Micro-temporal Interactions in Sitar and Tabla Duo Performance: An Analysis of a *Vilambit* Performance by Pt. Nikhil Banerjee and Zamir Ahmed Khan

Alec Cooper

THIS paper presents a micro-temporal analysis of a live, commercial sitar and tabla duo recording of *rāg Sindhu Khamāj* by Pt. Nikhil Banerjee and Zamir Ahmed Khan (Banerjee and Khan 1972). The entire performance lasts approximately 70 minutes, consisting of a relatively brief *ālāp* (un-metered introduction), followed by a *vilambit* (slow) section, a *drut* (fast) section, and a *jhālā* (very fast) section finishing with an extended question and answer passage, referred to as *sawāl jawāb* in Indian terminology. The analysis will focus exclusively on the slow *vilambit* section, which lasts approximately 34 minutes and therefore encompasses almost half of the entire performance's duration.

The term micro-timing refers to aspects of musical interaction occurring at a sub-rhythmic level, normally below the 100-millisecond threshold of rhythmic perception (London 2012). Although this level of musical performance lies largely beneath reflective awareness and agentive control, it nevertheless plays an important role in shaping performers' (and listeners') musical experience, as micro-fluctuations and asynchronies have been found to contribute toward musical expression (Clarke 1999; Collier and Collier 1996; Drake and Palmer 1993; Repp 1990; Todd 1989; Wesolowski 2016), the enactment of distinct musical roles (Doffman 2013; Rasch 1988), and pleasurable bodily sensations and reactions such as dance and groove (Iyer 2002; Keil 1994). Exploring how sitar and tabla performers interact micro-temporally can therefore offer insight regarding what several authors refer to as "co-subjective" (as opposed to "intersubjective"; see DeNora 2000; McGuiness and Overy 2011; Cooper forthcoming) aspects of shared social experience—meaning aspects of musical interaction that do not require reflective understanding of self and other as distinct intentional agents, but which can nevertheless have a profound effect on participants' shared affective states.

The goals of this research are to uncover regular patterns in these performers' micro-temporal interactions, reflect on these patterns' functional significance, and consider the extent to which they might be representative of sub-rhythmic interactions across the genre. My methodology involved extracting both performers' onset timing data (i.e., the precise moment in which their instruments are struck and the musical sound is initiated) occurring on the periodic level of "maximal pulse salience" (in this case the half-*mātrā*; see methodology section below) to the nearest millisecond to analyze their (i) tempo fluctuation, (ii) isochronization, (iii) mean asynchronization, and (iv) interpersonal entrainment. Together, these methods of analysis provide distinct yet complementary perspectives on these performers' musical actions at a micro-temporal level, for instance, by considering what are often referred to as vertical and horizontal perspectives, and by investigating their coordination in terms of synchrony, phase, and coupling (explained below). By adopting a fundamentally "relational" (Marsh et al. 2006) approach to musical analysis—that is, one in which performer's individual actions are always seen in relation to that of their co-performer(s)—this research emphasizes and reveals details of musical sociality as enacted in North Indian instrumental music (see Moran 2014; Cooper 2018).

This particular recording was appropriate for analysis for two reasons. First, the performers' skill level is considered exemplary for the genre, as Pandit Nikhil Banerjee (14 October 1931–27 January 1986) is considered by aficionados to be one of the greatest sitarists of the twentieth century. Secondly, the technical audio production features of this particular commercial recording include wide panning of sitar and tabla to almost entirely separate channels, allowing for the accurate extraction of both of the performers' onsets. It being a live performance gives the data greater ecological validity, as compared to unnatural conditions such as tracking or acoustic isolation within a studio. I focused only on the slow *vilambit* section because it best allowed for the extraction of precise and reliable onset data. This proved to be too problematic and inaccurate at higher speeds, as onsets tend to be separated from each other by only a few milliseconds, no longer producing distinct onset data.

Though research on this topic abounds in the musicological literature (as evidenced by the numerous sources mentioned above), most prior analytical work in the context of Hindustani music has tended to focus on broad-scale social, economic and historical dimensions (e.g., Clayton and Leante 2015; Kippen 1988; Neuman 1980; Widdess and Sanyal 2004), observational studies of performance pragmatics (e.g., Clayton 2000; Moran 2013a; Napier 2007; Rahaim 2012; Sorrell and Narayan 1980; Widdess 1994), or powerful and detailed analyses of video and audio excerpts (e.g., Clayton 2007; Moran 2013b; Will et al. 2005). A recent study by Clayton, Jakubowski, and Eerola (forthcoming) is the only other large-scale micro-temporal analysis of instrumental Hindustani music, in their case based on four complete *rāg* performances appearing on the North Indian Raga corpus released by the Interpersonal Entrainment in Music Performance (IEMP) project (see Clayton, Leante, and Tarsitani, 2018). While based on different musical material and relying on slightly different methods of data extraction and analysis, the findings of these two studies present both striking similarities and a few noticeable differences, suggesting what may be generic norms and personal idiosyncrasies at the level of micro-timing.

The paper begins with a brief explanation of certain Indian music concepts and patterns of formal and rhythmic interaction and a broad account of this performance's rhythmic and formal outline, both of which inform the subsequent analyses. This is followed by an explanation of the methodology used in extracting and analyzing the micro-temporal data, and the results obtained. The results for each of the different aspects of micro-temporal interaction are discussed in relation to each other, to other musical variables, and in light of existing research in this field. Lastly, the various findings are summarized to provide a detailed description of these performers' micro-temporal interactions, leading to suggestions for future lines for investigation.

A Note on Hindustani Music Theory and Performance

The following analyses require a basic understanding of sitar and tabla interactions at formal and rhythmic levels. Performances in this genre are predominantly improvised, in that there is no written score and most musical decisions are made spontaneously. However, these improvised interactions are regulated by very specific rhythmic, metric, and formal frameworks, which allow performers to anticipate and coordinate their spontaneous musical actions with great accuracy (see Clayton 2000). First of all, performers generally take turns carrying out improvised solos while the other provides a more stable accompaniment. Thus, their interactions are structured according to alternating musical roles. Second, these interactions are regulated by a metric framework called *tāl* in Indian terminology. *Tāls* are conceived as cyclic patterns of fixed length, defined primarily by their number of *mātrās*. *Mātrās* are small units of temporal measurement which in many cases are roughly equivalent to beats. However, in this paper the term beat is used to refer to a different level of metric structure, namely the half-*mātrā* level, for reasons explained in the following section. The terms beat and *mātrā* are kept distinct throughout.

The main significance of *tāl* lies in its cadential and cohesive function. Essentially, both sitar and tabla improvisations may start from any place within the cycle and may extend for any number of cycles but must typically emphasize and eventually end on the first *mātrā* of the *tāl* cycle, referred to as *sam*. While this is happening, one of the accompanist's main roles is to make the cycle clearly audible to facilitate this improvisational process and allow the audience to perceive it more clearly. The tabla player fulfills this role by playing a drum pattern called *ṭhekā*, while the sitarist does so by playing a brief, pre-composed melody called *gat*, both of which express the cycle's structure in various ways. In addition, the accompanist must adapt and respond to the soloist's ongoing improvisation, and most importantly, recognize and emphasize any cadence on *sam*. Consequently, the first *mātrā* is the point within the metric cycle when both performers tend to coordinate their actions more closely—a feature which, as the following analyses will show, is reflected in their micro-temporal interactions in various ways.

Performance Outline

As a preliminary step toward exploring micro-temporal interactions, let us begin by examining this *vilambit*'s metric structure, formal outline and rhythmic development as illustrated in Figure 1. Banerjee and Khan's interactions are underlined by a 16-*mātrā* cycle called *tīntāl*. As is commonly the case, Khan's tabla accompaniment is based on a sparsely decorated *ṭhekā,* in which the gaps in between each *mātrā* are often filled with a few additional drum strokes in order to provide greater rhythmic continuity and a clearer metrical structure, as well as in response to Banerjee's concurrent musical actions. Banerjee's accompaniment is based on a traditional *masītkhānī*-style *gat* (see Figure 2) —a popular type of slow instrumental composition characterized by a particular stroking

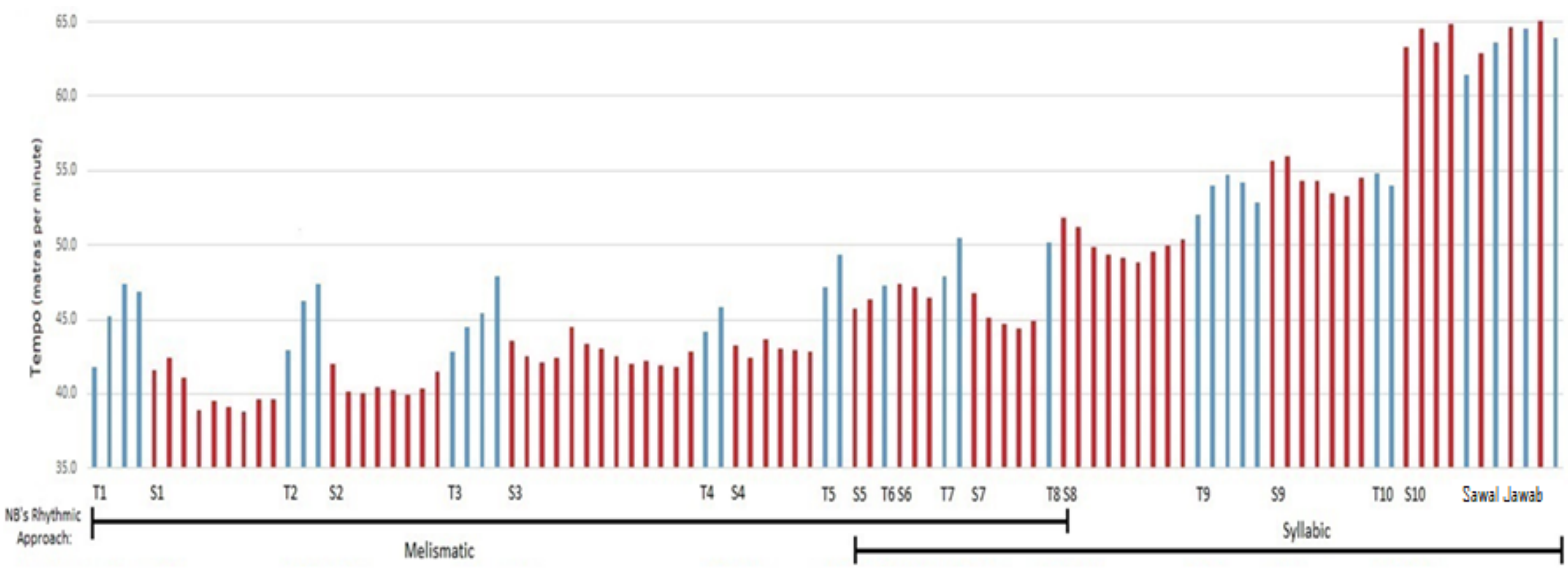

Figure 1. Outline of Pt. Nikhil Banerjee and Zamir Ahmed Khan's formal and rhythmic interactions and tempo fluctuations throughout the *vilambit* performance of *rāg Sindhu Khamāj* (Banerjee and Khan 1972).

Figure 2. *Masītkhānī gat* in *rāg Sindhu Khamāj*, as performed by Pt. Nikhil Banerjee (Banerjee and Khan 1972). Transcribed by author.

pattern and a *mukṛā* (i.e., melodic section preceding the first *mātrā* and often used as a cadential phrase) starting on the twelfth *mātrā.*

The average tempo for the entire *vilambit* is 50 *mātrās* per minute, making this a "slow" section regardless of the speed (i.e., rhythmic density) in which both performers play at certain moments. Each bar in the chart represents one complete *tāl* cycle. The height of each bar describes each cycle's average tempo in terms of *mātrās* per minute. This was calculated by measuring the duration of each cycle and dividing this figure by the number of *mātrās* per cycle (in this case 16). Blue bars represent cycles consisting of tabla solos and red ones consist of sitar solos. Sitar and tabla solos are labeled according to their sequential order within the performance: for example, T1 and S1 respectively mean first tabla solo and first sitar solo.

The rationale in drawing these specific boundaries between sitar and tabla solos was based on the following two premises. First, in order for a passage to qualify as a distinct solo it should be at least one cycle long. Second, since solos may begin from any place in the cycle but must typically come to an end on the first *mātrā*, the decision was made to identify and distinguish sitar and tabla solos based on their endings rather than their beginnings. In other words, the beginning of each new solo was determined by the place in time when the preceding solo came to an end, regardless of whether it took that performer several beats to commence his improvisation. Specifically, there are two instances within Banerjee's third and fourth solo during which he plays the *gat* for one cycle while Khan momentarily departs from the accompanying *ṭhekā*. These two moments are rather ambiguous as to whether they constitute sitar or tabla solos. However, following the aforementioned premises, the decision was ultimately made that due to their brevity and lack of impetus on Khan's part they essentially consisted of "fills" or "breaks" within Banerjee's more prolonged sitar solo.

As the plot shows, this *vilambit* performance consists of ten sitar and ten tabla solos, plus a closing passage in which Banerjee and Khan take turns carrying out brief, one cycle long solos for a total of seven cycles. As usual, sitar solos are consistently longer than tabla solos, and consequently encompass a predominant portion of the entire *vilambit* (73% to be precise). The final section is different in that every solo is short and of equal duration. Although the term *sawāl jawāb* (which literally means question and answer in Hindi) is normally used to refer to passages in which the tabla player imitates the sitarist over the course of several cycles, and although what Khan plays here is not meant to be an imitation of what Banerjee played before him, I nevertheless decided to label this section *sawāl jawāb* because the ultimate effect is very similar, and because it is a convenient way of distinguishing this section from the more expansive and personal solos which precede it. It is however worth clarifying that while real *sawāl jawāb* sections are normally performed with musicians taking turns playing by themselves (i.e., without accompaniment), in this "*sawāl jawāb*-like" case both performers continue to provide accompaniment while the other plays his brief, one-cycle solo.

The plot also indicates Banerjee's predominant form of rhythmic development during his sitar solos, based on Clayton's (2000) distinction between melismatic and syllabic approaches to improvisation. The main difference between these two rhythmic approaches is that the latter displays a stricter relationship between surface rhythm and underlining metric structure. In contrast, melismatic passages give the impression of a looser rhythmic/metric relationship through sparser rhythmic textures, syncopation, and as we shall see shortly, by higher levels of micro-temporal asynchrony. Melismatic sitar passages are also often characterized by the profusion of a specific technique called *mīnd,* in which several notes are made to sound with a single stroke by pulling the string laterally.

This distinction is made for analytical purposes, since in practice musicians may often combine melismatic and syllabic rhythms within the same solo, as Banerjee does in this recording. However, it also seems clear that Banerjee's initial solos display a strong melismatic, *ālāp*-like character whereas his latter solos are faster, denser and more rhythmically regular (i.e., on the grid). While the transition from a predominantly melismatic rhythm to a predominantly syllabic one is gradual and not entirely linear, it appears to happen primarily between S5 and S7, which is why I labelled this passage as both melismatic and syllabic. Such broad categorization of Banerjee's surface rhythm lacks certain nuance, but it will prove both useful and insightful as we explore how micro-temporal interactions vary according to the evolving rhythmic character displayed across Banerjee's sitar solos.

It should also be clarified that while the surface rhythm in Banerjee's sitar solos changes from melismatic to syllabic, tabla solos are always predominantly syllabic, as the instrument does not have the same capabilities of playing in a melismatic manner. Therefore, when the entire opening section (T1 to T5) is labelled melismatic, this term is only meant to describe the rhythmic character of the sitar solos within this portion of the performance. While this labeling may result in some confusion, my justification is that not only do Banerjee's sitar solos encompass a predominant part of the performance's duration, but more importantly, they also tend play a greater role in directing the performance's overall formal development (defined by long-term processes of temporal intensification and melodic expansion). By this I certainly do not mean to undermine Khan's role in carrying this performance forward, but simply argue that the internal structure of this particular *vilambit* performance can be best delineated by reference to Banerjee's overall rhythmic development from beginning to end.

METHOD OF ONSET EXTRACTION

The first step in this analysis involved extracting onset timing data for both performers to the nearest millisecond. The data collection focused exclusively on onsets occurring on whichever periodic level fell closest to the 600 ms range of "maximal pulse salience" (Fraisse 1964), following the rationale that periodic events falling within this range have particular effects: they tend to ground metrical attending and elicit the strongest bodily reactions (Clarke 1999; Iyer 2002; London 2012, 2006; Toivianen, Luck, and Thompson 2010). Since this performance is in a slow tempo averaging 50 *mātrās* per minute (meaning that the mean duration of one *mātrā* was approximately 1.2 seconds), the periodic level which comes closest to the range of maximal pulse salience is at the half *mātrā*. Consequently, only timing data for onsets occurring on this periodic level were extracted, excluding faster rhythmical events from consideration. As a result of this methodological decision, the term beat will be used throughout the remainder of this paper specifically in reference to the half-*mātrā* metric level.

The process of deciding whether rhythmic events were or were not meant to occur on this metric level was based on the following procedure. Firstly, since both sitar and tabla players play fairly fixed patterns when acting as accompanists (i.e., the melodic *gat* and rhythmic *ṭhekā*), their rhythmic events represent for the most part unambiguous expressions of metric structure, meaning that the metric level at which they occur is normally easy to determine. Once the accompanists' relevant onsets had been identified, then the soloists' quasi-simultaneous onsets were normally considered to be those which occurred closest to those of the accompanist, as long as there was no strong aesthetic and/or contextual reason for thinking that another, more distant onset may have actually been meant to occur on the half-*mātrā* metric level. If the soloist's nearest quasi-simultaneous onset occurred more than 100 ms (the lowermost threshold of rhythmic perception; London 2012) away from that of the accompanist, then it was normally considered not to have occurred on the same metric level, unless once more there was a strong reason for thinking otherwise.

The second deliberate constraint of the data collection concerns the focus on certain kinds of sitar string onsets. The sitar is composed of three sets of strings (the *baj/jora/khaṛaj*, *chikarī*, and *taraf* strings), each of which is played in a different way and serves a different musical function. Melody is played primarily on the *baj* string, and less so on the lower-sounding *jora* and *khaṛaj* strings. The *chikarī* strings are used either for rhythmic accompaniment or as sonic background, while the *taraf* strings are mainly meant to resonate without actually being struck. Considering that these various sets of strings may manifest different degrees of synchronization and entrainment with the tabla player, and that the melodic line is normally both more "meaningful" and perceptually salient, the decision was made to focus exclusively on melodic onsets. Thus, sitar data pertains solely to onsets belonging to the melodic *baj*, *jora*, and *khaṛaj* strings, excluding onsets from the rhythmic *chikarī* strings and resonating *taraf* strings.

While it could be argued that the *chikarī* strings play a significant role in regulating performers' interpersonal entrainment—for instance, by signaling the sitarist's intention to change tempo—this function is by no means consistent, as these set of strings can also be used as a way of filling the sonic space during melodic gaps. Data were therefore deemed to be more consistent, as well as more manageable in their extraction (see below), by focusing exclusively on melodic onsets. Moreover, because this analysis focuses exclusively on *onset* timings—that is, the moment in which the instrument is struck and the sound initiated—whenever Banerjee played several notes on his sitar through the use of special techniques such as *mīnd* (i.e., lateral pulling) or *krintan* (i.e., left-hand hammering), only the initial note—the one with the strongest attack—was taken into consideration.

Another important methodological decision was to identify both instruments' onsets according to the moment in which their amplitude started to rise. This decision was based on observation of both instruments' waveform which, due to their plucked/stroked means of producing sound, shared similar characteristics, consisting of a sharp rise in amplitude, which was sustained and gradually decreased over the course of several milliseconds. Due to this recurrent shape, the initiation of sound normally presented the most unambiguous moment in which to consistently identify both musicians' onsets throughout the performance.

Having made these methodological decisions, the method by which to extract the precise timing for the thousands of onsets occurring at a half-*mātrā* level would ideally have been to use software to automate this process. However, the trial data collected in this manner were found to be unreliable, likely as a consequence of the sound's complexity. Since all data points required re-checking for accuracy, onsets were extracted manually with Audacity 2.0.6 (2014), a task which involved extracting a total of about 3,000 onsets. In order to guarantee further accuracy, timing data for onsets which timing could not be determined within a 5 ms margin of error were disregarded.

Methods of Data Analysis

These timing series were used to analyze performers' micro-temporal interactions according to their isochronization, mean asynchronization, and interpersonal entrainment. The measurements were calculated for the entire *vilambit*, for specific formal sections determined by Banerjee's predominant rhythmic approach (see Figure 1), and by the performers' alternating role as soloist and accompanist, and for each of the 16 *mātrās* of the underlying metric cycle (*tāl*).

The term isochronization refers to the timing of consecutive tones meant to be of equal duration (see Rasch 1988). An isochronization analysis explores how each musician's separate periodic behavior departs and fluctuates from a perfectly metronomic beat. Whereas both asynchronization and entrainment describe inherently relational aspects of musical interaction, isochronization describes each performer's micro-temporal behavior separately. Therefore, this method of analysis provides valuable information as to how each performer's individual actions relate to variables such as alternating role, surface rhythm, and form, and how this in turn affects their synchronization and interpersonal entrainment.

The isochronization analysis was carried out according to Rasch's (1988, 75) methodology, which defines isochronization (or more accurately, a-isochronization) as "the standard deviation of tone durations meant to be equal." The analysis involved measuring the distance between each performer's consecutive onsets (normally referred to as inter-onset interval or IOI) throughout the entire data set and then calculating their standard deviation for every solo. Higher isochronization values describe less regular, more a-isochronous, periodic behavior (the isochronization value for a metronome or click-track would be 0 ms).

The term "mean asynchronization" refers to the average micro-temporal distance between onsets that are meant to happen quasi-simultaneously. This analysis provides an absolute measure of the performers' average level of synchronization with each other throughout various sections of the performance. This analysis involved (1) calculating the onset time difference for pairs of quasi-simultaneous onsets throughout the data set; (2) turning all onset time difference values into positive figures; and (3) calculating mean values for each solo.

The approach adopted in this paper differs from Rasch's (1988, 72) methodology, which defines asynchronization as the *standard deviation* of *signed* onset time differences, rather than the *mean value* of *unsigned* onset time differences as presented here (meaning that all negative values were turned positive, as explained above). The reason for analyzing asynchronization in this manner is that the results obtained according to Rasch's methodology are very similar to the length of mean vector values obtained through the interpersonal entrainment analysis described below, whereas analyzing asynchronization based on mean unsigned values presents an entirely distinct perspective on this aspect of performers' micro-temporal interactions. Unlike both Rasch's methodology and the interpersonal entrainment methodology, this approach describes how closely together performers' onsets sound on average—that is, their phenomenal (i.e., sonic) "togetherness"—regardless of who plays ahead and who plays behind, or whether they tend to entrain their micro-temporal interactions at a relative phase other than perfect synchrony.[1]

The term entrainment "describes a process whereby two rhythmic processes [in this case the actions of two separate musicians] interact with each other in such a way that they adjust towards and eventually 'lock in' to a common phase and/or periodicity" (Clayton, Sager, and Will 2005, 2). Crucially, entrainment is not about synchrony, but rather about the extent and manner in which performers couple their actions around a certain phase relationship. For example, when one musician plays on the downbeat and the other on the upbeat, their actions are entirely unsynchronized and yet entrained. On a subtler level, performers may sound slightly out of sync but keep the same micro-temporal relationship throughout long segments of a performance, thus displaying high levels of micro-temporal coordination regardless of their slight lack of synchronization.

An interpersonal entrainment analysis describes performers' micro-temporal coordination in terms of relative phase and strength of coupling (see Clayton 2012; Clayton, Sager, and Will 2005). Relative phase (also referred to as a mean vector (μ) or phase attractor) indicates performers' predominant micro-temporal position in relation to each other (i.e., who is playing ahead and who is behind, and by how much). Phase relationship is normally measured in degrees and in relation to the underlying beat, with 0° meaning perfect phase (or synchrony) and 180° meaning perfect anti-phase (e.g., having one performer play on the downbeat and the other on the upbeat). This is meant to facilitate comparative analysis across a wide range of tempos (Doffman 2013). Strength of coupling

1. For an analysis of Banerjee and Khan's asynchronization according to Rasch's methodology, see Cooper (2018).

(also referred to as length of mean vector (r)) describes the consistency with which a certain phase relationship is maintained. This is normally measured on a scale from 0 (meaning no coupling) to 1 (meaning perfect coupling).

The first step in this analysis involved calculating onset time differences between pairs of quasi-simultaneous onsets, as described for the asynchronization analysis above. However, in contrast to the asynchronization analysis, onset time difference values in this case were kept *signed* to maintain a description of the performers' micro-temporal position in relation to each other. Since onset time differences were calculated by subtracting tabla onset values from sitar values, positive figures indicate that Banerjee's onsets occur ahead of Khan's, while negative values indicate the opposite. Onset time difference values were then turned into relative phase values by contextualizing them in relation to the underlying beat and turning them into degrees, where

Relative Phase = 360 / (Mean Beat Duration Per Cycle / Onset Time Difference).

What this means is that performers' onset time differences were measured in relation to the mean beat duration of the cycle within which they occurred, thereby taking into account changes in tempo throughout the performance.

Mean beat durations per cycle were calculated according to the accompanist's mean inter-onset interval at the half-*mātrā* level, meaning that the tabla player's IOI data were used to calculate mean beat duration for sitar solos, and conversely sitar data were used to calculate mean beat durations for tabla solos. The rationale for this approach is that the accompanist is normally in charge of providing a relatively stable metric framework for the soloist. Consequently, the accompanist tends to play in a more isochronous fashion (as confirmed by the results from the isochronization analysis, see Tables 1 and 2 below), making his actions a more accurate indication of beat duration. These relative phase series were then used to calculate mean vector (μ) and length of mean vector (r) values for every solo using Oriana 4.01 (2015) software.

Lastly, these data were also used to analyze mean *mātrā* durations, as well as mean asynchronization, relative phase, and length of mean vector values for each of the 16 *mātrās* across the *vilambit* and its various formal cross-sections. Mean *mātrā* durations were calculated by averaging both performers' inter-onset intervals across onsets occurring on the *mātrā*. This method is different from the one used for calculating mean beat durations as described above, in that it combines both performers' onsets and considers inter-onset intervals at a higher metric level.

RESULTS

Table 1 presents the results for the isochronization, mean asynchronization, and interpersonal entrainment analyses for each separate solo, including a description of Banerjee's predominant rhythmic approach (melismatic or syllabic; see Figure 1 above) and the number of cycles in each solo. Recall that higher isochronization values describe a looser, more irregular periodic behavior (i.e., higher a-isochronization) and that negative relative phase values describe Khan playing ahead of Banerjee.

	T1	S1	T2	S2	T3	S3	T4	S4	T5
Surface Rhythm	Melismatic								
Number of Cycles	4	9	3	8	4	13	2	6	2
Sitar Isochronization (ms)	50	54	36	71	36	57	26	46	24
Tabla Isochronization (ms)	50	55	45	38	74	41	35	42	35
M. Asynchronization (ms)	42	48	52	49	48	33	33	41	51
Mean Vector (μ)	-20.9°	-9.3°	-26.8°	-8.8°	-20.8°	-3.3°	-15.0°	-5.6°	-14.3°
Length of Mean Vector (r)	0.937	0.888	0.908	0.868	0.913	0.91	0.951	0.85	0.866

	S5	T6	S6	T7	S7	T8
Surface Rhythm	Melismatic/Syllabic					
Number of Cycles	2	1	3	2	5	1
Sitar Isochronization (ms)	35	16	26	26	31	21
Tabla Isochronization (ms)	34	37	30	34	32	57
M. Asynchronization (ms)	27	49	25	39	26	38
Mean Vector (μ)	-0.1°	-23.8°	-3.9°	-21.2°	-4.3°	-18.7°
Length of Mean Vector (r)	0.944	0.921	0.954	0.947	0.946	0.944

	S8	T9	S9	T10	S10
Surface Rhythm	Syllabic				
Number of Cycles	9	5	7	2	4
Sitar Isochronization (ms)	37	25	26	23	16
Tabla Isochronization (ms)	32	32	26	34	27
M. Asynchronization (ms)	30	48	21	32	17
Mean Vector (μ)	-11.8°	-30.1°	-1.8°	-16.5°	-4.9°
Length of Mean Vector (r)	0.947	0.951	0.956	0.94	0.949

	SJ T1	SJ S1	SJ T2	SJ S2	SJ T3	SJ S3	SJ T4
Surface Rhythm	Syllabic (*sawāl jawāb*)						
Number of Cycles	1	1	1	1	1	1	1
Sitar Isochronization (ms)	24	36	31	14	21	15	20
Tabla Isochronization (ms)	33	27	32	27	30	28	21
M. Asynchronization (ms)	48	20	44	17	46	18	44
Mean Vector (μ)	-35.7°	-3.2°	-31.3°	11.6°	-32.5°	9.7°	-27.3°
Length of Mean Vector (r)	0.919	0.943	0.918	0.976	0.902	0.976	0.905

Table 1. Rhythmic, formal, and micro-temporal data for each sitar and tabla solo throughout the *vilambit* performance.

These data sets were also used to calculate performers' micro-temporal interactions across broader segments of the performance, including (1) the entire *vilambit*; (2) all sitar and all tabla solos combined; and (3) the four formal sections defined by Banerjee's predominant surface rhythm during sitar solos. These various results are presented in Table 2 below.

Mean asynchronization, mean vector, and length of mean vector values presented in Table 2 were calculated by using every single data point in the set. This was not possible for isochronization due to problems related to this performance's acceleration (almost

	Vilambit	T Solos	S Solos	Mel	Mel/Syl	Syl	SJ
Mean S Isochronization (ms)	40	27	36	51	28	28	23
Mean T Isochronization (ms)	39	39	34	46	34	30	28
Mean Asynchronization (ms)	36	45	32	44	30	28	34
Mean Vector (μ)	-11.2°	-23.3°	-5°	-11.8°	-8.6°	-10.8°	-14.8°
Length of Mean Vector (r)	0.909	0.921	0.919	0.89	0.937	0.936	0.88

Table 2. Sitar and tabla mean isochronization, asynchronization, and entrainment values across the *vilambit.*

doubling in speed from beginning to end). As already noted, Rasch (1988, 75) defines isochronization as "the standard deviation of tone durations meant to be equal." In the case of this particular performance, the tone durations at the start are by no means meant to be equal to those towards the end (as illustrated in Figure 1), which is why Rasch's methodology is inappropriate. Specifically, if one were to calculate the standard deviation of tone durations throughout the entire *vilambit* (or major sections of it), one would obtain a deceptively large value due to the wide range of IOI durations caused by the underlying acceleration.

This problem was therefore avoided by using the isochronization values of each separate solo as presented in Table 1 to calculate various *mean isochronization* values according to the afore-mentioned formal categories. Moreover, in order to account for the varied duration of each solo (particularly with regards to sitar solos being generally longer than tabla solos), mean isochronization values were calculated by multiplying each separate isochronization value by the number of cycles in that solo, adding these values together, and then dividing them by the total number of cycles in that entire section. For instance, Banerjee's mean isochronization value during the syllabic portion of the performance (S8 to S10) was calculated in the following manner:

$$\text{Mean Isochronization} = \frac{(37 \times 9) + (25 \times 5) + (26 \times 7) + (23 \times 2) + (16 \times 4)}{(9 + 5 + 7 + 2 + 4)} = 28.$$

Though this approach is not entirely consistent with Rasch's methodology (which is why the distinct term *mean isochronization* is used), it has the advantage of allowing comparison of each musician's isochronization over longer stretches of the performance.

Lastly, Tables 3, 4, and 5 present mean *mātrā* durations, mean asynchronization, relative phase, and length of mean vector values for each separate *mātrā* of the underlying metric cycle (*tīntāl*). Note that in this case the syllabic and *sawāl jawāb* sections had to be analyzed together as a single section. This is due to the *sawāl jawāb* section being only seven cycles long, meaning that there could have only been—at most—seven onset time difference values per *mātrā* upon which to make these calculations (in many cases even less). This was considered insufficient, which is why this section was merged with the preceding syllabic one (which shares a similar rhythmic character). Also note that a few cells are empty (e.g., *mātrās* 7 and 8 for tabla solos). This is likewise due to insufficient data for those particular cross-sections of the performance.

	Vilambit			
Mātrā	Mean *Mātrā* Dur. (sec)	Mean Async. (ms)	Mean Vector (μ)	Length M. Vector (r)
1	1.312	50	-26.9°	0.919
2	1.289	51	-11.0°	0.837
3	1.275	37	-5.0°	0.910
4	1.261	30	-10.5°	0.930
5	1.289	45	-24.2°	0.933
6	1.272	36	-12.7°	0.920
7	1.275	29	-0.5°	0.876
8	1.276	34	-8.3°	0.912
9	1.279	37	-17.2°	0.921
10	1.262	40	-17.7°	0.907
11	1.264	46	-15.7°	0.844
12	1.262	33	-12.7°	0.920
13	1.258	38	-13.9°	0.905
14	1.287	38	-16.9°	0.932
15	1.269	36	-13.5°	0.915
16	1.276	43	-3.6°	0.847

Table 3. Mean *mātrā* durations, mean asynchronization, relative phase, and length of mean vector values for each *mātrā* across the *vilambit.*

	Sitar Solos				Tabla Solos			
Mātrā	Mean *Mātrā* Dur. (sec)	Mean Async. (ms)	Mean Vector (μ)	Length M. Vector (r)	Mean *Mātrā* Dur. (sec)	Mean Async. (ms)	Mean Vector (μ)	Length M. Vector (r)
1	1.330	47	-23.7°	0.901	1.261	57	-33.1°	0.932
2	1.310	52	-4.8°	0.818	1.229	51	-19.1°	0.862
3	1.299	33	0.6°	0.913	1.210	47	-13.3°	0.920
4	1.284	28	-3.0°	0.925	1.195	35	-20.9°	0.961
5	1.312	42	-18.0°	0.942	1.223	53	-33.3°	0.939
6	1.300	32	-0.1°	0.954	1.186	43	-27.4°	0.938
7	1.298	30	1.2°	0.880	1.196	-	-	-
8	1.302	37	-8.1°	0.909	1.189	-	-	-
9	1.298	31	-5.1°	0.964	1.224	51	-35.7°	0.938
10	1.291	32	-4.4°	0.968	1.182	53	-40.7°	0.922
11	1.288	47	-8.5°	0.894	1.199	45	-27.3°	0.903
12	1.287	30	-4.6°	0.950	1.193	38	-22.8°	0.913
13	1.282	36	-10.5°	0.918	1.194	42	-19.5°	0.893
14	1.316	36	-13.4°	0.937	1.208	41	-23.6°	0.929
15	1.298	41	-9.9°	0.904	1.186	25	-20.5°	0.949
16	1.309	51	1.7°	0.800	1.179	25	-14.2°	0.967

Table 4. Mean *mātrā* durations, mean asynchronization, relative phase, and length of mean vector values for each *mātrā* for all sitar and all tabla solos combined.

	Melismatic				Melismatic/Syllabic				Syllabic + SJ			
Mātrā	Mean *Mātrā* Dur. (sec)	M. Async. (ms)	Mean Vector (μ)	Length M. Vector (r)	Mean *Mātrā* Dur. (sec)	Mean Async. (ms)	Mean Vector (μ)	Length M. Vector (r)	Mean *Mātrā* Dur. (sec)	Mean Async. (ms)	Mean Vector (μ)	Length M. Vector (r)
1	1.443	62	-30.6°	0.901	1.338	57	-32.2°	0.923	1.109	32	-20.2°	0.949
2	1.418	66	-8.5°	0.783	1.288	30	9.8°	0.964	1.100	42	-24.2°	0.903
3	1.397	40	-4.5°	0.903	1.291	25	4.1°	0.958	1.086	39	-11.5°	0.906
4	1.401	33	-9.2°	0.912	1.251	19	-6.2°	0.981	1.058	30	-14.0°	0.938
5	1.422	46	-22.9°	0.928	1.299	39	-12.2°	0.916	1.086	46	-30.6°	0.962
6	1.411	31	-6.8°	0.950	1.294	34	-15.1°	0.961	1.075	43	-23.3°	0.876
7	1.420	43	7.5°	0.762	1.298	-	-	-	1.062	23	-8.6°	0.961
8	1.423	50	-10.7°	0.871	1.283	-	-	-	1.067	17	-1.7°	0.961
9	1.414	45	-20.7°	0.922	1.280	33	-10.8°	0.926	1.076	29	-16.1°	0.924
10	1.390	51	-20.6°	0.884	1.275	26	-5.8°	0.941	1.065	28	-16.6°	0.936
11	1.396	65	-20.6°	0.846	1.275	42	-19.6°	0.922	1.067	28	-9.4°	0.926
12	1.393	38	-10.8°	0.906	1.276	25	-9.9°	0.956	1.064	30	-15.5°	0.926
13	1.390	49	-19.1°	0.908	1.258	46	-11.4°	0.853	1.064	25	-9.2°	0.928
14	1.410	43	-15.6°	0.921	1.307	27	-14.3°	0.976	1.094	35	-20.7°	0.927
15	1.397	46	-17.1°	0.894	1.268	22	-4.9°	0.957	1.088	29	-12.5°	0.931
16	1.405	-	-	-	1.284	-	-	-	1.090	27	-3.2°	0.922

Table 5. Mean *mātrā* durations, mean asynchronization, relative phase, and length of mean vector values for each *mātrā* across melismatic, melismatic/syllabic, and syllabic + *sawāl jawāb* sections.

Discussion 1: Tempo Fluctuation

The following discussion considers Banerjee and Khan's micro-fluctuations in tempo from two distinct perspectives: first, as mean values for each separate and consecutive cycle (as presented in Figure 1), and second, as mean values for each of the 16 *mātrās* composing the underlying *tāl* (as presented in Tables 3, 4, and 5). The first account provides a linear perspective on their tempo fluctuations throughout the course of performance, while the second provides a cyclical perspective in relation to metric framework.

As illustrated in Figure 1 above, this *vilambit* undergoes a process of temporal intensification typical of Hindustani performance on at least two levels. First, there is a gradual increase in tempo, with a sudden increase at S10 and some interesting local fluctuations discussed below. Second, this process of acceleration is accompanied by a gradual transition in Banerjee's surface rhythm from a sparser melismatic texture to a denser syllabic one, which happens together with a change in the sitar's timbre (from single-string *Da* strokes providing a clean and rather delicate sound, to double-string *Da Ra* strokes, which create a louder and more forceful sound).

However, this process is by no means rigid. Although there is a clear trend toward acceleration, there are nevertheless continuous fluctuations in tempo including several instances of deceleration. More importantly, these tempo fluctuations are not random, as they show consistent and what appear to be functional patterns, in that they seem to be consistently correlated to and supportive of other aspects of musical interaction. These patterns include, on the one hand, a tendency for tabla solos to accelerate consistently from beginning to end (every tabla solo except T9 and T10 follow this pattern), and, on the other hand, a tendency for sitar solos to begin with a significant drop in tempo compared to the preceding tabla solo (every sitar solo except S8, S9, and S10 does so), decelerating even further during first few cycles, and then accelerating back to a tempo roughly the same as the initial one. Although not every sitar and tabla solo follows this shape, most of them do. Moreover, these patterns are only disrupted towards the end of the *vilambit*, once Banerjee starts playing in a faster, syllabic manner, indicating that they may be more representative of sitar and tabla performers' micro-fluctuations in tempo while playing at slower speeds with sparser rhythmic textures.

The consistency with which these patterns in tempo fluctuation are maintained throughout the opening stages suggests a functional relationship between tempo fluctuation, musical expression, surface rhythm, and the alternation of musical roles. In general, tabla solos tend to display a linear increase in rhythmic density from beginning to end, in this case underlined by a concomitant increase in tempo. These two temporal processes are likely to complement each other in generating musical expression in the form of a build-up towards a climactic point at the very end of the solo. Although sitar solos are also generally structured in a similar rhythmic manner, they tend to display greater flexibility in this regard, as rhythmic density may vary more widely throughout a solo. This could explain why tempo tends to fluctuate in a less linear manner during Banerjee's sitar solos compared to Khan's. Furthermore, the fact that tabla solos display an immediate increase in tempo compared to the preceding sitar solos, whereas sitar solos tend to begin at a slower tempo than the preceding tabla solo, suggests that both performers use these small changes in tempo to create a contrast with the other instrument's solo and at the same time match their distinct expressive aims. Alternatively, such changes in tempo may emerge unintentionally and unconsciously as a result of their instruments' distinct sounds and expressive possibilities.

The results obtained from the mean *mātrā* duration analysis reveal even more nuanced as well as more consistent patterns in both performers' tempo fluctuations. As Figure 3 shows, the duration of the first *mātrā* is significantly longer than all the others, meaning that Banerjee and Khan tend to slow down upon reaching this cadential point in the cycle. Notably, this pattern does not seem to be affected either by performers' alternating roles nor formal development. This can be confirmed by Figures 4 and 5, which show the same pattern with regard to the first *mātrās*' comparatively longer duration regardless of these formal variables. In addition, Figure 4 also reveals how, overall, tabla solos are significantly faster than sitar solos, probably as a result of the tempo fluctuations discussed earlier.

Closer scrutiny of the data illustrated in these three figures shows finer yet equally consistent patterns in *mātrā* duration. Not only is *sam* (*mātrā* 1) consistently longer than all other *mātrās,* but in addition there is a gradual acceleration from *mātrā* 1 to 4, apparent throughout these various cross-sections of the performance. Also, all of these Figures reveal a deceleration on *mātrā* 14, which is when the tabla's bass drum (i.e., *bayan*) returns after the four preceding *khālī* (i.e., empty) *mātrās* while playing the accompanying *theka*.

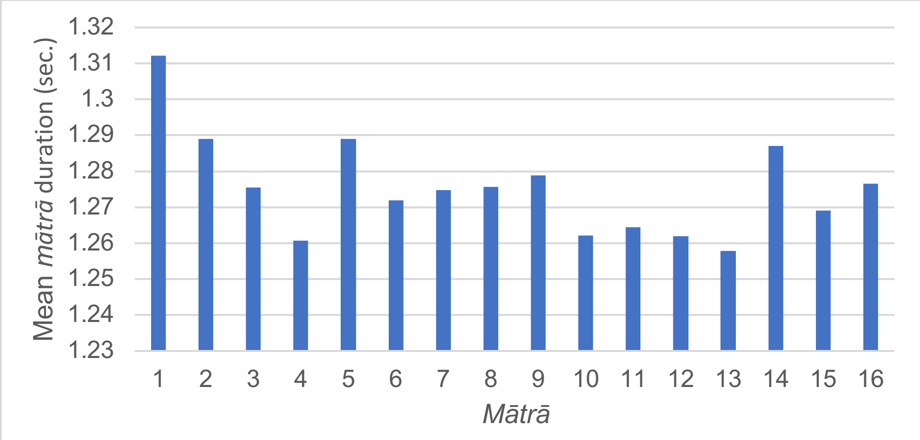

Figure 3. Mean *mātrā* duration values across the entire *vilambit*.

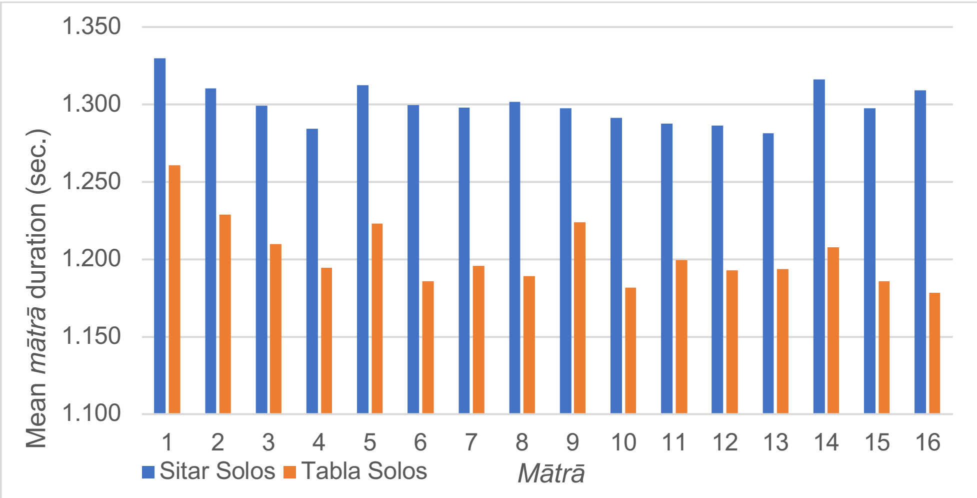

Figure 4. Mean *mātrā* duration values according to sitar and tabla solos.

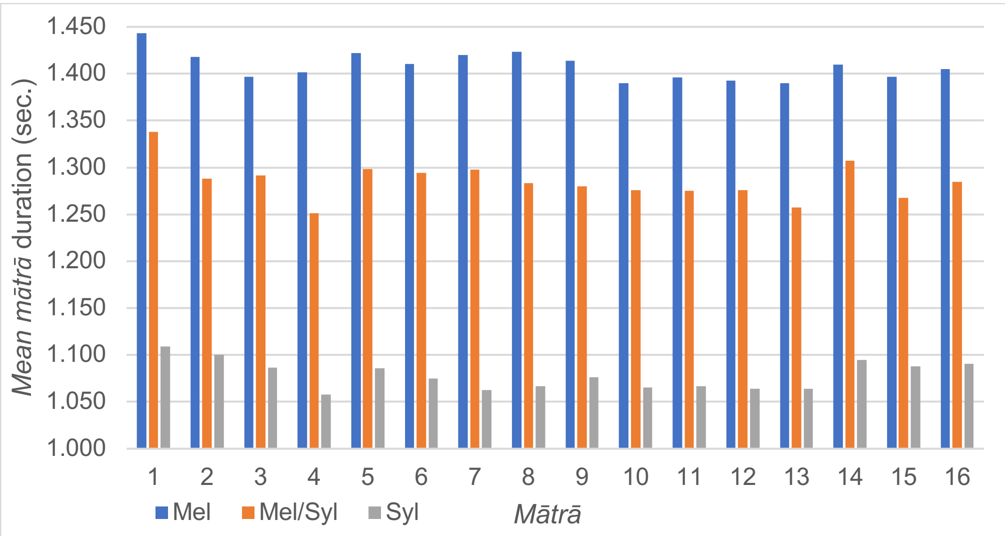

Figure 5. Mean *mātrā* duration values for melismatic, melismatic/syllabic, and syllabic + *sawāl jawāb* sections.

Given these patterns' consistency, it is quite likely that they help punctuate expressive and dynamic aspects relating to how both performers' musical actions are framed by *tāl*.

The tendency for micro-fluctuations in tempo to underlie and support musical expression is widely reported in the literature (e.g., Collier and Collier 1994; Repp 1990). This analysis demonstrates some ways in which this functional relationship operates in sitar and tabla performance. In addition, these findings also imply that Khan had greater input into tempo fluctuations—particularly during his tabla solos—than is normally attributed to tabla players. In other words, contrary to the notion that, as the main artist, the sitarist is solely responsible for determining tempo, this analysis shows that smaller yet significant tempo fluctuations may emerge from more egalitarian interactions between musicians. This consideration will prove relevant for interpreting the results obtained from the following micro-temporal analyses.

Discussion 2: Isochronization

Moving on to a discussion of both performers' isochronization, let us start by noting that Banerjee and Khan have almost identical mean values for the entire *vilambit* (40 and 39 ms), indicating that, overall, they both played with the same degree of micro-temporal irregularity. In addition, they both display higher isochronization values during the opening melismatic section of the performance compared to the following syllabic sections. This is almost certainly due both to Banerjee's melismatic rhythm, which is defined precisely by a looser relationship between rhythm and underlying metric framework, and by the slower speed and sparser rhythmic texture, which also allow both performers to play in a looser micro-temporal manner.

However, some important differences between performers become apparent by considering their isochronization values according to their alternating musical roles. The results show that, when soloing, their performance displays higher mean isochronization values compared to their performance as accompanists (36 ms as soloist and 27 ms as accompanist for Banerjee; 39 ms as soloist and 34 ms as accompanist for Khan). In other words, both performers play in a less isochronous (more irregular) manner when carrying out their own solos. This pattern is generally consistent throughout the *vilambit*. As can be seen in Figures 6 and 7, both performers display comparatively higher isochronization values during their own solos and lower isochronization values when acting as accompanists. This can easily be confirmed by noting that most sitar solo data points in Figure 6 (describing Khan's isochronization) tend to be located below tabla solo data points, while the opposite is true in Figure 7 (describing Banerjee's isochronization). Moreover, it is worth noting that in Banerjee's case (Figure 7) this pattern is firmly established from the beginning and only disrupted towards the end, from S10 onwards, while in Khan's case (Figure 6) this pattern becomes established from S5 and then maintained throughout until his very last solo in SJ T4. This points to further relationships between isochronization, musical role, and formal development, discussed below.

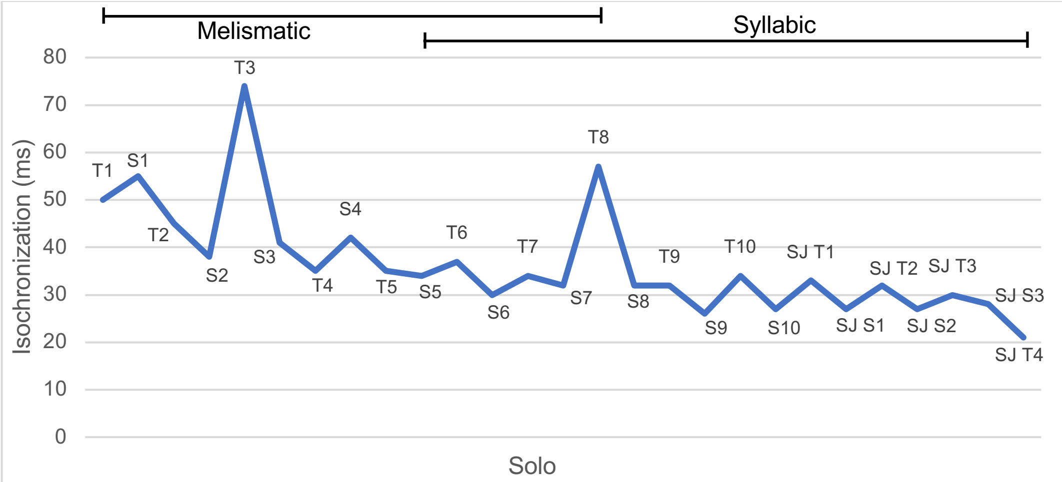

Figure 6. Tabla isochronization values for each solo throughout the *vilambit* performance.

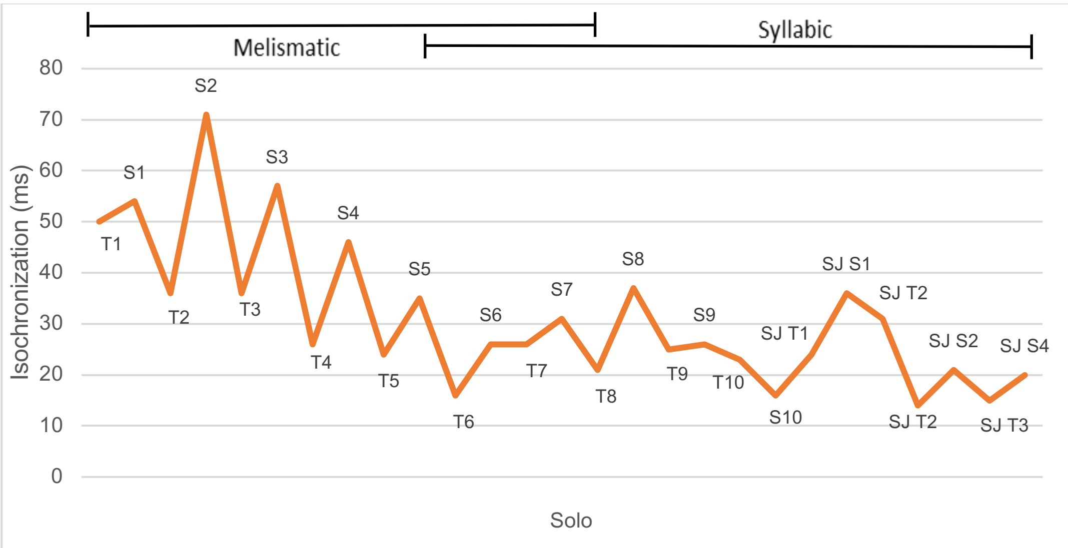

Figure 7. Sitar isochronization values for each solo throughout the *vilambit* performance.

Performers adopting less metronomic (i.e., more a-isochronous) behavior as soloists is consistent with wider empirical accounts postulating a relationship between micro-temporal irregularities on the one hand, and both musical expression and perceptual salience on the other (see Repp 1990; Iyer 2002; Keil 1994; Wesolowski 2016). Based on Gibson's (1975) theory that perceptual systems are coded to detect change (i.e., variance) in the environment, a-isochronization is argued to contribute toward making performers' sounds more noticeable and expressive. As Iyer (2002, 403) puts it, "expressive micro-timing represents a departure from regularity, so it is likely to be noticed in relief against the more regular background." Since the soloist acts as the main agent of musical expression, it makes sense that both performers adopt a more irregular micro-temporal behavior during their own solos. This also means that—as we noticed with regard to tempo fluctuations in the previous discussion—performers are enacting their alternating roles as soloists and accompanists through specific and consistent micro-temporal means.

Scrutiny of the data also reveals more complex functional relationships between isochronization, musical role, and formal development. First, the contrast in mean isochronization according to role is generally more pronounced during tabla solos (27 ms for Banerjee and 39 ms for Khan) than during sitar solos (36 ms for Banerjee and 34 ms for Khan). These values show that while both performers display similar levels of isochronization when acting as soloists, Banerjee's accompaniment during tabla solos is significantly more regular than Khan's during sitar solos. One possible interpretation of this finding is that tabla players tend to be more responsive and interactive as accompanists during sitar solos, which therefore makes them play in a less isochronous manner. Sitarists, on the other hand, are less prone to interact as overtly during tabla solos, which may therefore result in a more regular, isochronous accompaniment.

Second, while Banerjee displays higher mean isochronization values than Khan during the opening melismatic section (51 vs. 46 ms), this relationship is then inverted, with Khan displaying higher mean isochronization during the remaining syllabic sections (28 vs. 34 ms; 28 vs. 30 ms; and 23 vs. 28 ms). This pattern can be observed in Figure 8, which displays both performers' combined isochronization values throughout the *vilambit*, and shows that Khan's isochronization values (blue) become predominantly higher than Banerjee's from T5 onwards. While Banerjee's comparatively higher isochronization values during the opening melismatic section and subsequent decrease in the latter parts of the performance may be naturally accounted for by his transition towards syllabic rhythm, the fact that Khan's isochronization vales become predominantly higher than Banerjee's is harder to explain. This may, perhaps, be simply indicative of Khan's more irregular style of playing; or alternatively, of Banerjee's micro-temporal regularity once he starts playing syllabically. It may also be related to Khan's comparatively less isochronous approach towards accompaniment discussed above. Although wider comparative data would be required to make either assertion, this finding will nevertheless prove useful in trying to account for their asynchronization and entrainment data in the following sections.

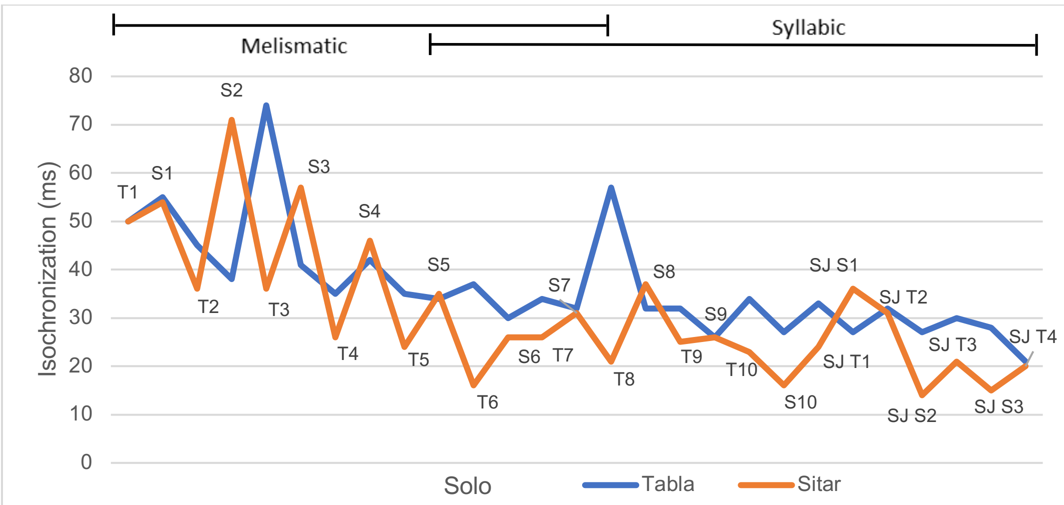

Figure 8. Combined sitar and tabla isochronization values for each solo throughout the *vilambit* performance.

In summary, the results of this portion of the analysis reveal a complex relationship between these performers' isochronization, their alternating roles as soloist and accompanist, and Banerjee's varying rhythmic approach across the *vilambit*. The most important and consistent finding is that whoever acts as soloist tends to display a more irregular micro-temporal behavior (i.e., higher isochronization values), which—it is argued—contributes both toward musical expression and perceptual salience. In addition, this contrast in isochronization according to role was found to be more pronounced for Banerjee than for Khan. This is probably related to tabla players' more interactive approach towards accompaniment, which causes them to play in a less isochronous manner compared to sitarists.

Discussion 3: Mean Asynchronization

Focusing now on Banerjee and Khan's asynchronization, it is worth noting first of all that the mean value for the entire *vilambit* performance (36 ms) falls within the norm of what is normally reported in the literature (Clayton, Jakubowski, and Eerola forthcoming; Iyer 2002; Rasch 1988; Pecenka and Keller 2011; Ragert, Schroeder, and Keller 2013). Unsurprisingly, mean asynchronization values display a clear relation to formal development, as the performers are noticeably less synchronized during the opening melismatic section (44 ms) compared to the following syllabic ones (30, 28, and 34 ms). These results mirror and are clearly related to similar patterns in isochronization discussed above: Banerjee and Khan's less isochronous playing up to S5, which I argue is caused by the slower tempo and Banerjee's melismatic surface rhythm, in turn causes their actions to be less synchronized, contributing further to matters of expression and perceptual salience. A similar relationship between higher tempo and rhythmic density on the one hand, and more precise synchronization on the other, was also found in Clayton, Jakubowski, and Eerola's (forthcoming) study.

What is perhaps more surprising is that tabla solos were found to be less synchronized than sitar solos during most of this performance, a finding which is also consistent with Clayton, Jakubowski, and Eerola's work. Not only is the mean asynchronization value across tabla solos (45 ms) notably higher than across sitar solos (32 ms), but as Figure 9 shows, tabla solos become consistently less synchronized than their adjacent sitar solos from T5/S5 onwards. As already noted, this is precisely when Banerjee starts playing in a more syllabic and isochronous manner. Therefore, the fact that sitar solos become comparatively more synchronized at this stage of the performance can be easily accounted for based on these two factors. In other words, Banerjee's more regular rhythmic and micro-temporal behavior from S5 onwards naturally results in more synchronized interactions, particularly in comparison to his first two solos, which are both the most melismatic in character and the least synchronized.

However, this does not explain why tabla solos display such high levels of asynchronization. Although this finding may be partly related to Khan's higher isochronization values discussed earlier, this can be accounted for even better by reference to certain patterns in these performers' relative phase, discussed in the entrainment analysis below.

One last point worth discussing is the higher mean asynchronization value for the *sawāl jawāb* section (34 ms) compared to the previous melismatic/syllabic (30 ms) and syllabic (28 ms) sections. These results would appear to indicate that performers revert to less synchronized behavior after having become increasingly synchronized throughout the course of the performance. However, this interpretation is inaccurate, since the higher mean asynchronization value for the *sawāl jawāb* section may be accounted for by two points: (1) as noted, tabla solos are consistently less synchronized than sitar solos from T5 onwards; and (2) the *sawāl jawāb* section is the only part of the performance in which tabla solos are more predominant than sitar solos. As Figure 9 shows, sitar solos during this closing section are actually the most synchronized of the entire performance, and the only reason why the mean asynchronization value for this section is comparatively high is because of the persistent lack of synchronization during tabla solos, which in this section are for the first and only time more prominent than sitar solos.

In summary, the most interesting finding to emerge from this analysis is that, contrary to what one might have expected, tabla solos are consistently less synchronized than sitar solos, especially once Banerjee adopts a syllabic approach from S5. As we shall see, this can be accounted for by reference to the performers' relative phase, discussed below. In addition, these results also display a relationship between higher levels of synchronization on the one hand, and both faster tempo and denser surface rhythm on the other.

Discussion 4: Interpersonal Entrainment

The following component of this micro-temporal analysis provides a study of the performers' interpersonal entrainment throughout the *vilambit* based on measurements of their relative phase (i.e., mean vector) and strength of coupling (i.e., length of mean vector). Perhaps the most interesting finding from this analysis is that Banerjee plays consistently behind Khan, as all relative phase values are negative (except for SJ S2 and SJ S3, which are only one cycle long each). The overall character of Banerjee and Khan's interpersonal

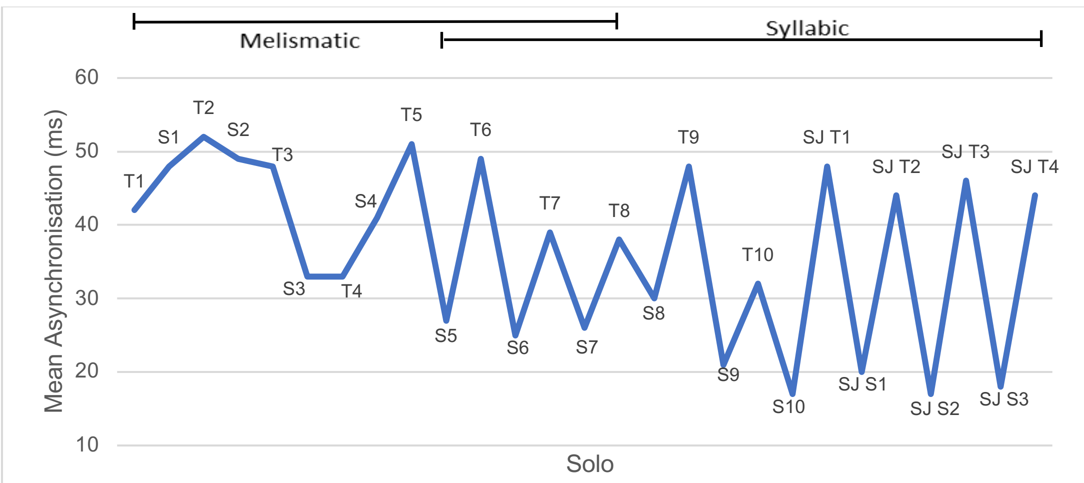

Figure 9. Mean asynchronization values for each solo throughout the *vilambit* performance.

entrainment throughout the *vilambit* is illustrated in Figure 10. Each point represents a distinct relative phase value—i.e., the onset time difference between couples of quasi-simultaneous onsets measured in relation to the underlying beat. The arrow's angle describes the performers' mean vector or phase attractor (-11.2°)—i.e., the predominant phase relationship throughout the data set—and its length describes their strength of coupling (0.909) —i.e., the overall deviation from the mean vector.

These initial results reveal something which at first might seem paradoxical. The sitarist, who is normally the main artist and leader, is in micro-temporal terms significantly behind the tabla player throughout almost the entire *vilambit*. One possible explanation for this finding may be that, as Doffman (2013) argues based on his entrainment analysis of a jazz trio, melodic soloists may lag behind the rhythm section for perceptual salience. This argument is similar to that proposed by Iyer (2002) and referred to earlier in the isochronization analysis, both of which describe ways in which soloists may carry out certain micro-temporal behaviors (i.e., playing in a less regular manner and lagging behind the rhythmic accompanist) in order to stand out from the other musician(s).

However, though this explanation is compelling, the results of the current analysis reveal a more complex situation. While on the one hand Banerjee plays consistently behind Khan (a result which in itself supports Doffman's proposition), on the other hand there is a consistent tendency for whoever is acting as soloist to be relatively ahead of the accompanist, or in the case of Banerjee, less behind (see Figures 11 and 12). In other words, although mean vector values are almost consistently negative, they tend to be smaller during sitar solos (-5°) and larger during tabla solos (-23.3°), implying that both performers may be enacting their roles as soloists at a micro-temporal level by playing more ahead in comparison to when acting as accompanist (or alternatively, they may be enacting their role as accompanist by lagging further behind).

This presents a somewhat paradoxical relationship between performers' musical role and their relative phase, in that the overall leader of the ensemble (Banerjee) plays

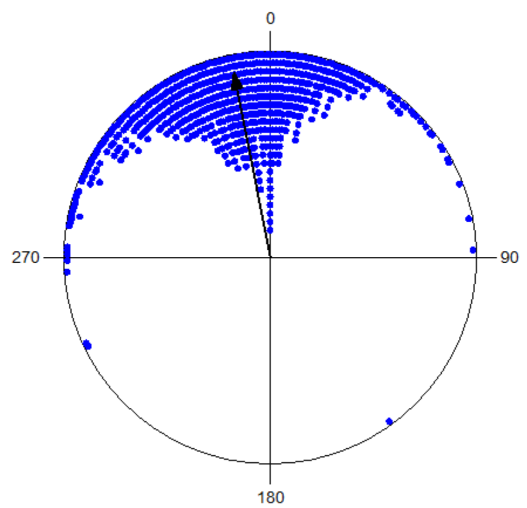

Figure 10. Interpersonal entrainment data for the entire *vilambit* performance.

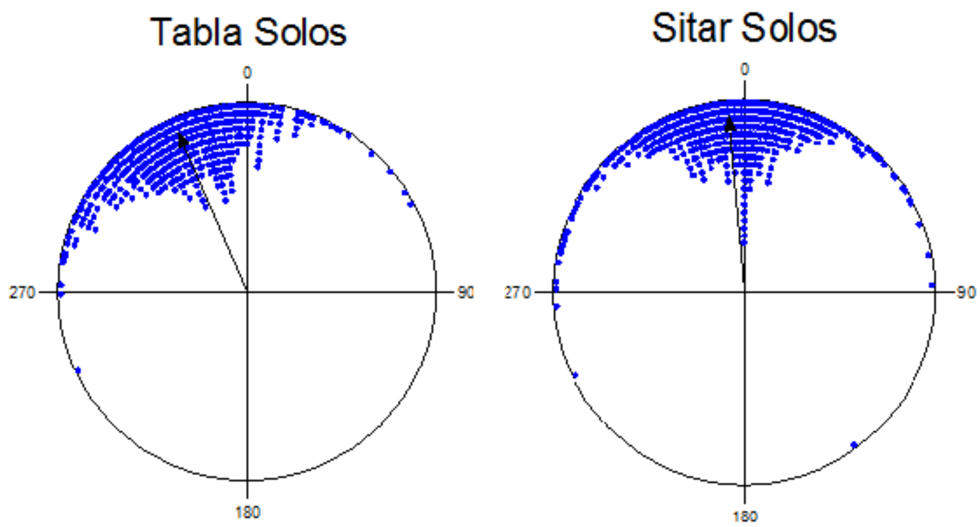

Figure 11. Separate interpersonal entrainment data for tabla and sitar solos throughout the *vilambit* performance.

consistently behind, and yet whoever is taking the solo plays relatively ahead. This tendency is notably consistent throughout the *vilambit*, as can be seen in Figure 12. It is also consistent with what is reported in Clayton, Jakubowski, and Eerola's (forthcoming) study, which also found the lead instrument playing consistently ahead of the accompanying one, thus suggesting this might be a common pattern in micro-temporal interaction in this genre. Moreover, Banerjee and Khan's relative phase appears to be in no way affected by the sitar's surface rhythmic or formal development, as Banerjee is consistently behind Khan by roughly the same angle throughout the *vilambit* (-11.8°, -8.6°, -10.8°, and -14.8°).

One possible interpretation of this relative phase pattern is related to the recurrent acceleration noted during tabla solos and absent during sitar solos discussed earlier (see Figure 1). Perhaps the acceleration during tabla solos is shaped by Khan pushing the

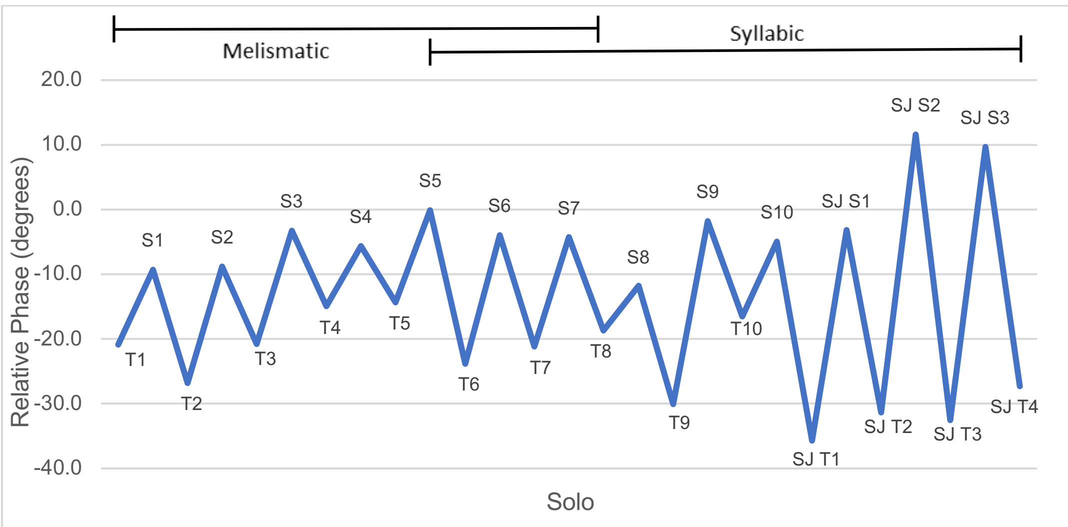

Figure 12. Relative phase values for each solo throughout the *vilambit*.

tempo upwards while Banerjee holds back, thereby causing their relative phase offset to become larger with Banerjee lagging further behind. During sitar solos, on the other hand, Khan is no longer accelerating so the performers fall into a closer phase relationship.

In any event, this pattern in relative phase throughout the *vilambit* explains why tabla solos were found to be consistently less synchronized than sitar solos: namely, because they lock into different phase relationships according to who is acting as a soloist. In other words, the main underlying cause behind their greater lack of synchronization during tabla solos is that Banerjee lags further behind (or Khan playing further ahead) in comparison to sitar solos, which causes their onsets to be less synchronized. And yet, importantly, while Banerjee and Khan are less synchronized during tabla solos, their strength of coupling—i.e., the consistency with which their micro-temporal actions entrain around a certain phase relationship— is largely unaffected by this process (0.921 during sitar solos and 0.919 during tabla solos). This means that although their onsets sound less synchronized during tabla solos, their micro-temporal coordination (in terms of interpersonal entrainment) is essentially the same regardless of their alternating roles.

In contrast, length of mean vector values does display a relationship to surface rhythm and formal development: that is, comparatively less coupled micro-temporal interactions during the opening melismatic section (r = 0.89); a marked increase during the following melismatic/syllabic (r = 0.937) and syllabic sections (r = 0.936); and a subsequent decrease during the closing *sawāl jawāb* section (r = 0.88). This pattern is essentially the same as the one regarding the relationship between formal development and synchronization discussed earlier, meaning that formal development had a similar effect on both synchronization and coupling. Thus, whereas role alternation seems to have affected synchronization and phase but not coupling, surface rhythm affected synchronization and coupling but not phase. Put differently, the relationship between performers alternating roles and synchronization (i.e., greater synchronization during sitar solos) appears to be caused by changes in relative phase (i.e., smaller phase values during sitar solos underpinning greater synchronization), whereas the relationship between surface rhythm and synchronization (i.e., increase in synchronization as Banerjee starts playing in a syllabic manner) is underpinned by an increase in coupling (i.e., more consistent phase relationship). In order to understand this relationship better, let us focus on the performers' strength of coupling for each separate solo across the *vilambit* as illustrated in Figure 13.

Here one can see that the performers' coupling not only becomes stronger, but also a lot less varied, once Banerjee starts playing in a more syllabic manner as of S5 until the beginning of the *sawāl jawāb* section. In other words, while these results show a noticeable contrast in coupling between sitar and tabla solos during the opening melismatic section and the closing *sawāl jawāb* section, this contrast is momentarily suspended during the middle syllabic sections. Furthermore, whereas sitar solos tend to be less coupled during the melismatic section, tabla solos tend to be less coupled during the closing *sawāl jawāb* section. How can this gradual change in the relation between instrumental solo and coupling be accounted for?

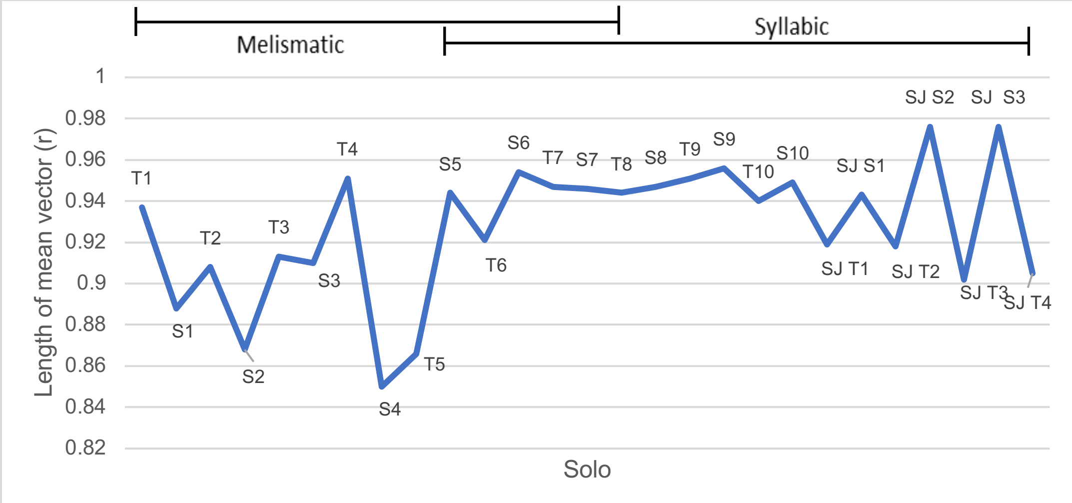

Figure 13. Length of mean vector values for each solo throughout the *vilambit*.

The fact that sitar solos are consistently less coupled than tabla solos from T1 to S4 is most likely due to the melismatic character of Banerjee's playing, which naturally causes the lowest levels of coupling for the entire performance. In contrast, Khan's tabla solos during this opening section are not as strongly affected by Banerjee's surface rhythm, since Banerjee's role as accompanist involves him playing the *gat* in a more rhythmically regular manner, which contributes toward tighter temporal coordination. Later, once Banerjee starts playing in a more syllabic manner, the difference in coupling between sitar and tabla solos is significantly reduced, and a slight tendency for tabla solos to be less coupled can be noted (especially during T6 and T10). This again can be accounted for by Banerjee's approach to surface rhythm and by Khan's comparatively more irregular isochronization from S5 onwards. During his sitar solos, Banerjee plays in an increasingly syllabic and isochronous manner that enables stronger coupling, and which therefore explains the higher length of mean vector values. This change does not apply for tabla solos, since the rhythmic character of Banerjee's accompaniment (based on the *gat*) is essentially the same throughout.

In summary, the results of the entrainment analysis show that Khan played consistently ahead of Banerjee during almost the entire *vilambit*, and that their relative phase was strongly affected by their alternation in musical role, with both musicians playing comparatively more ahead when acting as soloists. These findings explain why tabla solos were less synchronized than sitar solos. In addition, this analysis shows that while performers' strength of coupling was not affected by their alternating roles, it was affected by surface rhythm and formal development. Together, these findings highlight the complex relationship between sitar and tabla performers' micro-timing and other levels of musical interaction.

Discussion 5: Metric Synchrony and Entrainment

Lastly, this discussion considers Banerjee and Khan's mean asynchronization, phase, and coupling on each of the 16 *mātrās* of the underlying metric cycle throughout the *vilambit* and its various formal sections. Looking at the mean asynchronization values for the entire *vilambit* (see Figure 14), *mātrās* 1 and 2 display the highest levels of asynchronization. This pattern is generally consistent throughout sitar and tabla solos and the various formal sections, except for the closing syllabic one, as can be seen in Tables 3 to 5 above. These findings show that the metric place where performers are supposed to "come together"—that is, where their rhythmic actions tend to coordinate in the form of metric cadences—is also where their onsets tend to sound most separate. Presumably, this may once more be related to matters of musical expression and perceptual salience, as playing in a less synchronized manner on and around *mātrā* 1 may help emphasize the effect of metric cadences (i.e., *mukhṛās*, *tihāīs*, *cakkardārs*, etc.) ending on *sam*.

While mean asynchronization values for *mātrās* 1 and 2 are both equally high and almost identical, the relative phase and length of mean vector values for each of these two *mātrās* present very different scenarios (see Figure 15 and 16). On one hand, *mātrā* 1 has the highest (negative) phase value of all (-26.9°), meaning that Khan tends to anticipate Banerjee by the greatest micro-temporal margin on this cadential place in the cycle. In addition, the length of mean vector value for *mātrā* 1 is also comparatively high (r = 0.919), meaning that this phase relationship is maintained quite consistently throughout the performance. This is also apparent based on the relative phase and length of mean vector values for *mātrā* 1 throughout the various formal cross-sections (see Tables 4 and 5), all of which display high values compared to the other 15 *mātrās* within that section (again except for the closing syllabic one).

On the other hand, length of mean vector values for *mātrā* 2 are comparatively low (r = 0.837), meaning that no particular phase relationship is maintained in a consistent manner at this place in the cycle. In other words, Banerjee and Khan's entrainment during *mātrā* 2 is much looser, not only in comparison to *mātrā* 1 but also in comparison to the other 14 *mātrās* (as shown in Figure 16). This means that while their lack of synchronization during *mātrā* 1 is caused by Khan playing consistently ahead of Banerjee, their asynchronization during *mātrā* 2 is caused by a general lack of coupling.

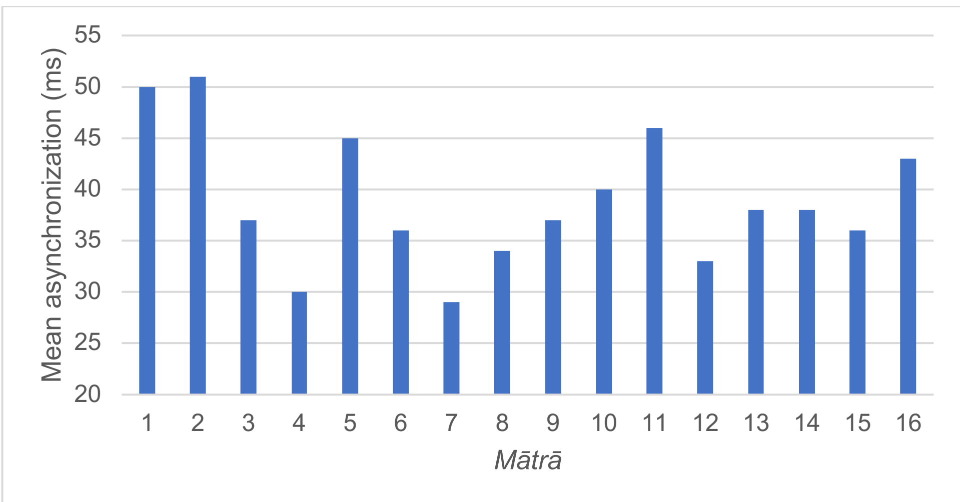

Figure 14. Mean asynchronization values for each *mātrā* throughout the *vilambit* performance.

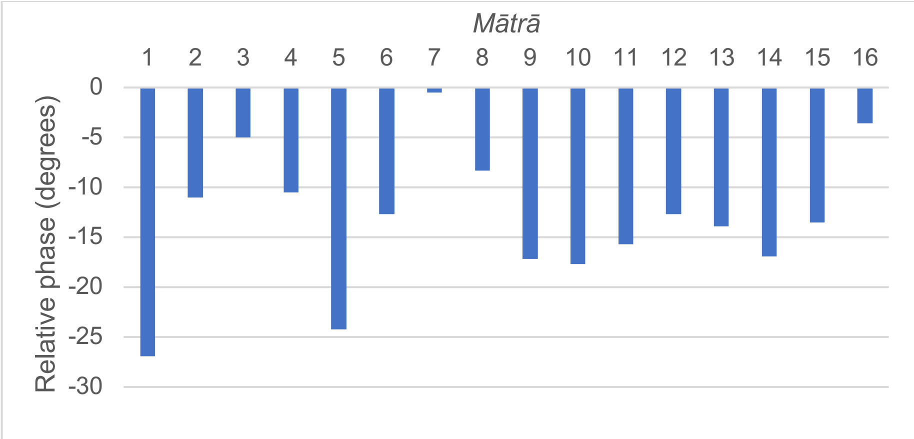

Figure 15. Relative phase values for each *mātrā* throughout the *vilambit* performance.

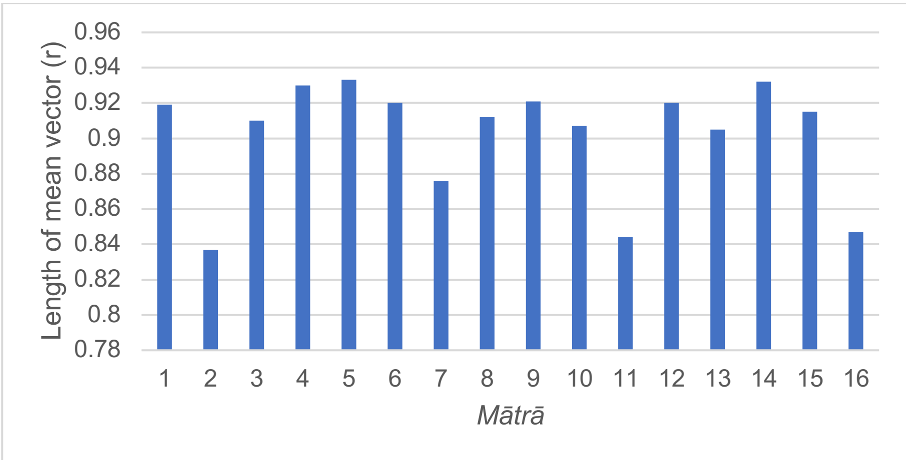

Figure 16. Length of mean vector values for each *mātrā* throughout the *vilambit* performance.

One interpretation of these findings is that performers use asynchrony during *mātrā* 1 for expressive effect—for instance, by having Khan anticipate *sam*, or by having Banerjee delay that final resolution—after which they momentarily loosen their metrical entrainment before re-establishing a closer coupling as of *mātrā* 3. This interpretation is supported by the results from the mean *mātrā* duration analysis (see Figure 3 above) showing a consistent deceleration on and right after *sam* (*mātrā* 1), which might be causing their momentary decrease in coupling. This pattern does not seem affected by performers' alternating roles as soloist and accompanist, as it can be identified throughout both sitar and tabla solos (see Table 4). However, it does seem to be affected by formal development, as it is much more pronounced during the opening melismatic section than during the following syllabic ones (see Table 5).

Interestingly, these findings represent the most noticeable contrast to results emerging from Clayton, Jakubowski, and Eerola's (forthcoming) study, where *mātrā* 1 was found to be characterized by slightly greater synchronization compared to the other 15 *mātrās*, and where melodic instrumentalists played ahead of rhythmic accompanists, especially during rhythmic cadences. Since this is the only significant discrepancy across both studies, it might point toward a specific stylistic strait in Banerjee's and/or Khan's way of approaching cadences on *sam.*

Summary of Findings

The above analyses of Banerjee and Khan's recording support the following conclusions:

- Linear micro-fluctuations in tempo underpin the performers' alternating musical roles, suggesting a functional relationship to each performer's distinct expressive effects and approach toward solo development.
- Cyclical micro-fluctuations in tempo involving deceleration on the first *mātrā* are followed by a gradual acceleration during the following three *mātrās*, suggesting these patterns help delineate the underlying metric structure (i.e., *tāl*) and emphasize certain cadential effects.
- Higher mean asynchronization values on and right after *sam* indicate that asynchronization is likewise used for similar purposes. While the lack of synchronization at *mātrā* 1 is caused by Khan playing consistently ahead of Banerjee (or Banerjee lagging behind Khan), their lack of synchronization during *mātrā* 2 is caused by a momentary decrease in coupling.
- Higher isochronization values for both performers when acting as soloist suggest that this aspect of micro-temporal behavior supports musical expression and perceptual salience (Iyer 2002). The contrast in isochronization according to role is less pronounced for Khan than for Banerjee, probably because the more interactive nature of tabla accompaniment causes less metronomic behavior (and therefore less contrast in relation to Khan's solos).
- Higher isochronization, mean asynchronization, and lower length of mean vector values during the opening melismatic section compared to the subsequent syllabic sections confirm that their micro-temporal interactions are "looser," or less coordinated, during this opening stage.
- Negative relative phase values throughout practically the entire *vilambit* indicate that Khan (the rhythmic accompanist) tends to play consistently ahead of Banerjee (the melodic leader).
- Consistent patterns in relative phase relating to the performers' alternating musical roles, with whoever momentarily acts as the soloist playing comparatively more ahead, or in Banerjee's case less behind. This pattern is particularly noticeable and pronounced during the closing *sawāl jawāb* section, when Banerjee plays ahead of Khan for the first and only time in the performance.
- Higher mean asynchronization values during tabla solos, especially once Banerjee starts playing in a more syllabic manner from S5, are primarily due to the consistently larger relative phase values during tabla solos (and not due to a lower level of coupling, which is almost identical for sitar and tabla solos).

CLOSING REMARKS

The purpose of this paper has been to provide a detailed description of some of the musical interactions among highly competent sitar and tabla performers from an as-yet largely unexplored micro-temporal perspective. Certain patterns in micro-temporal interaction were found to underpin and support perceptual salience, musical expression, formal development, and the enactment of musical roles. The consistency with which these patterns are maintained throughout this *vilambit* performance, combined with the fact that they are largely coherent with similar findings based on both similar (Clayton, Jakubowski, and Eerola forthcoming) and different kinds of musical ensembles (e.g., Doffman 2013; Iyer 2002; Rasch 1988), suggests that they are likely to be representative of how most sitar and tabla players interact on a micro-temporal level (see Cooper 2018 for further empirical evidence).

The discovery of these micro-temporal patterns raises numerous questions regarding their cause, phenomenological significance, and musical function. For instance: What makes these patterns so consistent? Are the performers somehow controlling these intentionally, do they emerge entirely unintentionally, or does the answer lie somewhere in between? What do these different degrees of isochronization, asynchronization, phase, and coupling feel like? Can performers tell the difference between, for example, being micro-temporally ahead or behind? In what ways do these micro-temporal asynchronies support and generate musical expression? Would this music become less expressive—or differently expressive—if it were to depart significantly from the specific patterns of micro-timing uncovered in this analysis? And at what point would performers and listeners be able to tell? Although these are all questions that lie largely beyond the scope of this paper, their pursuit will allow us to gain a better understanding of the role and significance micro-timing plays in shaping both performers' and listeners' musical experience in various ways.

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