# Observing entrainment in music performance:

# Video-based observational analysis of Indian musicians' tanpura playing and beat marking

**Martin Clayton**

**(Open University)**

Address for correspondence:

Dr Martin Clayton, Faculty of Arts, Open University, Walton Hall,

Milton Keynes, MK7 6AA, United Kingdom

Email: m.r.l.clayton@open.ac.uk

# 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 2004) as well as in other scientific fields (see e.g. Strogatz 1994, 2003).  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 attracting increasing attention 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 Jones 1999, Large 2000), although 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, for instance (see Clayton 2005b).[1]

Clayton, Sager and Will (2004) 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. 27-39). 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 (p. 26). 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) and child development (e.g. Trevarthen, 1999-200). Observational analysis techniques have moved on from the manual coding of 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, 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, 53).

Using a clip from an Indian vocal performance and a manual coding technique,[2] Moran demonstrated a relationship between the time structure of the 'global gesture phrases' (McNeill 1992, 83f) of the singer Veena Sahasrabuddhe and one of her tanpura players. 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 potenially significant results.

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 itself 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 Appendix A. 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). Examples of these plots and their interpretation are given in the case study below: for more detail see Clayton, Sager and Will 2004 (pp. 27ff). 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.[3]

# Case study

## 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 2005a).

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>

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; depending on the raga and the performer's preference, other notes may be substituted or added, but this need not concern us here).[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 not only do not intend, but 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; 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 offords 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 Appendix A, and instructions followed by each coder are reproduced as Appendix B. 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 and SPSS 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.

## 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 certainly reflect the difference in the instruments' relative size, with the singer's (smaller) instrument being played significantly faster (Table 1). It is also clear from this data that the pattern of Tanpura L shows more variation than the other two.

< Table 1>

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 about 2.5 to 3.5 seconds, that could also be described as a delay of one second before the striking of the first string: this will be examined further below (see Figure 2 at around 40 secs).

<Fig. 2. Excel chart>

**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 2) 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 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).[8]

<Table 2>

<Fig. 3. Excel duration plot>

<Fig. 4a-c. Autocorrelation plots >

## 3. Tanpura playing: correlations between players

The relative phase of the tanpuras was calculated between each pair of players (Tanpura L vs Singer, Tanpura R vs Singer, Tanpura R vs Tanpura L, 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).[9] Two of the three relative phase plots (Tanpura L vs Singer, Tanpura R vs Tanpura 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 Tanpura R vs Singer, seems to show a bimodal distribution, with points aligned just below 360° and on or just below 180° (Fig. 5b). This indicates that Tanpura R alternates between an in-phase and anti-phase relationship with respect to the Singer (the former tending actually to play slightly ahead of the latter): this could suggest that the players are mutually entrained. The alternating in-phase/ anti-phase relationship 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).

<Fig. 5. Plot of rel. phase of patterns>

## 4. Beat markers: correlation 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. 6) shows that the two musicians follow a similar pattern, starting and ending at a faster rate, and dropping to a slower rate inbetween (c. 20-32 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. 7) illustrates the same data in a different format, from which it can easily be seen that the two tapping rates fall roughly into a 2:1 ratio (the average IOIs are 0.67 and 1.35 secs respectively).

<Fig. 6. Observer plot of beats>

<Fig. 7. Excel plot of beats>

The relative phase plot (Fig. 8) 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 to say who is adjusting to whom however). This type of continuous correction process is typical of entrainment processes, and clearly indicates interaction between the two series of beat markers, and therefore a significant degree of entrainment between the two musicians.

<Fig. 8 rel phase of singer/harm beats>

## 5. Correlations between beats and tanpura playing

Figure 9 presents plots of relative phase of each tanpura pattern with respect to the singer's marking of the beat. Again, two of the plots (Tanpuras L and R against the beat) seem to indicate a continuous phase drift, whereas the third (the singer's tanpura against her own beat, Fig. 9a) seems to show a clustering of points around the 0°/360° and 180° lines.[10] Again, this indicates a degree of synchronisation between the two rhythmic processes being manifested by the same musician.

<Fig. 9a-c. Phase of tanpura players vs. singer's beats>

## 6. Correlations between tanpura playing and cadences

I noted above the curious lengethening 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. 10) 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 out of 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 this player does not display any entrainment effects with respect to the other periodic rhythms considered above, she does perform a very 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.

<Fig. 10. Observer plot of cadence detail>

## 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 follwing 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 synchronised, with string one in each case alternating in-phase and anti-phase. 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 singer's tanpura playing (average period 2.03 secs) and beating (0.67/1.35 secs) seem to be mutually entrained, alternating in- and anti-phase relationships. No such entrainmnt effect was found between the beats and either of the other tanpura patterns.

v. Alignments between data points immediately before the main cadence reveal not only the tanpura phase realignment noted above, but also the emergence of a 3:1 hierarchical relationship between the beat and the singer's tanpura pattern, which may reveal an emergent ternary metre at this point in the perfomance.

The relationhips between the various periodicites are summarised in Table 3. 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*.[11] 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. This emergent order 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 in fact  be required on the part of a tanpura player to *avoid* playing in time with the music).

<Table 3>

## Discussion

These results argue strongly for the pervasiveness of entrainment phenomena in musical performance, and offer a strong, albeit preliminary, 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 manifest in performances of Indian raga music. I also anticipate similar studies involving observational analysis of audience members, as well as performers.[12]

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 hierarchies of entrained movement patterns even in the course of producing music with a much simpler consciously-perceived metrical structure. Large also encourages researchers to take on board the complex nature of acoustical stimuli. Since it is debatable

whether, for instance, Tanpura R can *hear* the periodicity of the singer's tanpura pattern to which she seems to be entraining, we must consider the possibility that she is entraining her pattern to a periodic *visual* rhythm (e.g. in the movement of the singer's back and shoulder), a possibility that potentially raises the complexity stakes greatly. Large's description of the processes involved in movement synchronisation in terms of the properties of pattern-forming dynamical systems (2000:560) is consistent with the results presented here.

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.

## Data reliability

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.

<Table 4>

<Table 5>

All figures in Tables 4 and 5 (inter- and intra-coder reliability respectively) are based on data from the beat markers and the plucking of string one only, with a tolerance of +/- 1 frame (0.04 secs). With a tolerance of 2 frames (0.08 seconds), agreements reached 100% in virtually all cases). This profile (c. 100% of measurements reliable to within two frames, > 80% within 1 frame, > 50% on the same frame) reflects several factors inherent in the task. First, the nature of the movements themselves means that coding often involves subjective judgement (does the beat occur the moment the hand first strikes the leg, or when the palm is completely flat on the leg?). Secondly, given a frame rate of 25Hz some coded events clearly fall between frames (e.g. the hand is about to strike on one frame, and has just struck on the following frame). Thirdly, accurate coding of tanpura plucking depends on a clear image of the string concerned, and since the musicians shift position slightly over time, the clarity of this image also varies somewhat.

In brief, the data presented here are probably close to the maximum accuracy possible, working with a real-life performance recorded at a frame rate of 25Hz. Using figures from the most consistent coder – as I have done above – 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°. Although these video-based measurements are significantly less accurate than those based on audio recordings, they are sufficiently accurate to track phase relationships fluctuating as much as that between singer's and harmonium player's beats in this clip (roughly +/- 60°, see Figure 8).

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## Table captions

Table 1. Average periodicities of the three tanpura patterns (in seconds), and their variability (standard deviation).

Table 2. 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 3. 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 phase plots revealed no entrainment effect in this case.

Table 4. 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 5. 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 B). A tolerance of +/- 1 frame (0.04 seconds) was allowed.

# 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. VS = Veena Sahasrabuddhe, the singer; 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 180° and 360° lines, indicating a consistent relationship between the two patterns (Tanpura R and the singer).

Fig. 6. 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. 7. Plot of the intervals (IOI) between the beat markers of the singer and harmonium player. This chart shows the data from Figure 6 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 6, although the alignment of the beats is much less apparent.

Fig. 8. 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. 9 a-c. Relative phase plots of the three tanpura patterns against the singer's beats. Figures 10b and 10c show no significant pattern, and therefore do not supply any evidence of entrainment. Figure 9a, however, shows a significant proportion of data points collecting around the 180° and 0°/360° lines (0° and 360° are equivalent), which suggests that the two rhythms (the singer's beating and tanpura playing) are mutually entrained.

Fig. 10. 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 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.

# Tables

Table 1.

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

Table 2.

|  | *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 3.

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

Table 4.

| 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 5.

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

# Figures

Fig. 1.



Fig. 2.

Fig. 3.



**Tanpura R all strings**

Fig. 4a



**Tan_Singer_time**

Fig. 4b

**Tan_L_time**



Fig. 4c

**Tan_R_time**

Fig. 5a.



**Relative phase of tanpuras (L vs Singer)**

Fig. 5b.



**Relative phase of tanpuras (R vs Singer)**

Fig. 5c.



**Relative phase of tanpuras (R vs L)**

Fig. 6.

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



Fig. 7.



Fig. 8.

Fig. 9a.



**Relative phase of tanpura vs beat marker (Singer)**

Fig. 9b.



**Relative phase of Tanpura L vs beat marker (Singer)**

Fig. 9c.



**Relative phase of Tanpura R vs beat marker (Singer)**

Fig. 10.



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

## Appendix A. Extracts from Observer configuration

## Configuration Review - Veena_1235-1321

### Subjects

*Number of Subjects: 6*

| Subject Name | Code |
|---|---|
| Missing subject | ? |
| Soloist | s |
| Tabla player | t |
| Harmonium player | h |
| Tanpura L | l |
| Tanpura R | r |

*Element Descriptions:*

| Subject Name | Description |
|---|---|
| Missing subject | |
| Soloist | |
| Tabla player | |
| Harmonium player | |
| Tanpura L | tanpura player left of screen |
| Tanpura R | tanpura player right of screen |

### Behaviors

*Number of behavioral classes: 6*

*Behavioral Class 1: Singing*
*Type: Nominal*
*Number of Elements: 3*

| Behavior Name | Code | Type | Modifier Class 1 | Modifier Class 2 |
|---|---|---|---|---|
| Voice | v | State | (None) | (None) |
| Silent | - | State | (None) | (None) |
| Breath | ' | Event | (None) | (None) |

*Element Descriptions:*

| Behavior Name | Description |
|---|---|
| Voice | Soloist singing (including short breaths) |
| Silent | Soloist resting (apart from short breaths) |
| Breath | mark after singer stops singing |

*Behavioral Class 4: Tanpura*
*Type: Nominal*
*Number of Elements: 5*

| Behavior Name | Code | Type | Modifier Class 1 | Modifier Class 2 |
|---|---|---|---|---|
| String_1 | j | Event | (None) | (None) |
| String_2 | k | Event | (None) | (None) |
| String_3 | l | Event | (None) | (None) |
| String_4 | n | Event | (None) | (None) |
| String_5 | m | Event | (None) | (None) |

*Element Descriptions:*

| Behavior Name | Description |
|---|---|
| String_1 | plucking tanpura string 1 (right of screen) |
| String_2 | plucking tanpura string 2 |
| String_3 | plucking tanpura string 3 |
| String_4 | plucking tanpura string 4 |
| String_5 | plucking tanpura string 5 |

*Behavioral Class 5: Form*
*Type: Nominal*
*Number of Elements: 2*

| Behavior Name | Code | Type | Modifier Class 1 | Modifier Class 2 |
|---|---|---|---|---|
| Cadence | * | Event | (None) | (None) |
| Beat | b | Event | (None) | (None) |

*Element Descriptions:*

| Behavior Name | Description |
|---|---|
| Cadence | mark focal point of mukhra/tihai etc |
| Beat | mark beat with e.g. hand or finger |

*Behavioral Class 6: Gesture*
*Type: Nominal*
*Number of Elements: 1*

| Behavior Name | Code | Type | Modifier Class 1 | Modifier Class 2 |
|---|---|---|---|---|
| Gesture | g | Event | (None) | (None) |

*Element Descriptions:*

| Behavior Name | Description |
|---|---|
| Gesture | mark significant gestures with comment |

## Modifiers

*Number of modifier classes: 0*

## Channels

*Number of channels: 10*

| Channel Name |
|---|
| Harmonium player*Harmonium |
| Harmonium player*Gesture |
| Soloist*Singing |
| Soloist*Form |
| Soloist*Gesture |
| Soloist*Tanpura |
| Tabla player*Tabla |
| Tabla player*Gesture |
| Tanpura L*Tanpura |
| Tanpura R*Tanpura |

*MC Sept 2004/ March 2005*

# Appendix B. 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

*We can put the colour versions of the figures, and a streaming video clip of this extract, on our web site*

*([www.open.ac.uk/arts/experience](www.open.ac.uk/arts/experience)) and/or on the journal's website.*

# Notes

[4] For more discussion of this performance and Shree Rag, see Clayton 2005a. Will et al (in preparation) discuss tapping responses to extracts from this same performance. Extended discussion of the temporal organisation of this repertory will be found in Clayton 2000.

[5] 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.

[7] Bispham defines Interpersonal musical entrainment (IME) as "Interpersonal behavioural synchrony based upon the perception of pulse in acoustic signals created by human movement" (in Clayton, Sager and Will 2004: 44).

[8] For a simple introduction to the autocorrelation function, see Clayton, Sager and Will (2004: 40-41).

[9] 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.

[10] In fact, there may be some relationship between the singer's beats and Tanpura R, but this is not shown unequivocally on the relative phase plot.

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

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