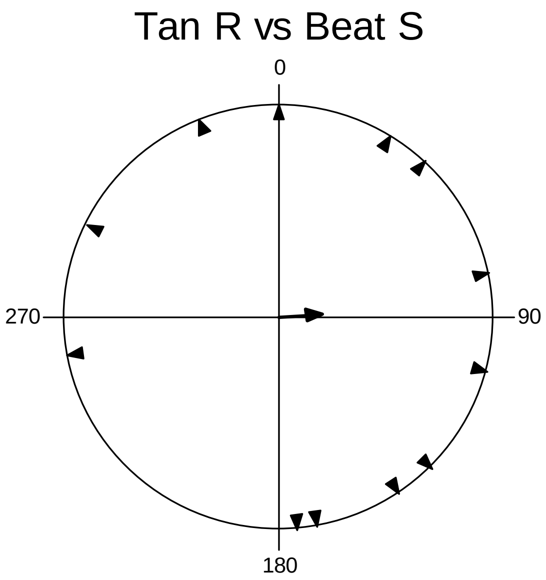


Fig. 13.

| Subject | Behavioral Class |
|---|---|
| Soloist | Singing |
| Soloist | Tanpura |
| Soloist | Beat |
| Harmonium player | Beat |
| Tanpura L | Tanpura |
| Tanpura R | Tanpura |

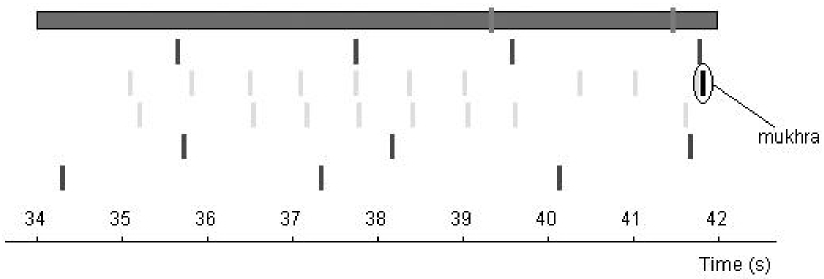
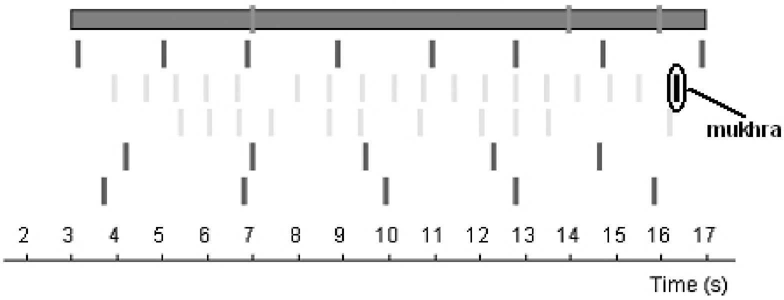


Fig. 14

| Subject | Behavioral Class |
| --- | --- |
| Soloist | Singing |
| Soloist | Tanpura |
| Soloist | **Beat** |
| Harmonium player | **Beat** |
| Tanpura L | Tanpura |
| Tanpura R | Tanpura |



**Appendix. Observer coding instructions**

[These instructions were written for a first run of coding in which only the first tanpura string was coded; a similar procedure was used later for the all-strings coding.]

**Extract**: the extract to be coded comprises the time range 12:35:00-13:20:24 from Veena Sahasrabuddhe's recital of Shree Rag, recorded in Mumbai. This follows a harmonium solo, and comprises the first section of jor/madhya alap.

**File**: [The file used is an AVI2 format video file prepared in ProCoder (with no interlacing, size 720x540 and frame rate 25 fps, for which I set the data rate at 18Mbps) from a QuickTime reference file generated in Avid Express Pro.]

**Observer project**: The latest version of the Observer project is Veena_esem_6.

**Observation files**: Should be named esem_6_mc1, esem_6_ll1 etc

**Coding procedure**:

i. From project "Veena_esem_6" load the observation module. Make sure the [correct] video file is loaded, and that you choose or assign a suitable observation file name (see above). Set the starting states as harmonium=accompaniment; soloist=silent; tabla=silent. If prompted, tick the box for "Use video time as start time for observation".

The following instructions indicate the way I coded the file. If you find better ways to do things, please make a record of them!

ii. Code Veena (soloist) as she starts singing, and then as she takes breaths. I did this at ½ speed (Alt-3) and checked it at full speed (Alt-4) - don't worry about being frame accurate on this one.

iii. Code the cadences. I did this at full speed. (By cadence I mean a clear indication in the music that a passage is completed.)

iv. Code Veena beating the pulse with her left hand. I did this advancing frame by frame, by holding down Alt-] and switching to tapping Alt-] as I got closer (Alt-[ gets you back one frame). <u>Alt-] runs the video silently: if you do this any other way then please do this coding and all of the following steps without sound, so we can be sure we are not influenced by the sound track</u>.

v. Code Veena plucking her tanpura's first string (R of screen, with her second finger). I tried to catch the frame after the pluck. I suggest marking this when you see the string move.

vi. Ditto for the tanpura player on the Left of the screen.

vii. Ditto for the tanpura player on the Right of the screen.

viii. Code the harmonium player beating time with her left index finger. Mark this as soon as her finger lands (she tends to squeeze it a little after landing, unlike Veena's hand which usually bounces straight back up).

ix. Optional: code Veena's gestures (I marked a couple of hand gestures which are not beats - go into edit mode (F4) and add a comment to say what they are).

x. Optional: code the harmonium player's and tanpura players' gestures - whatever you think could be significant, but don't waste time on this. (I marked a few nods that seemed to be beats, coding them as gestures with a comment to say they were nods.)

*MC 6 Sept 2004*

**On-line Annexe**

A streaming video clip of this extract, and details of the Observer coding configuration, can be found online at www.open.ac.uk/arts/music/mclayton.htm.

**Notes**

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[1] A more extensive literature review, taking into account studies in physics, biology, neuroscience, social and cognitive psychology and a range of musical disciplines, can be found in Clayton, Sager and Will, 2005.

[2] The video recording was taken from Clayton and Sahasrabuddhe (1998).

[3] See www.open.ac.uk/arts/music /mclayton.htm.

[4] For more discussion of this performance and Shree Rag, see Clayton, 2005. Extended discussion of the temporal organisation of this repertory will be found in Clayton, 2000.

[5] Depending on the raga and the performer's preference, other notes may be substituted or added. See also Dick (online).

[6] It is now common practice (as in this performance) for performers to also use an electronic version of the same instrument (a small rectangular box producing essentially the same sound).

[7] Bispham defines Interpersonal musical entrainment (IME) as "Interpersonal behavioural synchrony based upon the perception of pulse in acoustic signals created by human movement" (Bispham, 2005, p. 80).

[8] The data reliability figures below are based on comparisons between the codings produced by three coders in September 2004; and for two of these three coders, between runs carried out in September 2004 and March/April

2005. These figures are based on codings for the main data series analysed above (beat markers and tanpura plucks): not surprisingly, other features of the performance such as the singer's breaths, and a loosely-defined miscellaneous "gesture" category (not referred to in the results above) show greater variability than the relatively objective events on which the main part of this study is based.

[9] For a simple introduction to the autocorrelation function see Clayton, Sager and Will, 2005, pp. 72-3.

[10] The relative phase of Series B relative to Series A is calculated using the formula (B1-A1)/(A2-A1)x360. Relative phase of 0° (or 360°) indicates exact phase alignment; 180° indicates anti-phase alignment, and so on. The relative phase plots (Figures 5, 9, and 11) have been plotted from -180° to 180°, to make the distribution around 0° as clear as possible: in this case -60° is equivalent to 300°, -120° is equivalent to 240°, and so on.

[11] Fisher introduces this procedure as a method for converting axial data to vectorial data (1993, p. 37), but also applies it to the analysis of a bimodal sample of vectorial data (pp. 98-9). Batschelet applies the same method to both axial and bimodal vectorial data (1981, pp. 21ff).

[12] Excluding the two series of beat markers, which would be expected to correlate closely.

[13] This was actually the intention of the present video recording, although unfortunately the video of the audience proved unusable for this purpose.