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General paper

IDIOSYNCRATIC ELEMENTS IN MUSIC-RELATED GESTURE-SOUND RELATIONSHIPS: A HINDUSTANI DUET PERFORMANCE ANALYSIS

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Abstract. *This study investigates the correlation between body movements and the voice in the context of North Indian Classical (or else Hindustani) vocal music, specifically focusing on its Dhrupad subgenre. In particular, it examines manual interactions with imaginary objects (MIIOs) commonly observed among vocalists, including actions such as stretching, pulling, pushing, and throwing, as well as the physical effort exerted on these occasions. The analysis employs video observations of originally recorded audio-visual material from a Dhrupad vocal improvisation performance. A previous association analysis conducted between MIIO gesture classes, perceived effort levels, and melodic aspects revealed a certain level of consistency among the two vocalists, albeit with individual variations revealing an idiosyncratic aspect in the way these gestures might be expressed. Given that the selected performers (brothers, Umakant and Ramakant Gundecha) share the same musical background and experience and that they are recorded singing in duet in a single performance of the same melodic mode (raga), instead of examining their common gesturing manners, the current paper focuses exclusively on the idiosyncratic deviations in gesturing habits observed between the two brothers and the associations of these gestures to their melodic counterparts. The analysis relies on quantitative statistical methods of pertinent movement and acoustic features, and the results yield valuable insights in ethnomusicology and embodied music cognition. They additionally offer crucial guidance on the use of music technologies and motion capture methods to develop quantitative approaches that complement existing qualitative methodologies.*

Key words: *gesture-sound relationships, music and motion capture technologies, systematic musicology, ethnomusicology, embodied music cognition*

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1. INTRODUCTION

In recent years, a shift towards embodied approaches in music performance studies has emerged (Leman 2007), with a focus on understanding sound-movement relationships. However, there's limited research on accompanying gestures in singing, especially in non-western 'oral' music traditions (examples include (Paschalidou 2022); (M. Clayton et al. 2022); (Pearson and Pouw 2022); (Fatone, Clayton, and Leante 2011); (Rahaim 2012); (Moran 2007). Additionally, while the significance of physical effort in music has been acknowledged, systematic examinations remain scarce due to its subjective nature and dual goal (Massin 2017). In Dhrupad vocal music, a sub-genre of North Indian Classical music (or else Hindustani), singers simulate interactions with imaginary objects, suggesting distinctive patterns of acoustic features in the voice linked to effortful interactions. This study explores the uncharted connection between hand gestures and the voice during these interactions, labeled as "MIIOs" (Manual Interactions with Imaginary Objects). Drawing on embodied music cognition theories (Leman 2007), the research aims to understand the functionality of MIIOs, assess perceived effort, and explore their relationship with melodic elements, aiming to discern consistency across performers and identify conceptual aspects versus vocal production requirements.

For this, the current paper explores gesture-sound-effort correlations for two musicians with the exact same musical background in Hindustani Dhrupad vocal music, namely the Gundecha brothers (Umakant and Ramakant), singing in duet in the same melodic mode (raga). Both trained by Zia Fariduddin Dagar and Zia Mohiuddin Dagar, the brothers have consistently performed together, which provides a unique opportunity to investigate the impact of shared background and constant collaboration on their renditions of the same raga. In a forthcoming publication currently undergoing review, the paper aimed to better understand whether there are consistent gesture-sound-effort associations for each of the two performers, and also whether these associations—if they exist indeed—are shared among vocalists, or if they are mostly idiosyncratic, revealing personal preferences. The emphasis of that paper was primarily centered around the shared principles between the two brothers. However, the present paper shifts its focus to accentuating the deviations and disparities in their gesturing manners.

Specifically, the paper scrutinizes a tendency observed in Umakant's gesturing habits to move his left hand along the horizontal plane (left-right), contrasting with Ramakant's inclination to move his right hand along the vertical plane (up-down). This observation may suggest either a deliberate choreographed performance agreed upon by the brothers, hinting at a visually captivating musical presentation, or it may signify individual idiosyncratic tendencies. While Ramakant's vertical movements resemble the action of lifting a (heavy or light) object into the air and allowing it to fall under the influence of gravity, a movement performed against a partly real and partly imagined force, Umakant's horizontal gestures suggest movements opposing a purely imagined resistive force in the horizontal plane. The underlying question is whether, despite their spatial disparities, they still share some common underlying movement qualities and whether these correspond to shared melodic characteristics. Furthermore, the paper explores a unique observation regarding Umakant Gundecha's utilization of different grips (ranging from closed to open) in relation to the syllables used, a practice not observed in Ramakant Gundecha's performance.

For this, the paper presents a third-person non-participant video observation analysis of an alap vocal improvisation in raga Bhupali, sung in duet (called jugalbandhi) by the two brothers. The study involves systematic annotation of audio-visual material, followed by an association analysis between movement and sound aspects. It explores connections among gesture classes, melodic movement classes, musical context, and effort levels, specifically focusing on those gestures that are not shared between the brothers. The paper outlines the annotation process and presents individual results for each performer, facilitating a comparison between the brothers' findings towards the end of the paper.

2. BACKGROUND

2.1. Introduction to Dhrupad

Dhrupad, a prominent style of Hindustani music, is a monophonic, primarily improvisational, vocal music genre, that strictly adheres to rule-based structures of a so-called raga (melodic mode) system (Sanyal and Widdess 2023). The improvisation gradually unfolds, starting slow and building up in pace, pitch, and tension. Non-lexical syllables called 'nom-tom' (ibid.) like 'ra', 'na', and 'num' are employed, with melodic tension released through stops on the tonic and the 5th. Dhrupad's continuous pitch "space" concept (Fatone, Clayton, and Leante 2011), where singers approach notes through smooth trajectories, makes it suitable for exploring associations with movement.

2.2. Gestures in Hindustani vocal improvisation

Dhrupad is a so-called oral music tradition, where knowledge is transmitted through direct interaction with the teacher, repetition and imitation rather than on written notation. While not formally instructed, it is evident that gestures hold significance in the realm of Dhrupad vocal education.

In Hindustani performance and instruction alike, hand gestures serve multifaceted purposes, conveying the artist's affinity with the music, fostering interaction between performers, and connecting with the audience or learners (Paschalidou 2017, Pearson 2016, Rahaim 2012, Clayton 2007, Leante 2009, Fatone et al. 2011, Moran 2007).

In Dhrupad, singers engage with melodic content through either open-handed or closed-handed modes, reflecting distinct body-voice relationships (Rahaim 2012). The open-handed mode features effortless hand movements mirroring melodic contours, while the closed-handed mode involves powerful manual interactions with imaginary objects (termed MIIOs in this work) that do not appear to be a simple melographic representation of the voice (ibid.). Despite the absence of real objects, these gestures seem to align well with the voice, materializing the melodic intention of the performer (Paschalidou 2022).

2.3. Theories of music embodiment

Despite the wide array of viewpoints in music embodiment theories, they collectively refute the Cartesian division between mind and body, advocating instead for a perspective where cognitive processes transcend the confines of the brain (Noë 2006, (Varela, Thompson, and Rosch 1993, Gallagher 2023). They emphasize the significance of an individual's physical embodiment and its interaction with the environment in shaping cognitive abilities (Gibson 1986).

Consequently, enactive theories and ecological psychology emphasize the importance of sensorimotor skills and movement-sound contingencies developed through patterns of real-world interactions with objects (Gibson 1986). These patterns form the basis for understanding any sound, both actual and virtual (Clarke 2005). Expanding on this notion, the human body is now acknowledged as a vital aspect of our musical experiences (Cox 2016; Johnson 1992), leading Leman to introduce the concept of 'embodied music cognition' (Leman 2007). Imagined objects in Manual Interactions with Imaginary Objects (MIIOs) may carry universal patterns and behavioral opportunities, influencing sonic outcomes based on their physical characteristics. However, to the best of our knowledge, the relationship between hand gestures and voice in respect to the concept of effort in MIIOs has received limited attention and only few systematic approaches exist. Specifically, although imaginary objects in Hindustani singing have been previously discussed by Rahaim (2012) and they have been systematically explored with a focus on the concept of effort in the context of the Dhrupad subgenre by Paschalidou (2022), it is the first time that idiosyncratic associations and their melodic counterpart are scrutinized by comparing two performers of the exact same background singing together in duet in the same raga. Hence, to the best of our knowledge, this is the first time that a comparative ethnomusicological inquiry on gesture-sound relationship of MIIOs in Dhrupad is conceptualized and executed within the most ecologically valid setting of fieldwork conditions. More specifically, this study diverges from conventional laboratory experimental methodologies reliant on brief sound stimuli, opting instead for real performance recordings. Leveraging a distinctive setting, characterized by the identical musical (and other) background of the siblings and their duet performance in the same melodic mode, provides a unique research opportunity.

2.4. Effort

Effort, often challenging to define precisely (Dewey 1897), is conceptualized in this study as reflecting an active or passive response to physical conditions during intentional musical tasks.

In music, effort is seen as integral to the "energy and desire, attraction and repulsion in the movement of music" (Ryan 1991), reflecting the tension within a piece and evoking emotional responses crucial for performers and audiences (Cox 2016; Krefeld and Waisvisz 1990; Kurth 1922; Lerdahl and Krumhansl 2007; Olsen and Dean 2016). Performers exert effort to highlight tension, while audiences must perceive this effort to discern intense musical passages (Vertegaal, Ungvary, and Kieslinger 1996).

In the domains of movement, dance, choreography, and kinesiology, effort is viewed as a subjective measure of expression characterizing movement qualities that reflect an individual's active or passive engagement with physical conditions influencing movement (Bartenieff and Lewis 1980; Maletic 1987; Hackney 2003). Rudolf Laban (1879-1958) considers effort the cornerstone of all human body movements, encompassing the dynamics and inner impulse driving movement (Laban and Lawrence 1974).

The study adopts a qualitative approach due to the subjective nature of effort, aiming to explore associations between MIIOs, melodic attributes, and perceived effort levels during Dhrupad vocal improvisation.

2.5. Aims and objectives

Through the systematic treatment of coded features, the aim is to draw conclusions on whether there are any underpinning qualities that are shared between the two performers, or if, alternatively, movement is primarily idiosyncratic. This section first includes a detailed audit trail of the annotation process and then it presents the results for each of the performers separately. The paper concludes with insights drawn from the comparative analysis.

3. METHODOLOGY

3.1. Methodological approach

To maintain ecological validity, the study abstained from designed experiments. Instead, it employed a non-participant third-person video observation approach, analyzing qualitative data from recorded improvisation performances in India. This method facilitated a thorough examination of enduring gesture-sound connections developed by vocalists through years of practice, as opposed to spontaneous reactions to stimuli. The analysis consists of first annotating the audio-visual material and then performing an association analysis between various aspects of movement, sound and effort. A single observer manually annotated the audio-visual material of the vocal improvisation, by visually identifying, segmenting, and labelling MIIO events, coding them for various melodic and movement aspects (categorical descriptors), and annotating effort levels. Finally, two choreographers conducted an inter-coder agreement test to cross-validate these manual annotations.

3.2. Data collection

The recording of the Gundecha brothers (Umakant and Ramakant) took place on 16.01.11 at their music school in Bhopal, India. The video was captured using night-shot (infrared light) to accommodate the low lighting necessary for minimizing unintended reflections during the simultaneous recording of motion data via a passive optical motion capture system. Before each performance, participants signed written informed consent and recording agreement release forms, outlining the collection and use of data, including publication rights. Participants retained the option to withdraw from the study at any point. A modest compensation was provided to participants. Figure 1 illustrates the recording setting.

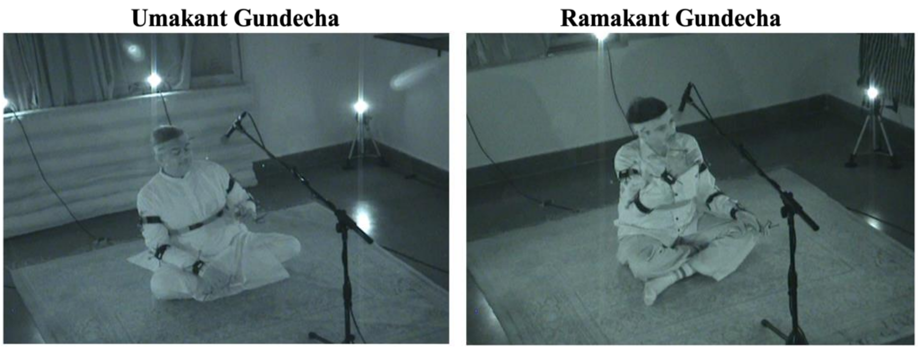

Fig. 1 Gundecha brothers recording session, Umakant on left, Ramakant on right

However, due to the brevity of their performances, an alternative recording of the brothers singing in duet, captured by Clayton, Leante, and McGuiness at Aikatan Auditorium in Kolkata in February 2007, was employed for the analysis. The taňpurā was tuned to the musician's preferred pitch, with the tonic at 138.5Hz, approximately equivalent to C#2 in Western terms. Only the initial 25-minute slow section of the alap is utilized in this study.

4. ANALYSIS

4.1. Analysis of raga Bhupali

Initially, I delve into the theoretical framework of raga *Bhupali* and subsequently address aspects of how the Gundecha brothers interpreted the raga. Key features of raga *Bhupali*, as outlined by (Bor 1999) and (Rao and van der Meer 2006) are supported by the pitch distribution graph of Figure 2, which was extracted from the audio recorded material and reflects the tonal hierarchy of raga *Bhupali* as rendered by the Gundecha brothers. These key features include the following:

1. The tonal elements consist of 1, 2, 3, 5, 6, forming a pentatonic scale in both ascending and descending sequences.
2. Both ascent and descent follow a direct path, with the majority of Bhupali's elaboration occurring in the upper part of the lower octave and the middle octave.
3. Prominent notes include the 3rd and the 6th, and phrases often conclude on the 1st, 3rd, and 5th degrees.
4. Notably, in ascending movements, the 2nd, 3rd, and 6th degrees are typically approached from a higher pitch. For instance, when ascending to the 2nd degree, the singer briefly and softly touches the 3rd degree before descending to the 2nd degree.
5. Descending movements often connect the 3rd and 6th through smooth glides, such as 5\3 and 2\6/1[1]. Occasionally, a sharpened 4th or a natural 7th may be used in these glides, suggesting the influence of the related raga, Kalyan.
6. Characteristic phrases include 3-2\6/1 and 3-2-5\3.

The following points in the way raga *Bhupali* was rendered by the Gundecha brothers are worth mentioning:

1. Contrary to music theory, double pitch glides are infrequent, with notes primarily approached through direct ascending glides.
2. The alap predominantly focuses on approaching and establishing stable pitches (tonic, 3rd, or 5th degree) using repeated ascending monotonic melodic glides (5/1, 6/1, 3/1, 1/3, 5/3, 1/5 and 3/5), creating an impression of attraction from the first pitch to the target note, which is then held steadily in place.
3. Melodic activity aligns with the upper half of the lower octave and the middle octave, consistent with music theory.
4. Not only the 3rd and 6th degrees, but also the 5th and sometimes the 2nd are often approached through a monotonic descending glide.
5. The vocalists employ a range spanning nearly two octaves. They commence by establishing the middle tonic, subsequently exploring the upper section of the lower octave, then moving through the lower and upper portions of the middle octave. Finally, they ascend to the upper tonic, briefly touching the 3rd degree of the highest octave before descending back to the middle tonic.

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[1] The "/" symbol signifies a seamless upward melodic glide, creating a fluid connection between the adjacent notes. Likewise, "\" denotes a smooth descent. Symbols "-/" and "-\" indicate a stepwise ascent and descent, respectively, indicating melodic progressions where notes are not smoothly connected through a glide. The "^" symbol is employed to highlight emphasis on the pitch preceding the symbol, as seen in phrases like "weight & release". Finally, the "-" symbolizes and emphasis and prolonging of the note preceding the symbol.

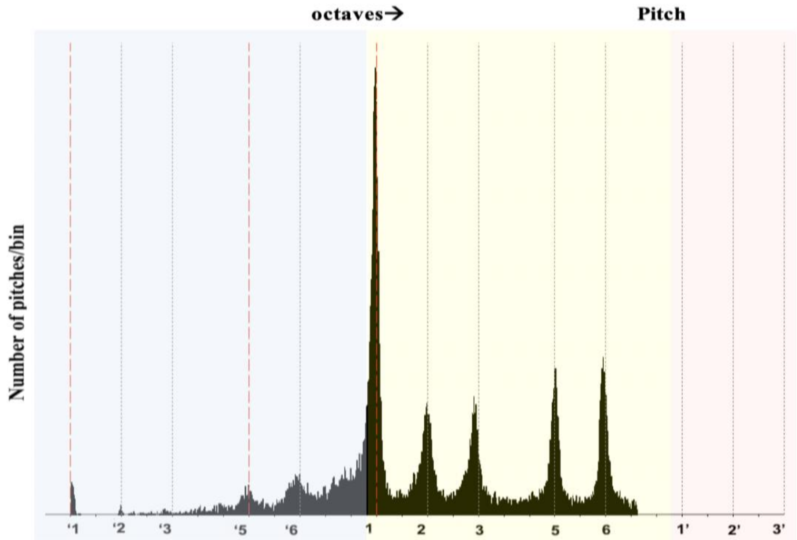

Fig. 2 Gundecha brothers: Pitch distribution (in cents) extracted in Praat (Boersma and Weenink 2016) of vocal improvisation in raga Bhupali. The red lines indicate the frequencies of the taňpurā tuning. Tonic was tuned at 138.5Hz

4.2. Annotation coding scheme

The coding and segmentation process was carried out separately for each of the performers and includes the following aspects: {gesture, sound, effort}.

As shown below, the coding scheme for Umakant incorporated additionally the palm shape alongside the concurrent use of syllables in the IPA system ("International Phonetic Association IPA," n.d.). This decision stemmed from interview reports and observations, indicating a potential systematic link between the openness of the palm and sonic qualities akin to the openness of the voice.

4.2.1. Gestures

The main coded gesture classes include the following:
{stretching; pushing-to-compress; pulling; collecting; pushing-away; throwing},
which are subdivided as such:

- Interactions with elastic objects: {stretching; pushing-to-compress}
- Interactions with rigid objects: {pulling; collecting; pushing-away; throwing}

Also, peculiar to each of these specific performers are the following gesture codes:

- For Umakant: side-gestures, classified as {passive-passive; active-passive; passive-active} and left-hand palm shape, classified as {closed; half-closed; half-open; open}
- For Ramakant: lifting gestures akin to moving against gravity, classified as {lifting; lifting & letting fall}.

4.2.2. Sound

The sound was coded according to: {melodic movement classes, syllables (IPA); pitch interval}. The following are the coded melodic movement classes for the voice:

{double-sloped pitch glide; straight ascent; straight descent; 1+ octave (large) ascending glide; weight & release; single note}.

Note: The class known as "weight & release" represents a melodic movement where the initial pitch is emphasized as a distinct note, followed by a light monotonic ascending or descending slide (the release) to another note. This type of glide differs from the typical pitch glides discussed earlier, as it places emphasis on the first note, contrasting with the usual focus on the target note in traditional pitch glides.

Peculiar for Umakant, were also the concurrently used syllables in the IPA2 system that were coded as: {u; i; ɪ; o; ə; ɜ; ʌ; ɐ; a}

Pitch intervals were organized in numbers of scale degrees.

4.2.3. Effort

Effort was annotated on a numerical scale of 0–10, with 10 being the highest.

4.3. Scrutinizing the annotated material

4.3.1. Umakant Gundecha

4.3.1.1. Effort levels

The mean effort value for Umakant Gundecha lies at around 3.8, which means that the vocalist mostly uses the middle and lower part of his effort level range.

4.3.1.2. Gesture classes

The entire alap's movement annotation comprised 127 gestures, categorized into eight classes of MIIOs, with durations ranging from 0.28 to 14.76 seconds. Table 1 presents the frequency of appearance of each gesture type.

Table 1 Umakant Gundecha: Gesture classes

Umakant Gundecha			
gesture classes		number	percentage (%)
	passive-passive	21	16.5
side-gestures	active-passive	2	1.6
	passive-active	3	2.3
stretching		11	8.7
pushing-away		8	6.3
pushing-compressing		11	8.7
pulling		19	15
throwing		3	2.4
collecting/taking		22	17.3
holding steady		27	21.2

Throughout Umakant Gundecha's performance, side-gestures, maintaining steady hand positions, and pulling gestures are the most frequently employed movements. Peculiar to Umakant, not used by Ramakant, are side-gestures. This type of gesture may involve a single motion or two spatially opposing sequential motions of the left hand, performed in

[2] International Phonetic Alphabet

the horizontal plane. In the first part, the hand moves sideways to the left, away from the musician's torso, while the second motion moves inward, approaching the body. While there are several similar gestures in terms of spatial orientation, careful observation reveals variations in the perceived effort during different parts of the gesture. In some instances, more effort seems to be exerted during the outward movement, whereas in others, the inward movement appears more effortful. This variability in effort reflects the imagined interaction and the level of active or passive involvement in the task. The underlying cause of the movement could be either: (a) Throwing an object from the right to the left hand, where the left-hand catches and halts it mid-air, or (b) Stretching an elastic object from its resting point to the left side of the musician. In the first case, such as throwing a ball, the movement of the left hand is considered passive, as it does not initiate the motion of the imagined object. The left hand merely tracks the object's position and naturally retracts toward the body after reaching its limit of extension. In contrast, in the second case, the left hand initiates an active movement by extending and stretching the imagined elastic object, with the subsequent motion resembling a recoil pulling the hand back toward its initial position. This gesture could also simulate a more complex interaction, such as throwing an object attached to one end of an elastic band from the right to the left hand. The distinction lies in the movement of the left hand: in the first case, the initial part of the gesture is relatively effortless, while in the second case, it requires more effort. The subsequent motion in the first case involves a passive retraction of the hand toward its resting position, while in the second case, it simulates the recoil of the object toward its original position or a pull toward the musician's body. Combining these alternatives yields three subclasses of side-gestures for the left hand, that were used in the annotation process:

- Passive-passive, involving throwing and retraction (the left hand merely tracks the object's position and returns effortlessly toward the body);
- Passive-active, involving throwing and pulling (the return is achieved through a dynamic pull);
- Active-passive, involving stretching out and recoil (a stretching movement toward the left side of the musician's body).

To differentiate between a passive and an active first part of a side-gesture, when this distinction is challenging, the annotation relied on either an initial short flick of the left hand, as if throwing, or the dynamics of the first part of the movement.

4.3.1.3. Melodic phrase classes

The melodic annotation for the entire alap comprised 127 segments, encompassing 30 distinct melodic movement types categorized into six pitch classes, as shown in Table 2.

Table 2 indicates that the primary melodic activity in the alap revolved around approaching and establishing the crucial and stable notes of raga Bhupali, evident in various pitch glide types. It is essential to consider the placement of melodic emphasis or “weight” and how it may be reflected in its corresponding movement.

4.3.2. Ramakant Gundecha

4.3.2.1. Effort levels

The mean effort value lies at around 4.4, which means that, like his brother, the vocalist seems to use mostly the middle and lower part of his effort level range.

Table 2 Umakant Gundecha: Melodic phrase classes

Umakant Gundecha					
melodic phrase classes			number	percentage (%)	total
Straight ascent	.../1	5/1	8	6.3	43
		6/1	15	12	
	.../5	3/5	12	9.6	
	.../3	1/3	3	2.4	
		2/3	1	0.8	
		5/3	2	1.6	
	.../2	5/2	1	0.8	
		1/2	1	0.8	
Straight descent	...\1	3\1	1	0.8	8
	...\5	1\5	2	1.6	
		2\5	1	0.8	
	...\3	1\3	2	1.6	
	...\6	1\6	1	0.8	
	...\2	1\2	1	0.8	
1 octave+ ascending glide		1/1'	4	3.2	6
		5/5'	2	1.6	
double pitch glide		6/1\5	1	0.8	2
		5/1\6	1	0.8	
weight & release	(...-/) ^...\...	(3-/) ^5\2	2	1.6	9
		(6-/) ^1\5	1	0.8	
	(...-\) ^.../...	(2-\) ^5/1	1	0.8	
	(...-/) ^.../...	(5-/) ^6/1	2	1.6	
	(...-\) ^...\...	(3-\) ^1\6	1	0.8	
		(3-\) ^2\6	1	0.8	
		(5-\) ^3\2	1	0.8	
single note (either short or prolonged)		1	32	25.6	59
		5	15	12	
		3	9	7.2	
		6	1	0.8	
		2	2	1.6	

4.3.2.2. Gesture classes

The complete alap is annotated with 47 gestures, categorized into six MIIO classes, each lasting between 0.28 and 14.76 seconds. Table 3 presents the frequency distribution of each gesture type in the context of Ramakant Gundecha.

Table 3 Ramakant Gundecha: Gesture classes

Ramakant Gundecha			
gesture classes		number	percentage (%)
lifting	lifting	5	10.7
	lifting & letting fall	9	19.1
stretching		16	34
pulling		7	14.9
collecting/taking		2	4.3
holding steady		8	17

Stretching an elastic object, pulling and lifting a rigid object are the most commonly employed gestures, in addition to maintaining the object in a stationary position. Peculiar to Ramakant, not used by Umakant, are the lifting gestures, performed in the vertical plane.

Lifting exhibits comparable dynamic characteristics to pushing against a constant opposing force; however, in this instance, the gesture is executed upward, counteracting gravity. Depending on the scenario, the hand may either maintain its elevated position after lifting the object or return to its initial location. In other words, this type of gesture may involve a single upward motion as if lifting an object or two spatially opposing sequential motions of the left hand as if lifting and letting an object fall.

4.3.2.3. Melodic phrase classes

The melodic annotation for the entire alap encompasses 47 segments, featuring 35 distinct melodic movement types, categorized into the six pitch classes of Table 4.

Table 4 Ramakant Gundecha: Melodic phrase classes

Ramakant Gundecha					
melodic phrase classes			number	percentage (%)	total
1. straight ascent	.../1	5/1	1	12.8	6
		1/5	1		
	.../5	2/5	1		
		3/5	1		
	.../2	1/2	1		
	.../6	1/6	1		
2. straight descent	...\1	2\1	1	8.5	4
	...\5	6\5	1		
	...\3	5\3	1		
	...\3	3\2	1		
3. 1+ octave ascending glide		1/1’	1	4.3	2
		5/6’	1		
4. double pitch glide		2/5\3	2	42.5	20
		1/5\3	2		
		1/5\1	1		
		1/3\2	3		
		2/3\2	1		
		3/1\6	1		
		1/2’\5	1		
		1/6\5	1		
		5/6\5	1		
		1/1’\6	1		
		5/5’\3	1		
		5/1\6	3		
		6/1\5	1		
		5/3\2	1		
5. weight on one note and release on another	(...-/) ^...\...	(2-/) ^5\3	1	8.5	4
	^.../...	^5/6	1		
	(...-) ^...\...	(6-) ^6\5	1		
	(...-) ^...\...	(3-\) ^5-(5)	1		
6. single note (either short or prolonged)		1	3	23.4	11
		5	2		
		3	3		
		6	1		
		2	2		

Ramakant employs double-sloped pitch glides more extensively than Umakant Gundecha, which aligns with expectations for raga Bhupali, particularly for approaching the 2nd, 3rd, and 6th degrees. Single prolonged notes and straight ascents are less common by Ramakant.

5. RESULTS

The two brothers were analyzed separately and therefore the results of each are presented individually. Findings are compared only at the end of the paper. First, the annotated material aiming to reveal clusters and patterns for each performer and then idiosyncratic trends, uniquely identified for each of them, are discussed separately.

5.1. Comprehensive exploration of annotated material

5.1.1. Umakant Gundecha

Specific associations observed for Umakant Gundecha are discussed in the forthcoming publication mentioned in the introduction. However, in order to draw a general sense of the complexity in the implicated data and the degree of overlap or similarities between the two brothers, a cluster analysis was performed for each and the results were then compared. To run the cluster analysis on similar content, a dataset was developed comprising similar types of features, namely:

df = {start, duration, effort, basic gestures, spatial phases, melodic phrases, melodic direction}

'Start' (start time of each annotated gesture) and 'duration' (both in msec), and 'effort' (0-10) are numerical variables, while the other variables are categorical. 'Basic gestures' denote gesture classes specific to each performer. 'Spatial phases' describe the number of spatial directions of each performed gesture, comprising three levels: single, dual, and steady, where 'dual' indicates movement in two opposing directions, 'single' in one, and 'steady' indicates no movement in space. 'Melodic phrases' refer to classes of melodic movement, and 'melodic direction' signifies the direction of each melodic movement, encompassing three levels: 'double', 'monotonic', and 'none'.

While often erroneously applied by converting categorical to ordinal variables, in principle k-means clustering is fundamentally unsuitable for categorical and mixed variables. Consequently, agglomerative clustering based on Gower distance was employed instead, as it is specifically designed for mixed variables, encompassing both numerical and categorical types. Gower's coefficient (Gower 1971) computes the distance between observations weighted by variable type, and then takes the mean across all variables. The resulting agglomerative coefficient was 0.9759256 (i.e. higher than 0.05), indicating significance and suggesting the presence of natural clusters within the dataset.

Various metrics exist to aid in determining the optimal number of clusters to be extracted in a cluster analysis. Utilizing the previously calculated Gower distance matrix, the number of clusters was determined using the partitioning around medoids (PAM) method, considering clusters ranging from 2 to 10. For this, the silhouette width was first computed, an internal validation metric which is an aggregated measure of how similar an observation is to its own cluster compared its closest neighboring cluster, with values ranging between -1 to 1 (higher values better). A plot for the PAM algorithm is presented in Figure 2a, indicating a group of 5 clusters that yield the highest silhouette width value. Similarly, Figure 2b depicted the silhouette plot of these 5 clusters.

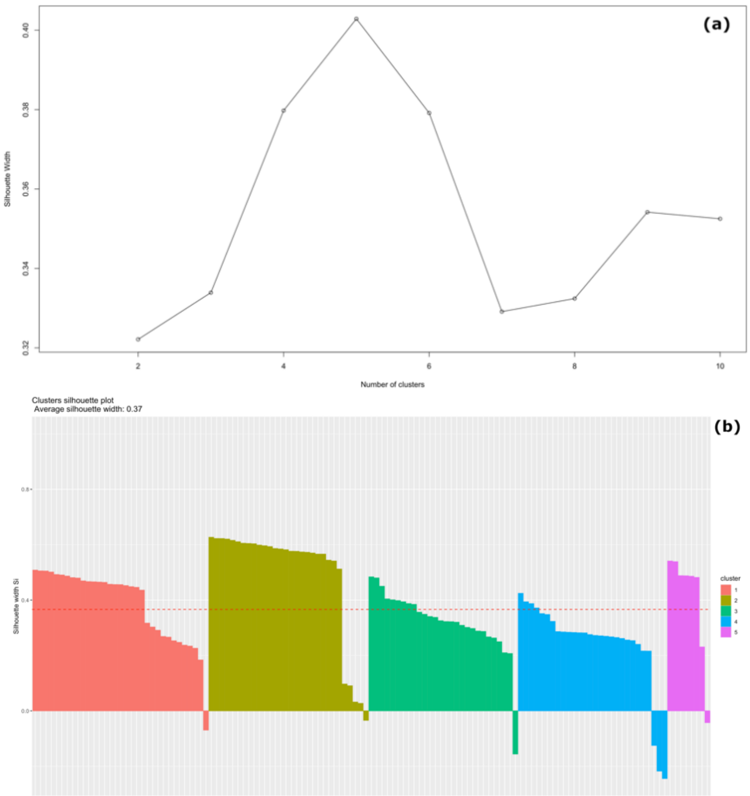

Fig. 3 Umakant Gundecha on entire dataset: Umakant Gundecha on entire dataset: (a) Plot for PAM algorithm, indicating a group of 6 clusters that yield the highest silhouette width value, (b) 5 clusters silhouette plot.

A hierarchical clustering depicted by the dendogram of Figure 3a clearly illustrates the presence of the five distinct groups. However, the limited (two) dimensions of the scatter plot in Figure 3b fall short of capturing the cluster tendencies embedded in the data:

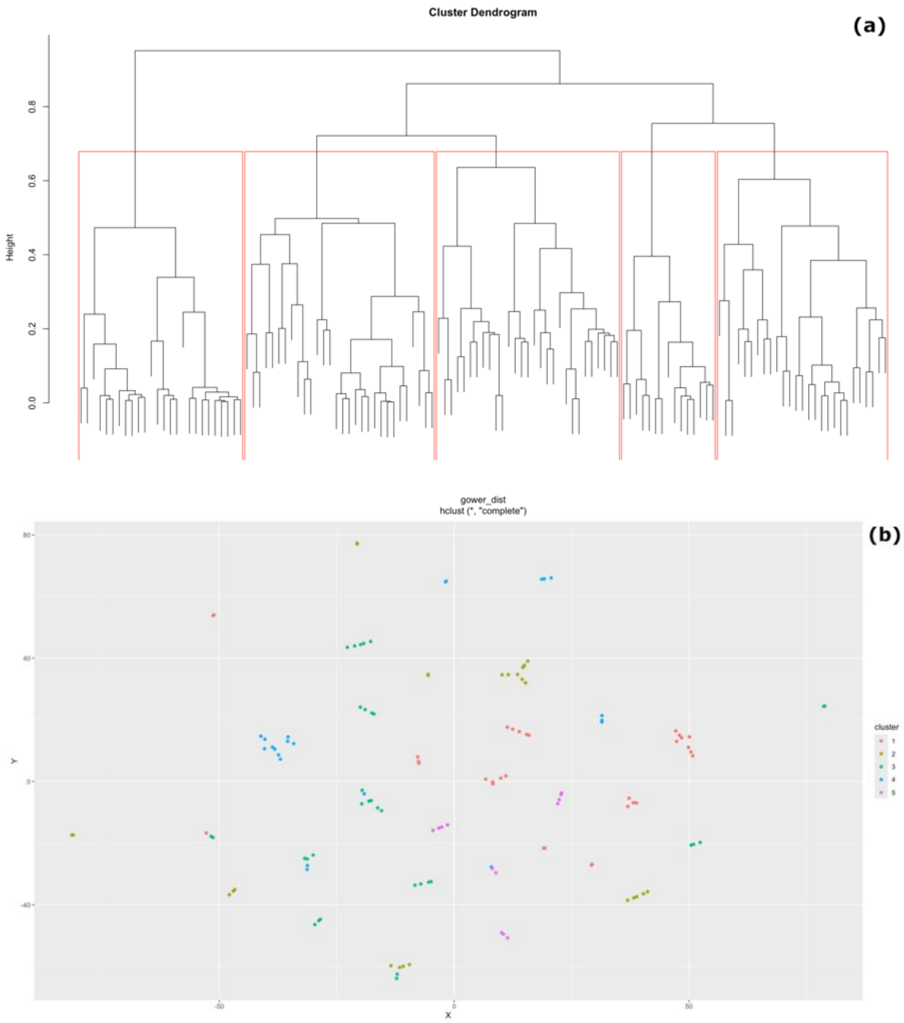

Fig. 4 Umakant Gundecha on entire dataset: (a) dendogram for 5 clusters and (b) two-dimensional scatter plot.

The plot of Figure 4 illustrates the univariate effects of effort across distinct categorical variables, with efforts ranging between low and high levels. Double melodic glides and dual spatially performed gestures seem to require higher effort levels, followed by single/monotonic and finally steady notes with no gestural movement in space.

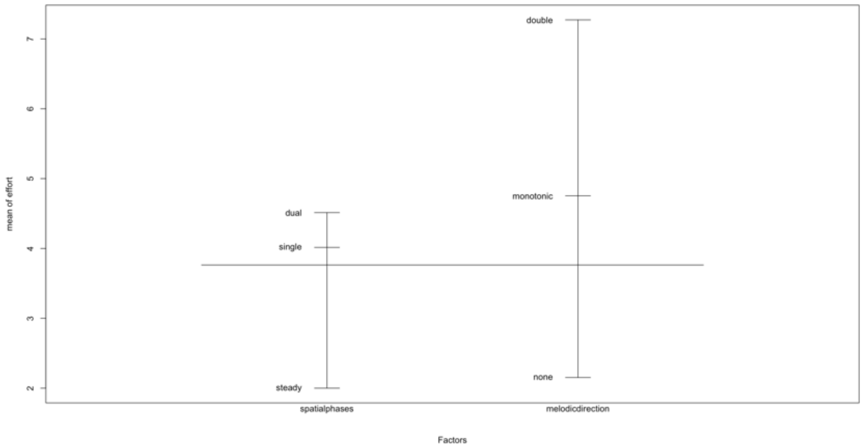

Fig. 5 Umakant Gundecha on entire dataset: univariate effects of effort across the categorical variables of 'spatial phases' and 'melodic direction'.

Figure 4 seems to suggest, among other things, a morphological association between gestures and sound, with double melodic pitch glides most likely being performed in conjunction with gestures executed in opposing (dual) spatial directions, monotonic melodic glides (ascending or descending) with gestures performed in a single spatial direction, and sung steady notes with gestures resembling the action of holding an object without movement in space.

However, the stacked bar chart of Figure 5 indicates that these associations are not as clear-cut. This might possibly suggest that most often gestures are extended in opposing spatial directions to accommodate single (perhaps larger than what the space can afford) melodic movements and vice versa.

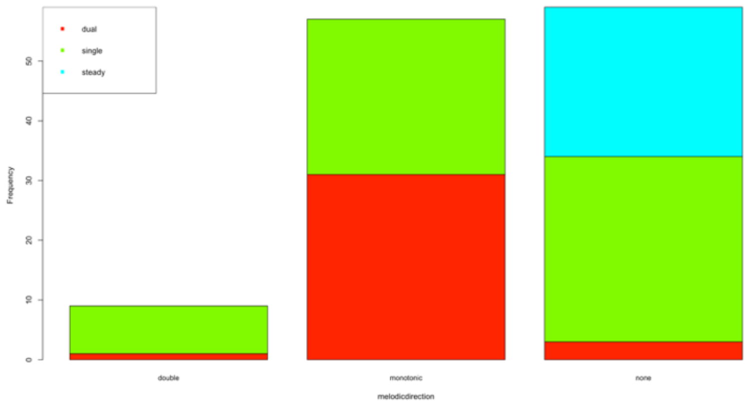

Fig. 6 Umakant Gundecha on entire dataset: stacked bar plots illustrating a rather blurred relationship between melodic direction (double, monotonic, none) and spatial phases of performed gestures (dual, single, none).

5.1.2. Ramakant Gundecha

This section offers a presentation of results for Ramakant Gundecha. Particularly notable is assessing the extent to which they agree with the results for his brother, Umakant Gundecha.

As with Umakant, a cluster analysis was first performed on the entire dataset, including the same set of features, namely:

df = {start, duration, effort, basic gestures, spatial phases, melodic phrases, melodic direction}

The computed agglomerative coefficient measuring the dissimilarity based on Gower's distance was 0.9230606 (i.e. higher than 0.05), indicating significance and suggesting the presence of natural clusters within the dataset for Ramakant too.

A plot for the PAM algorithm is presented in Figure 6a, indicating various options for the optimal number of clusters, with 3 being the lowest number that yields a high silhouette width value. Similarly, Figure 6b depicted the silhouette plot of these 3 clusters.

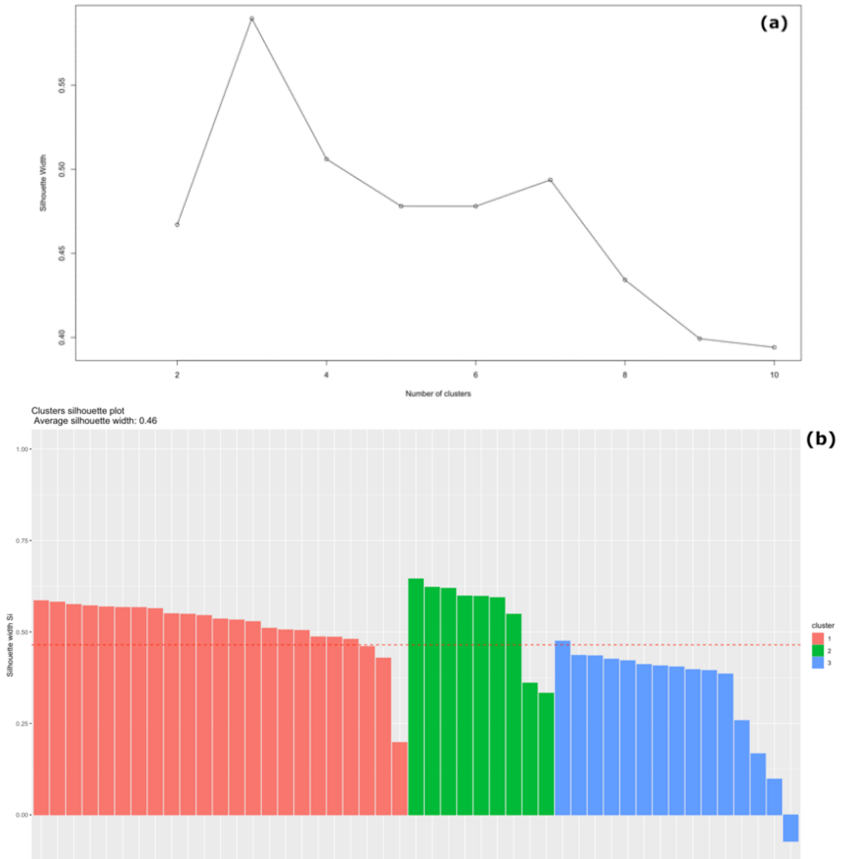

Fig. 7 Ramakant Gundecha on entire dataset: (a) Plot for PAM algorithm, indicating a group of 3 clusters that yield the highest silhouette width value, (b) 3 clusters silhouette plot

A hierarchical clustering depicted by the dendogram of Figure 7a clearly illustrates the presence of the three distinct groups for Ramakant. However, the limited (two) dimensions of the scatter plot in Figure 7b fall once again short of capturing the cluster tendencies embedded in the data:

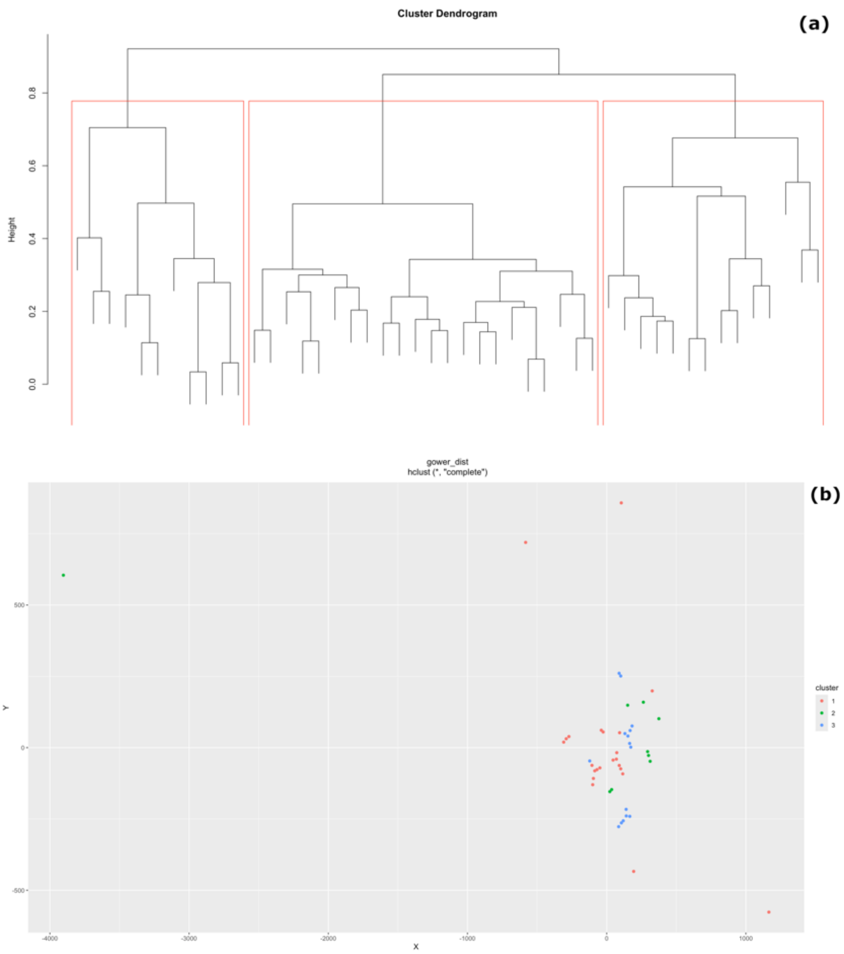

Fig. 8 Ramakant Gundecha on entire dataset: (a) dendogram for 3 clusters and (b) two-dimensional scatter plot.

The plot of Figure 8 illustrates the univariate effects of effort across distinct categorical variables, with efforts ranging between low and medium levels. Similarly to Umakant, double melodic glides and dual spatially performed gestures requiring higher effort levels, followed by single/monotonic and finally steady notes with no gestural movement in space.

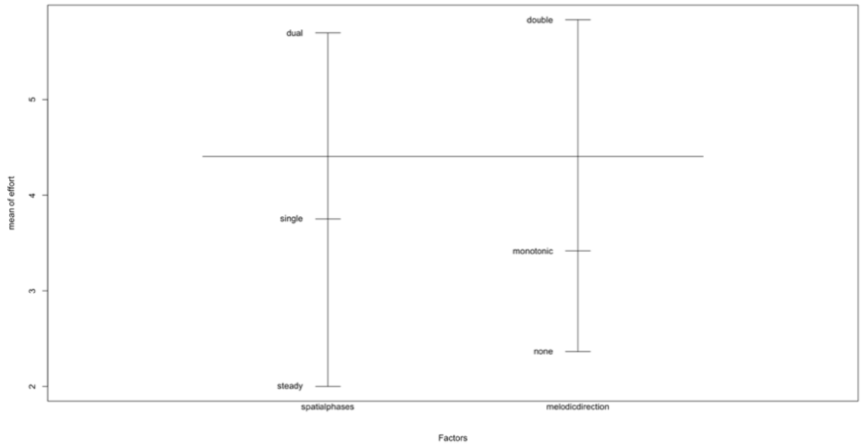

Fig. 9 Ramakant Gundecha on entire dataset: univariate effects of effort across the categorical variables of ‘spatial phases’ and ‘melodic direction’.

Figure 8 seems to suggest, among other things, a morphological association between gestures and sound, with double melodic pitch glides most likely being performed in conjunction with gestures executed in opposing (dual) spatial directions, monotonic melodic glides (ascending or descending) with gestures performed in a single spatial direction, and sung steady notes with gestures resembling the action of holding an object without movement in space.

The stacked bar chart of Figure 9 confirms the trends suggested by the previous Figure 8, indicating a clear-cut morphological association between melodic movements and spatially performed gestures, with double melodic pitch glides most likely being performed in conjunction with gestures executed in opposing (dual) spatial directions, monotonic melodic glides (ascending or descending) performed exclusively with gestures executed in a single spatial direction, and steady notes most likely sung with gestures resembling the action of holding an object without movement in space.

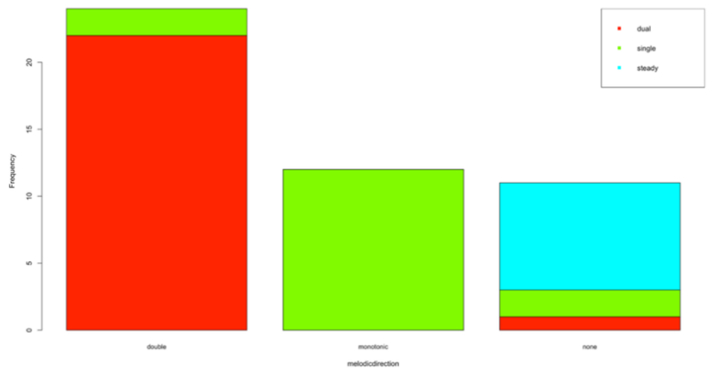

Fig. 10 Ramakant Gundecha on entire dataset: stacked bar plots illustrate a strong morphological relationship between melodic direction (double, monotonic, none) and spatial phases of performed gestures (dual, single, none).

5.2. Idiosyncratic elements

5.2.1. Umakant Gundecha

5.2.1.1. Horizontal side-gestures

This part of the analysis is performed on the subset of horizontal side-gestures, only performed by Umakant Gundecha, classified as {passive-passive; active-passive; passive-active}. The bar plots of Figure 10 reveal that these horizontal gestures are exclusively associated with monotonic ascending melodic glides, regardless of whether the gestures are performed in a single direction in space or in two consecutive opposing directions. This finding deviates from the strong gesture-sound morphological associations of other MIIO classes, whereby double pitch glides are associated with bidirectional gestures and monotonic pitch glides with unidirectional gestures. This might suggest that performing double side-gestures is potentially necessary to address the spatial limitations of arm extension, especially when considering the pitch interval of the melodic movements being sung.

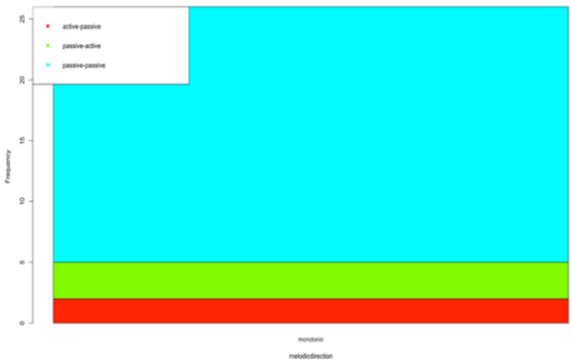

Fig. 11 Umakant Gundecha on side-gestures' subset: stacked bar plots illustrate that all side-gestures are exclusively associated with monotonic, ascending melodic glides.

An alternative use of a heatmap plotted in Figure 11 with the colour code mapped to effort levels rather than number of appearances, reveals association trends between melodic movement types and side-gesture types for Umakant Gundecha.

This plot reaffirms the previously discussed deviation from the commonly anticipated morphological association between unidirectional gestures and monotonic ascending melodic glides, as well as between bidirectional gestures and double melodic glides, additionally suggesting that passive-active side-gestures call for higher levels of effort (mean values ~6.7), followed by passive-passive and finally active-passive side-gestures in the lowest end of the effort scale. Hence, even effort level values deviate from the anticipated behaviour of active gestures calling for higher effort levels than those of a passive character.

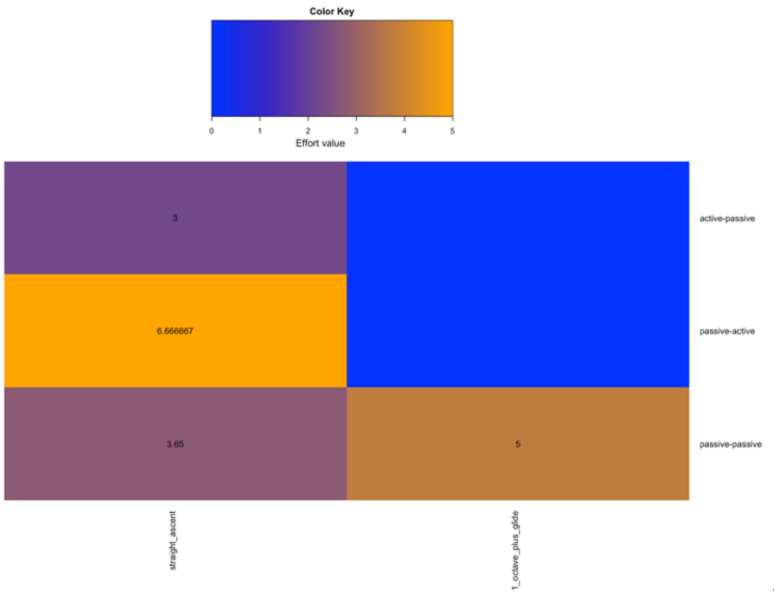

Fig. 12 Umakant Gundecha on side-gestures' subset: alternative use of heatmap with colour code mapped to effort levels rather than number of appearances, illustrating a deviation from the common morphologically-based relationship between gestures and sound and the expected mean effort values. In this context, all side-gestures—whether bidirectional or not—are consistently linked only with monotonic ascending melodic movements. Strangely, passive-passive side-gestures are also executed with higher values compared to those classified as active-passive.

5.2.1.2. Palm shape-vowel association in side-gestures

One notable aspect of side-gestures was the varying palm shape employed for the left hand—from completely open to half-open, half-closed, and completely closed—closely associated with a variety of employed vowels in nom-tom syllables. This suggested a correlation between the hand's and the voice's openness. This observation suggested a parallel between the openness of the hand and the openness of the voice, which was supported by the performer's interview testimony:

> 'Especially this movement [he moves his two hands apart and upwards, with open palms]… I feel that the voice is free, and especially when you go to the Sa; upper Sa [the tonic]… The voice is free. And showing with hands… this open feeling… feeling of openness. [...] When I want to say that the voice is open, very clear, you know... staying there... so the hands are open. And also if I am putting open voice… [he sings a rising melodic movement for approaching the tonic by pronouncing the "a" vowel and keeps both his palms open]. Whereas if I… [he sings the same rising pitch by pronouncing the syllable "num" and moves as if stretching an elastic band, by closing the palms and moving his hands apart]. If I am doing "num", then I will not do this [he moves his two hands apart and upwards, with open palms]. Because the voice is closed [he illustrates the dependence of the palm shape to the used syllable by

repeating the same melodic phrase with either the "num" syllable and palms closed or the "a" vowel and palms open]. So, it depends on the variety of notes… if it is open, if it is closed, or if it is half-closed [he sings "ri" and adds]. Like "ri", what is "I"? It is half-closed. "Num" is totally closed. "A" is totally open. "Ri" is half-open or half-closed'.

(Umakant Gundecha, interview, Bhopal, India, January 16, 2011)

These ideas are further substantiated by an interview with Mohi Bahauddin Dagar, a descendant of the prominent Dagar family in the Dhrupad tradition. During a discussion centered around the usage of the term 'pulling' for specific syllables ('how much do you pull the "ri"'), Dagar's insights prompted further inquiries into whether he employed the verb 'pull' due to its association with gestures commonly performed on the rudra vina3 when transitioning to a higher pitch through a glide. His response was as follows:

'Yeah. You are right. Because you are physically pulling the note. Because… [he gives a few examples where he imitates the pulling of a string on the rudra vina while singing various pitch glides on the syllables "rae", "na"] when you are playing the simple notes [here he means syllables], it is always on the note [meaning that the pitch should not move much]. Sometimes you will pull that note. But when you pull a simple syllable like "rae" – "ae" [closed "a" as in "ɜ" of the IPA chart] it will be one note; it will never do that [he sings a double-sloped pitch glide], because that would be grammatically wrong. The "a" [open] you will pull more [he makes a longer phrase starting with "ri" and transforming it to an "α", which is used for making double-sloped pitch glides]. So, "ae" ["ɜ" of the IPA system] will go for one note. "A" ["α" of the IPA system] will go for twice the length or three times the length. And "I" will go higher. And "e" will go even higher. It [rudra vina] is an instrument of measure. It measures all the smallest microtones. Which is a strong characteristic in Dhrupad. So, that's why the rudra vina is used. Because all the different Re's [Re is the note D in western music, the 'e' here corresponding to "e" in IPA], all the different Sa's [Sa is the note C in western music, the "a" here corresponding to "α" in IPA], all the different Ga's [Sa is the note E in western music, the "a" here corresponding to "ɜ" in IPA] you can play them on the vīṇā and then you can… even an entire phrase you can time it [he gives examples with different syllables (ta, na and ri) while moving his hands]. So, which syllables to use… [is important]. Because in Hindi language there is the "i" and "ee", the "u" and the "uu". And there is "ra", "na" [syllables]. So, there are three things [meaning the notes, the type of syllable used and the quality of the way that syllable is pronounced]'.

(Mohi Bahauddin Dagar, interview, Rotterdam, the Netherlands, 28 September 2010)

All these concepts are explored here systematically. Defining what constitutes an open voice may not be immediately apparent. According to the International Phonetic Association, the articulatory qualities of vowels are influenced by the shape and size of the oral cavity and the shape of the lips. In practice, this means they are determined by the combination of three factors, as appearing in Table 5.

[3] The main instrument used in Dhrupad, a type of stick zither played with a plectrum, with the left hand being responsible for stopping, pressing, pulling, and bending the strings. Adjusting the degree to which the strings are pulled results in changes to the pitch.

Table 5 IPA vowel features

IPA System	position		
Vertical position of tongue (vowel height)	close	near-close	open
Horizontal position of tongue (vowel backness)	front	central	back
Roudness of lips (lips shape)	unrounded (neutral)	protruded	compressed

Vowel height: This is determined by the relative vertical position of the tongue in the mouth. 'Close' indicates the tongue is positioned as close as possible to the roof of the mouth, while 'open' means it is as far away as possible.

Vowel backness: Achieved through the relative horizontal position of the tongue in the mouth, ‘front’ implies the tongue is as far forward as possible, while ‘back’ means it is as far backward as possible.

Lips shape: Determined by the roundness of the lips or the degree of aperture between them. It can range from ‘unrounded’ (relaxed lips, as in ‘ɑ’) to ‘protruded’ (when the corners of the mouth are pressed together but the lips protrude, as in ‘u’) and ‘compressed’ (when both the corners and lips are pressed together, as in ‘ɤ’).

The combination of these three factors is dictated by the tongue's position in the oral cavity, illustrated in Figure 12.

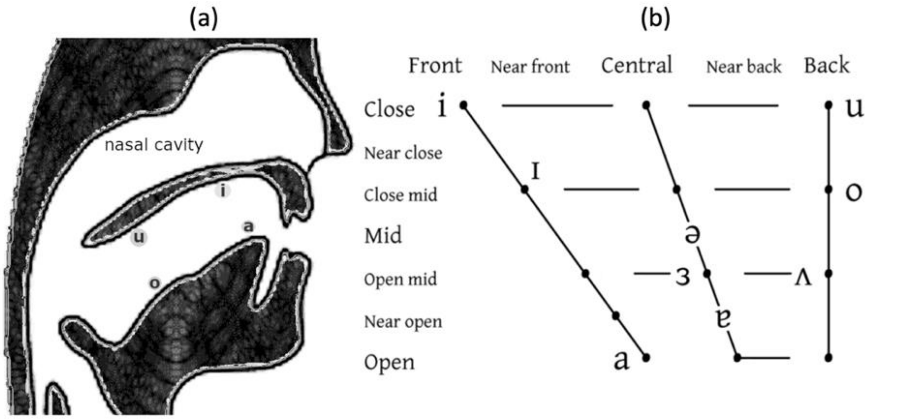

Fig. 13 Adaptation of (a) the positioning of the tongue for front and back vowels as proposed by (Catford 2004), and (b) the cardinal vowel chart as proposed by (Zsiga 2013) to the specific needs of the analysis for Umakant Gundecha.

It is important to clarify that the term ‘open’ (vs. ‘closed’) concerning sound quality should not be confused with the ‘open’ (vs. ‘close’) designation in the cardinal vowel chart. The former describes an acoustic quality, while the latter is an anatomical descriptor for the vertical distance of the tongue from the roof of the mouth. Additionally, the chart pertains to spoken vowels rather than those sung. In singing, vowel articulation can vary based on the melodic context and musical style.

The notion of ‘openness’ in the voice may be linked to the lax vs. tense quality, indicating the looseness or tightness of each vowel. Unlike the horizontal position of the tongue, this quality is determined by the tension of the tongue.

Figure 13 presents the results of an association analysis between the vowels of sung nom-tom syllables (e.g., ‘om’, ‘num’, ‘ta’, ‘ra’, ‘na’, ‘ri’) and the shape of the left-hand during side-gestures. Vowels, annotated based on the IPA standard, include ‘o’ (as in ‘om’), ‘u’ (as in ‘num’), four variations of ‘a’ ranging from quite closed to quite open (as in ‘nā’, ‘na’, ‘rā’, ‘ra’, ‘ta’), and two variations of ‘i’ (as in ‘ri’).

In broad terms, the findings suggest a clear correspondence between the openness of vowels (in terms of the vertical position of the tongue) and the openness of the left palm. This aligns with both the IPA system and the musician's reported observations on the relationship between hand shape and vowel articulation when approaching a stable note in the raga. Specifically, the open ‘a’ is predominantly associated with an open or half-open hand, while a closed 'a' correlates with a closed or half-closed palm. Both types of ‘i’ and the ‘o’ vowel are executed with a half-closed palm shape.

A potential deviation from Umakant Gundecha's interpretation in the interview is the association of the supposedly closed vowel ‘u’ with an open or half-open hand shape. It is possible that the musician's reference to the syllable 'num' being associated with a closed hand relates to the quality of the voice described as free vs. closed, which involves factors beyond the simple anatomical position of the tongue. A free or open voice is characterized by roundness, relaxation, lack of restriction, richness, and resonance, possibly linked to the lax vs. tense quality of a vowel. Adjustments, such as lifting the soft palate and lowering

Umakant Gundecha: hand shape vs. vowel								
close → open vowels								
close to mid-close vowels				**mid-open to open vowels**				
‘u’	**Close to mid-close ‘i’**		**‘o’**	**close → open‘a’**				
u	**i**	**ɪ**	**o**	**ə**	**ɜ**	**ʌ**	**ɐ**	**a**

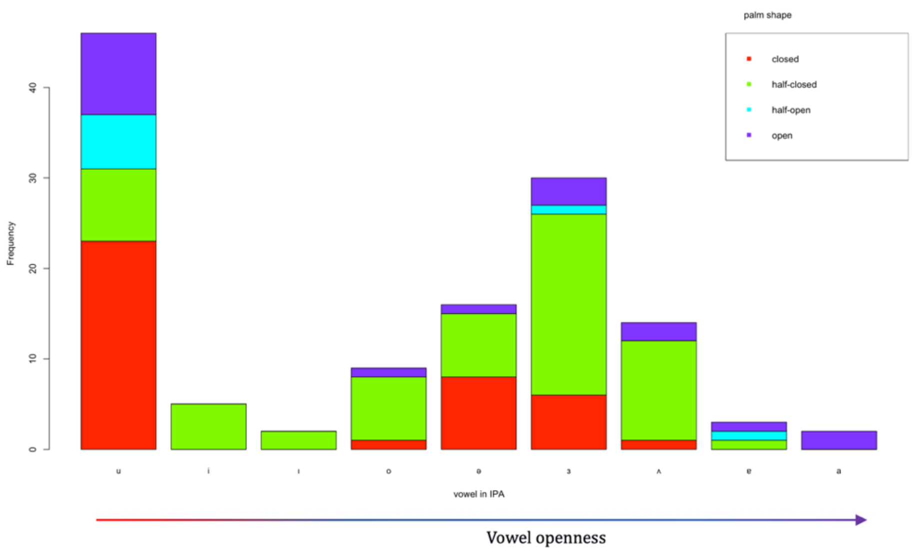

Fig. 14 Umakant Gundecha on side-gestures’ subset: Stacked bar chart of left-hand shape (closed; half-closed; half-open, open) versus vowel openness (close; mid-close; mid-open; open).

the larynx through ideal positioning of articulators, can contribute to achieving an open voice. This involves dropping the jaw, protruding the lips, and compressing the tongue downwards, increasing the mouth cavity size and creating a resonant sensation at the back of the mouth. This approach allows the vocal tract to maintain an open posture, preventing tension in the throat area. Consequently, qualities of openness, flow, or freedom in the voice can be produced for both ‘a’ and ‘u’ vowels, avoiding a throaty quality. For instance, a common instruction to produce an open ‘u’ is to wrap the lips around an ‘a’ vowel. On the contrary, variations of ‘i’ and ‘e’ vowels appear to be more tensed.

5.2.2. Ramakant Gundecha

5.2.2.1. Vertical lifting gestures

This part of the analysis is performed on the subset of vertical gestures performed by Ramakant Gundecha, classified as {lifting; lifting and letting fall} (i.e. single versus double-phase gestures). While Umakant systematically utilizes gestures in the horizontal plane, Ramakant appears to make mostly use of the horizontal plane. The barplots of Figure 14 indicate a strong morphological relationship between vertical (lifting) gestures and sound, with double melodic pitch glides most likely being performed in conjunction with ‘lifting and letting fall’ gestures executed in opposing (dual) spatial directions and monotonic melodic glides (ascending or descending) with lifting gestures performed in a single spatial direction.

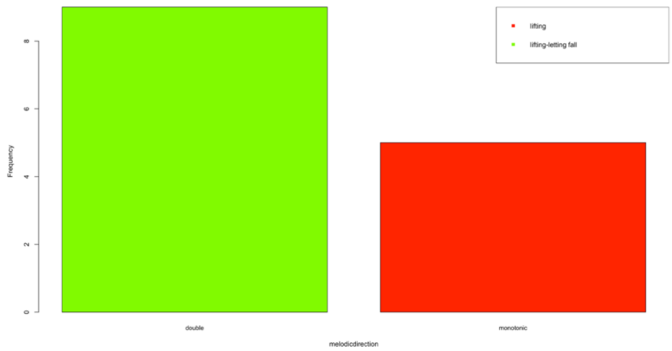

Fig. 15 Ramakant Gundecha on lifting gestures’ subset dataset: stacked bar plots illustrate a strong morphological relationship between melodic direction (double, monotonic, none) and the spatial direction of performed vertical gestures, i.e. lifting (single spatial engagement) versus lifting and letting fall (dual spatial engagement).

A heatmap plotted in Figure 15 with the colour code mapped to effort levels instead of the number of appearances, reveals association trends between melodic movement types and side-gesture types for Ramakant Gundecha.

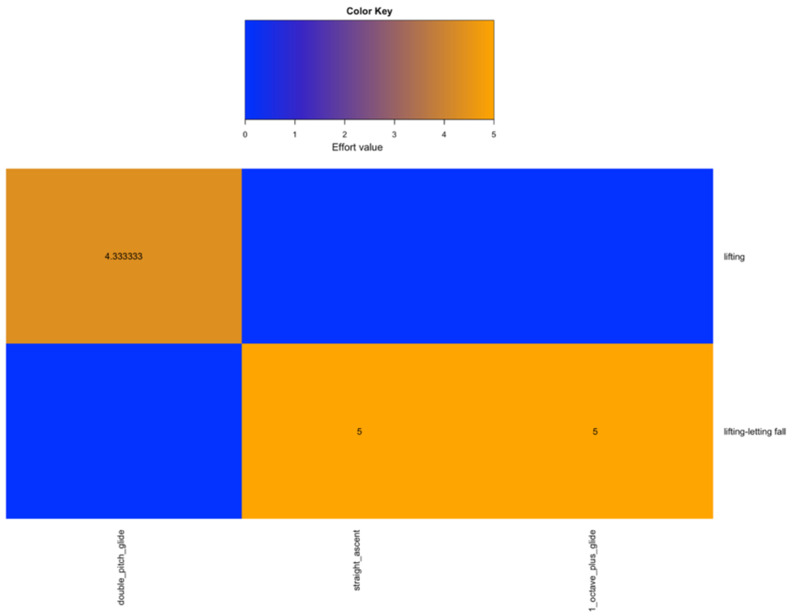

Fig. 16 Ramakant Gundecha on lifting gestures' subset dataset: alternative use of heatmap with colour code mapped to effort levels rather than number of appearances, illustrating a strong morphological relationship between lifting gesture types (lifting versus lifting and letting fall) and melodic phrases (double pitch glides versus monotonic ascending melodic movements, of either small or large pitch interval).

Specifically, the heatmap confirms the strong morphological association of unidirectional 'lifting' gestures with monotonic ascending melodic glides (of either a small or a larger pitch interval, comprising one octave or more) performed most likely with higher effort levels (mean effort values 5 out of 10), and of bidirectional 'lifting and letting fall' gestures with double pitch glides performed with slightly lower effort levels (mean effort values ~4.3 out of 10).

6. Conclusion

This study delved into a joint performance by two Dhrupad singers, who incidentally are siblings and share identical musical backgrounds, exploring the idiosyncratic ways by which they encompass and perform Manual Interactions with Imaginary Objects (MIIOs) and the way MIIOs are associated with effort levels and the melodic context. From the examination of annotated audiovisual material concerning the Gundecha brothers in previous research work it has been inferred, that there is a significant level of consistency in the movement repertoire and in the association between gestures, melodic phrases, and effort levels, which is maintained by the musicians throughout the entire performance and suggests a shared understanding of certain underlying concepts between the two vocalists.

However, it is also noteworthy to observe that, despite their common musical experience, the brothers also display some distinct gestural variations and a level of adaptability in how they render and convey the same melodic mode, namely raga Bhupali. Even in aspects like spatial progression, direction, grip type, and the musician's active/passive approach to perceived resistance, diversity in associated gestures is evident. This highlights the dual nature of performer idiosyncrasy, blending unconscious personal style with conscious, intentional choices in embodying music. The emphasis of that paper was primarily centered around the deviations and disparities in the gesturing manners of the two brothers.

At the outset, the complete dataset for each performer underwent analysis, considering seven shared movement and melodic characteristics. This examination uncovered a distinct clustering pattern disparity between the two brothers, potentially indicating individualized deviations in how they express the common raga-specific melodic material. Subsequently, habitual idiosyncratic gestural behaviors were examined for each brother, with specific attention given to contrasting Umakant Gundecha's side-gestures in the horizontal plane with Ramakant Gundecha's lifting gestures in the vertical plane.

For Ramakant Gundecha’s vertical (lifting) gestures, findings confirmed the anticipated strong morphological associations between gestures and the voice. Specifically, unidirectional ‘lifting’ gestures were most likely performed with monotonic ascending melodic glides and higher effort levels, while bidirectional ‘lifting and letting fall’ gestures were most often linked to double pitch glides performed with slightly lower effort levels. In contrast, for Umakant Gundecha’s side-gestures, a deviation from common morphological gesture-sound associations was revealed. Instead of the anticipated link between unidirectional gestures and monotonic ascending melodic glides, as well as between bidirectional gestures and double melodic glides, all side-gestures—whether bidirectional or not—were consistently linked only with monotonic ascending melodic movements. Strangely also, passive-passive side-gestures were executed with higher values compared to those classified as active-passive. Finally, findings suggested a notable correlation—only evident in Umakant Gundecha's case but not observed in Ramakant's—between the shape of the palm and the articulation of vowels based on the IPA system, consistent with the musician's interview testimony.

The results provide useful insights in the ethnomusicology and embodied music cognition endeavours about the way that Dhrupad musicians conceptualize melodic movement and exert effort during improvisation. It also offers essential direction regarding music and motion capture technologies, including multi-camera optical passive marker-based systems, inertial full-body systems, and electromyography sensors. The guidance extends to identifying acoustic and motion features that can capture the nuanced gestures of Dhrupad vocalists, enabling the development of quantitative approaches to complement current qualitative methodologies.

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