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The individuality of metrical engagement: describing the individual differences of movements in response to musical meter

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Abstract. Evidence behind theories about musical meter and rhythm is based on averages across empirical sets of data. Theory is also commonly forged from general observations of music practices. Ethnomusicology describes rhythm and dance based on patterning characterizations inside cultures. Without neglecting the value of that knowledge, so far we know very little about how individuals´ bodies respond to music. Derivation of common laws from controlled experimentation may have obfuscated the understanding of differences between individuals, their music, movements and dance. How large are these differences as expressed, and how our bodies map these idiosyncrasies are questions that still need answers. In this paper we look into a detailed account of differences between individuals by looking at their free movement responses to music. Using the state-of-the-art of motion capture technologies and a set of analytical techniques we uncover the embodied metric organization, exposing the idiosyncrasies between different people.

Keywords: movement, rhythm, meter, embodiment

1 Introduction

Most of the evidence behind the theories about musical meter and rhythm is based on averages across empirical sets of tapping data. Tapping in synchrony with music has been and is still considered a canonical task to gather knowledge about meter encoding in music cognition, under the assumption that meter perception is related to the listener´s sensitivity to time regularities [1]. Therefore, theoretical and/or idealized hierarchies of accented musical structures [2] can be scrutinized by means of entrainment, that is, the ability to keep time with the music [3]. Data collection of beat responses in laboratory research environments is thus assumed to account for the experience of time structure during perception [4, 5] and is intended to show the way sensorimotor synchronization with time takes place in performance [6].

However, tapping may offer a constrained rendition of metric experience. According to recent developments in cognitive science, the estimation of metric experience by means of tapping may not take into account the complexities of the whole body involvement with music. Under the umbrella of new insights in the science of mind [7, 8] authors such as Leman [9] helped to develop an embodied perspective for the study of music, namely the embodied music cognition. According to this view, engagement of the whole body in movement with music is an unavoidable component of music cognition, and the complexity of its study requires that movement analysis be tackled, that is to say, described and analyzed, in terms of the complexities of cultural, naturalistic, ecological and scientific settings. Not only are contexts of real musical practice (music performance and dance) (see for example [10, 11]) ideal scenarios for embodied cognition research, but also are data collection from music and movement samples obtained in lab environments using mediation technologies and/or designing experimental settings that take into account the variability of musical practice (see for example [12, 13, 14]).

The fields of ethnomusicology and cognitive neuroscience have also dedicated combined efforts to describe the comparative and biological bases involved in rhythmic and dance patterns. Pulse salience is posited as a cognitive process intrinsically related to beat structure, as it appears hypothesized in music cognitive systems theory [15]. But in order to keep track with the beat or tactus (the most relevant feature of periodicity, present both in theories of musical meter and entrainment) the models of cognitive processing sometimes shape metric experience aligning experimental data on human movement to the temporal corset of the metrical grid. Expected regularities within and between individuals support generalizations that describe common features in musical experience, allowing us to gain knowledge about the commonalities of socio-cultural practices. The anthropological perspective also brings some insights about the new challenges of musical inquiry. It has been suggested that (i) constraints of scientific procedure, (ii) the relevance of socially created significance, and (iii) methodological differences in human science and cultural studies are important issues to take into account. Consideration of their implications might lead to distinguish between what is the exact, universal, and decontextualized and what is culturally situated. This is the main concern on Geertz's idea of approaching people as individuals, and trying to understand why they do what they do [16].

But so far we know very little about differences between individuals and how their individual bodies respond to music. The necessity to derive common laws from controlled experimental results may have obfuscated the importance of understanding the range of individual differences between people, their music, movements and dance. How large are these individual differences, how they are expressed and how our bodies map these idiosyncrasies are questions that still need to be approached.

In this paper we look into a detailed account of individual embodiment of metrical properties by exploring the analysis of their free movement responses to music styles.

We collect the movements using the state-of-the-art of motion capture technologies associated to a set of recent analytical techniques. These techniques help to uncover the organization of metrical accents along the movement. The organization of these accents around the body and across musical structure is used to expose the idiosyncrasies between different personal profiles.

2 Method

2.1 Participants

Two subjects (1 Argentinian and 1 Brazilian) were selected out of a sample of 12 participants in a cross cultural study on free movement responses to Argentinian and Brazilian music (for a full description of the main cross cultural study see Naveda et al in this symposium). Participants were selected because, despite their belonging to two different cultural environments, both reported familiarity with Chacarera style. The motion pattern of both participants presented consistent samples of metrical adjustment, but deploying different morphologies of movement.

2.2 Apparatus

The movements of the participants were recorded using a motion capture system (OptiTrack) composed of 6 infrared cameras and a control system (PC). Before the experiment, 4 rigid-body groups of markers were placed at the torso (4 markers), head (4 markers), left (4 markers) and right (4 markers) hands of the subjects, totalizing 16 markers. The subjects were also oriented to move freely respecting a limit at the center of the recorded area (signalized on the ground). The stimuli (mono aural samples) were played through one speaker attached to a sound card and a computer. The stimuli were synchronized with video and mocap recordings by means of synch markers in the audio, mocap and video. Video recordings were realized for reference purposes.

The pre-processing of mocap files involved the preparation for synchronization, basic filtering and cleaning in the software Motive (Natural Point). Further processing, normalization and calculation of features were realized using algorithms and tools from MocapToolbox [17] and Samba toolbox [18], for Matlab (Mathworks).

2.3 Procedure

The subjects performed two tasks for two styles of music stimuli: chacarera and samba. In the first task the subjects were asked to try free and spontaneous movement "strategies" in response to the music stimuli. Strategies were defined and instructed as a way to respond to the rhythm of music being played. No other orientation, limitation or task was given and subjects were free to move around the recording area.

In the second task the subjects were instructed to choose the best movement strategies experimented in the first part. Then, the subject was asked to continuously perform the chosen strategy until the end of the musical sequence (stimulus). The analysis presented in this study is applied to 12 bar length segment selected of the second task. In this study we only consider the movement of the hands.

2.4 Stimuli

Chacarera music is, along with *zamba*, *milonga*, *malambo*, and of course *tango*, one of the most representative rhythms of Argentina. Although it does not have a fixed instrumentation, instruments most frequently reported are Spanish guitar, *bombo* (a kind of percussion instrument like a drum made of wood and leather), violin and voice. The accompaniment texture is generally performed by guitar and *bombo*. In the stimulus used in this study, instrumentation consists only of a *bombo* percussion and clapping hands. The *bombo* percussion is distinguished by two timbres: sounds produced by tapping the wood ring and sounds produced by tapping on the leather patch. Thus, the rhythmic structure of chacarera is the result of the combination of sharp sounds matching the ring taps and marking the ternary (6/8) meter, and low sounds matching the patch taps and marking the binary (3/4) meter that overlap.

Chacarera is mainly characterized as a courtship dance of loose and independent couple of dancers with animated movement. There are few records that document their roots and it is impossible to know whether it was danced before 1850. It belongs to the picaresque dances, which in turn come from an old generation of European dances that at the end of the colonial era were irradiated from Peru through South America (except Brazil).

Chacarera music exhibits clear Western metrical characteristics such as the beat (tactus) and bar metric levels; however, the rhythm basis is a polyrhythmic structure of crossed binary and ternary meters (6/8-3/4) (see an abstract scheme in Figure 1). Timbral differences are related to meter: sharp sounds correspond to 6/8, while low sounds correspond to the second and third time of 3/4. They are relevant to hear in the rhythmic texture pattern this typical sound of chacarera [19].

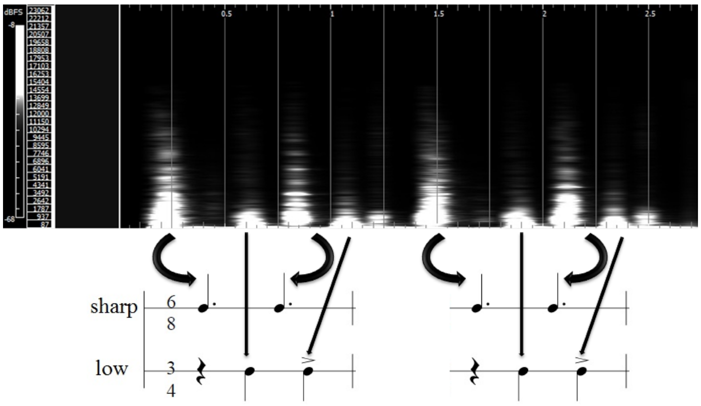


Fig. 1. Spectrum analysis and overlapping music notation of a bar extracted from the rhythmic base of *Chacarera* used in the study. The two lines overlapped show the 6/8-3/4 textural pattern of the crossing meter. Ternary beats appear on top and binary beats on bottom, respectively.

The rhythmic basis used in the present study is formed by 4 ternary beats-6 binary beats x 12 eighth-note structure, that is to say, 12 metrical elements organized polyrhythmically in groups of 3 and/or 2 eighth-notes by beat, according to its correspondence to the binary and/or ternary structure, respectively. The metrical fragment over which subject´s movement pattern is organized and repeated for 60 seconds represents two 6/8 - 3/4 bars (see Table 1). Data processing takes into account the 12 repetitions collected from the recordings. As to interpretation of data analysis, one of the two metric grids from table 1 will be used to present results in the way that is most convenient.

Table 1. Equivalences between metrical segments for 12/8 and 3/4 in *Chacarera*.

12/8 cues	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3
3/4 cues	1.1a	1.2a	2.1a	2.2a	3.1a	3.2a	1.1b	1.2b	2.1b	2.2b	3.1b	3.2b
	1st bar						2nd bar					

2.5 Movement analysis

In this paper we make use of movement analyses that support the description of intrinsic (individual) metrical structures in free movement responses to music. This kind of analysis is very specific because it should encompass the variability and flexibility of free movements and be able to represent the cross-modality between music and movement. If we assume that movement and music share metrical properties, the representation of these properties can be realize in two ways: (1) visualizing musical information in the structure of movement trajectories or (2) visualizing movement information in the (metrical) structure of musical. The methods used in this study reflect these analytical possibilities are briefly described below:

1. **Movement** properties represented in the **musical** structure:

   (i) **Accumulative velocity levels** across metric levels [21] - This analysis is calculated as the accumulative instantaneous velocity deployed in each metrical segment. It reflects the distribution of energy represented across the metric levels annotated in the stimuli. Its profile and variability across metric levels indicates where the subject engage into energetic profiles of movement and how they vary in relation to the cycles of metric levels.

   (ii) **Density of directional change** [21] - This analysis is realized by measuring the changes of directions in the axes of trajectories and representing the distribution in an histogram across the metric levels annotated in the stimuli. It estimates the density of sharp changes of trajectory direction, which might indicate musical metrical accents in the morphology of movement trajectories.

2. **Musical** properties represented in the **movement** structure:

   (iii) **Topological Gesture Analysis** [12] - This analysis uses the movement trajectories to support the representation metrical categories of music stimuli are distributed across space of trajectories. It makes possible to visualize the regions around the body where music properties accumulate over time.

These methods are not aimed to provide an statistical account of the cues. Instead, they provide an exploratory visualization of how music properties are objectively embodied in the cross-modal individual relationships encoded in the space (topology) and form (morphology) of the gesture. We borrow from computer science and systematic musicology the possibilities of analysis and visualization that are used to drive observations in the form of cultural studies and ethnography. In what follows, the analyses are applied to two case studies, involving detailed analysis of each subjects movement responses to the properties of chacarera music.

3 Case Studies

3.1 Case 1.

Subject 5 is a 27 year-old Brazilian male that works as a DJ and dance teacher. He is a dancer and reported being familiar with the music of chacarera.

3.1.1 Cumulative velocity level Analysis. Analysis of distributions of cumulative velocity across metric levels (right hand)

Analysis of average velocities shows two contrasting moments. Moment 1 starts at 3.2b; ends at 3.2a; while moment 2 starts at 1.1b, keeps pace at low velocity, and ends at 3.1b, where motion pattern begins again and so on until the 12th repetition is finished (Fig. 2). The cumulative velocity of movement shows an increased/decreased energy profile that is best understood according to a binary metric pattern (3.2b-1.1a; 1.2a-2.1a; 2.2a-3.1a; 3.2a/1.1b). Inference from this analysis indicates that the subject is configuring the motion pattern mainly around a binary 3/4 meter.

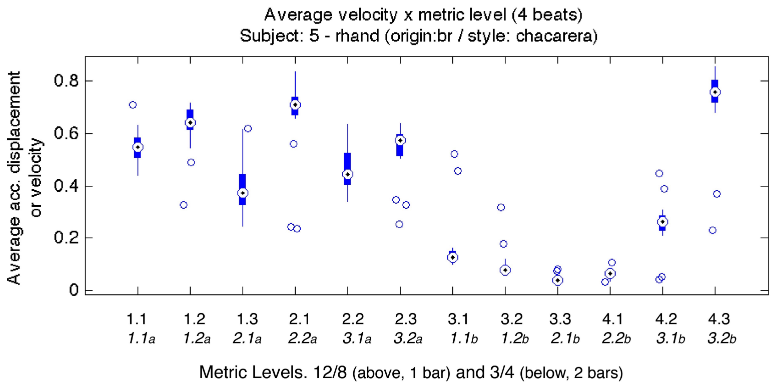
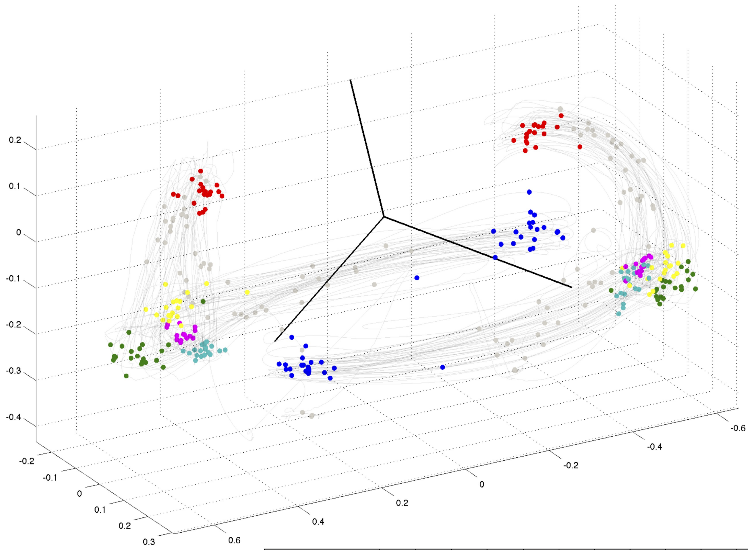


Fig. 2. Levels of accumulated velocity for subject 5 (Brazilian), right hand. Stimulus: chacarera music (N=12).

3.1.2 Topological Gesture Analysis (TGA) (right and left hand)

In order to obtain a more direct representation of motion temporal articulation, we used some concepts of the Topological Gesture Analysis (TGA) methodology [12]. The TGA relies on the projection of musical cues onto gesture trajectories, which generates point clouds in the three-dimensional space. Point clouds can be interpreted as regions in space equipped with musical qualities, which gives us an idea about the relationships between gesture, space, and music properties. In order to project the metric units of the music stimuli we used color cues associated to metric levels. These colors help to associate the point-cloud sets to their metric location onto the morphology of the movement pattern (Fig. 3).

The organization of color point-cloud sets in Fig. 3 follows results of the analysis in Fig. 2, by illustrating the distribution of the metrical properties in the space. The subject uses a "L" shape gesture where the extremities are populated by 1st and 3rd binary beat cues. The space in the middle is populated by the remaining beat levels. Since first and third beats occupy different regions in space, the topology of the music-gesture space suggests a 3/4 metrical structure.



12/8 Cues 1 Bar	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3
3/4 Cues 2 Bars	*1.1a*	*1.2a*	*2.1a*	*2.2a*	*3.1a*	*3.2a*	*1.1b*	*1.2b*	*2.1b*	*2.2b*	*3.1b*	*3.2b*
Color Cues - S5												

Fig. 3. Point-cloud representation in the 3-dimensional space showing the trajectories (after normalization) of subject 5, with metrical categories projected on it.

3.1.3 Analysis of Density of Directional Changes

In a general overview, we focused on the spikes data of the first component (chart 1 of Fig. 4) at 1.1, 1.3 and 2.2., that exhibit a slight anticipation of 1.1 (located at the right border of the chart). We expected to find a spike at 3.1 but here the events occur in a disperse way. This trend is contrasted in 1.3 and 2.2, where we observe a higher event density that conveys subject´s precision and synchrony along the pattern recurrences.

Another unexpected result was found between positions 3.1 and 4.3, were the analysis of accumulated velocity had shown a rather static moment in the trajectory movement development (see Fig 2). Instead, we observe in the histogram continuous activity throughout this metric segment. We realize that body “resonant” movements like knees up/down articulation that might “lead” the other joint’s movement and produce “noise” in the data might cause it.

3.2 - Case 2

Participant 2 is a 50 year-old Argentinian female. She is a pianist and reports high familiarity with Chacarera. Frequently plays and dance this music. She also informs competence playing the bombo (see 2.3 above).

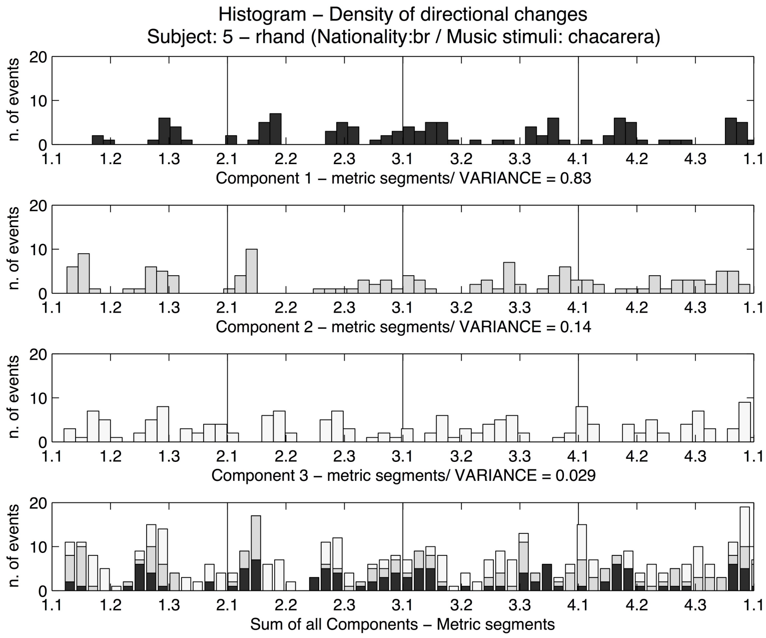


Fig. 4. Density of directional events across 1 bar of chacarera (12/8), for subject 5. The shades of gray indicate the proportion of events associated with each PCA components.

3.2.1 Cumulative velocity level Analysis. Analysis of distributions of cumulative velocity across metric levels (right and left hands).

Left Hand

The analysis of average velocities in left hand (see Fig.5) shows in the first place repetition of the energy profile patterned by bar, that is to say, the whole 2-bars pattern is divided into two similar profiles. Second, an internal contrast is observed: lowest velocities are at metric location 1.1a (1st binary beat) and highest velocities at metric location 3.1a (3rd binary beat) in both bars are identified in the fragment. The remaining metric locations (1.2a, 2.1a and 2.2a) also show high levels of average velocity, probably due to the quality of sharpness in each of the attacks of the performance gesture. Finally, location 3.2b shows low velocity level probably due to the lack of activity observed in the next metric unit (1.1a).

In sum, left hand velocity profile seem to follow the pattern of movements deployed during performance of the low line in the *bombo* (see Fig 1). This means that the 1st beat is muted and the 2 and 3 articulated in percussion. An alternative explanation would be the organization of the profile starting at the position 3.1b. In this explanation, we would obtain a velocity profile of three descendant metric units

(3.2b, 1.1a, 1.2a, etc.) and in this way we would have four groupings that would result in a ternary organization of velocities. An observation of the video recording prompted the first interpretation. But is interesting that somehow the polyrhythm chacarera profile emerged in velocity cues.

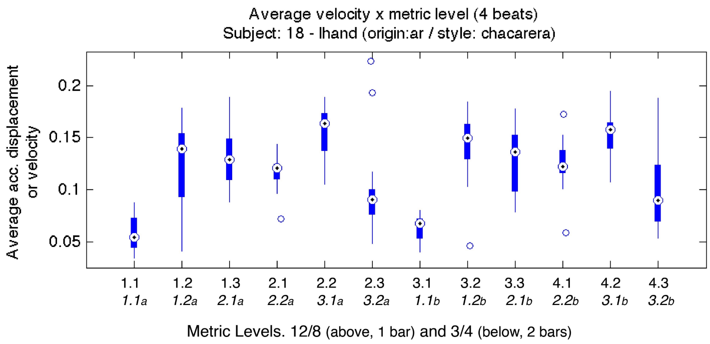


Fig. 5. Levels of cumulative velocity for subject 18 (Argentinian), left hand. Stimulus: chacarera music (N=12).

Right Hand

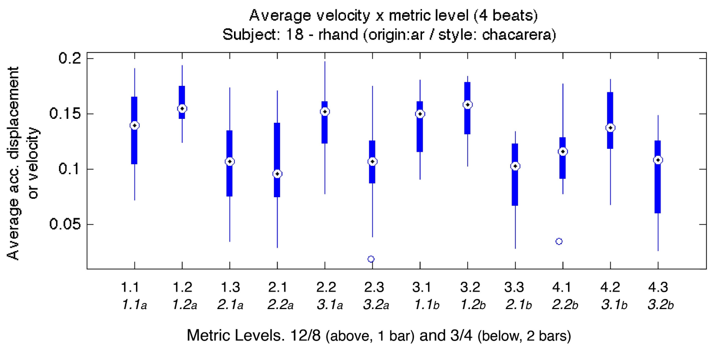
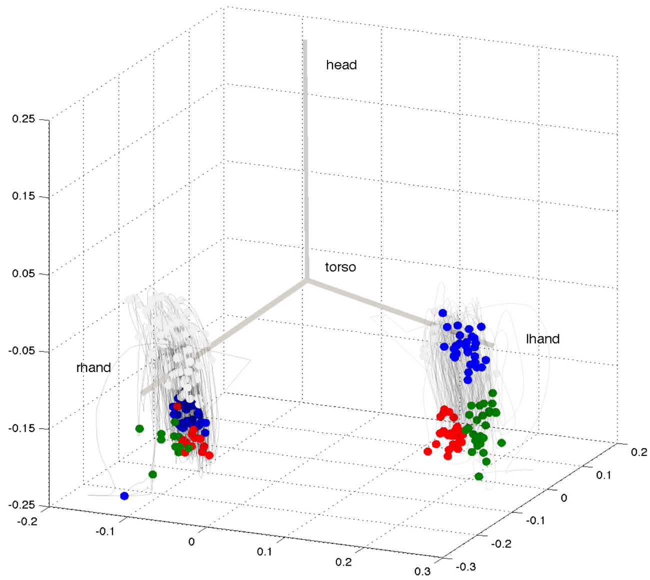


Fig. 6. Levels of cumulative velocity for subject 18 (Argentinian), right hand. Stimulus: chacarera music (N=12).

The velocity profile of right hand (see Fig.6) also shows a 2 bars pattern of similar design delineated by 1.1, 1.2, 2.2 and 3.1, 3.2 , 4.2 segments. In that locations highest velocity levels are consistent with a percussion trill gesture performed at the eight-note level that can be visualized in the video at the beginning of ternary beats 1 and 3. In other sense, activity in segment 2.2 and 4.2 reveals coincidence with the typical accent of *bombo* percussion in 3/4 binary meter.

3.2.2 Topological Gesture Analysis

Following the analysis of velocity levels and the video recording observation, we adopted a binary grouping strategy to treat metrical music information in the left hand and a ternary grouping strategy to organize metrical music information in the right hand (see Fig.7). Movement trajectories were then configured along 3/4 meter and 12/8 meter respectively. Both trajectories show a defined vertical morphology that refers us to a mimic gesture of *bombo* percussion [20]. Left hand point-clouds appear clearly grouped at beat 1 (up), and at beats 2 and 3 (bottom), exhibiting the articulatory consistency of the left hand trajectory. Right hand also shows clear location of the four ternary beats grouped in the downwards area.



12/8 Cues 1 Bar	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3	4.1	4.2	4.3
rhand												
3/4 Cues 2 Bars	*1.1a*	*1.2a*	*2.1a*	*2.2a*	*3.1a*	*3.2a*	*1.1b*	*1.2b*	*2.1b*	*2.2b*	*3.1b*	*3.2b*
lhand												

Fig. 7. Point Cloud Representation in the 3-dimensional space showing the trajectories (after normalization) of subject 18, with metrical categories projected on it.

3.2.3 Density of Directional Changes Analysis

Right hand

The distribution of right hand events in Fig. 8, shows activity at every eight-note, with more synchronization of the events in-between the first and the third beat. The number of events is organized in a way that suggests two trends, with increased activity between 1.1 to 2.1 and 3.1 to 4.1. Second component analysis suggests some kind of reinforcement on 1.1, 3.1 and 4.1. The analysis shows a clear organization around the ternary beats.

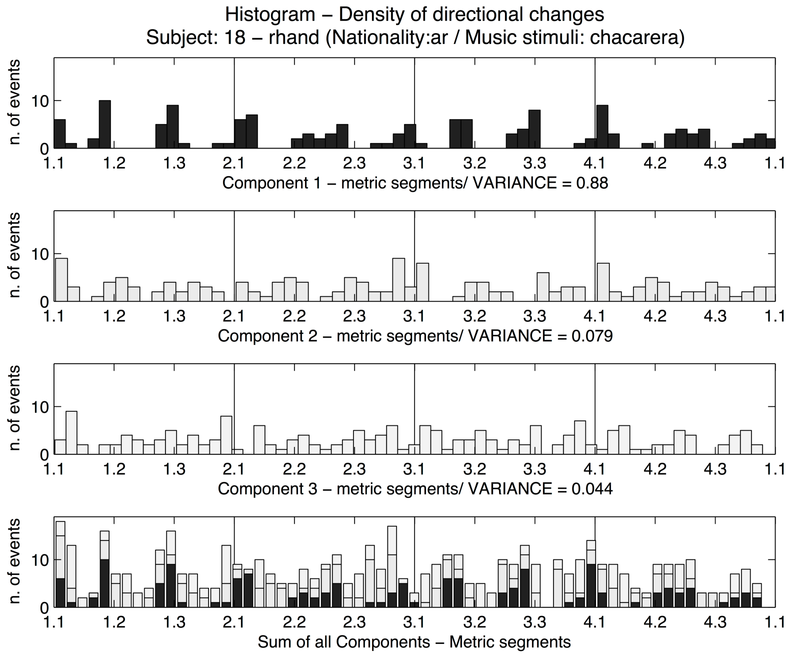


Fig. 8. Density of directional events across 1 bar of chacarera (12/8), for subject 18 (right hand).

Left Hand

Changes of direction occur at the level of eight-note. Taking into account an analytical perspective based on video observation and TGA analysis, we understand left hand trajectory as an intentional motion that leads to articulate an accentuation of beats 2 and 3 of 3/4 binary meter (see Fig. 9). Nevertheless, that purposeful action seem to articulate the binary beat (quarter note), which can be decomposed into two events: (i) a change of direction at the beginning of the ascendant trajectory and (ii) another change of direction at the beginning of the descendant movement until the stress point is reached. Guided by this analytical perspective we infer from the first component histogram binary groupings of events, organized in the following sequences of arsis/thesis alternation: 1.2/1.3; 2.1/2.2; 3.2/3.3 y 4.1/4.2. The agreement between these two analytical perspectives leads the consideration of a number of components of the unit of analysis: according to metric perspective there would be 1 component (to articulate the binary beat) while from the movement perspective we find 2 components (change of direction to ascend and change of direction to descend).

Another feature inferred from the analysis of the second component in the histogram is the shaping brought for the second component to the movement pattern design around segments 2.2 and 4.2. Somehow this can be related to the intention of emphasize beat 3 in the binary meter, in agreement with stylistic precisions of this genre.

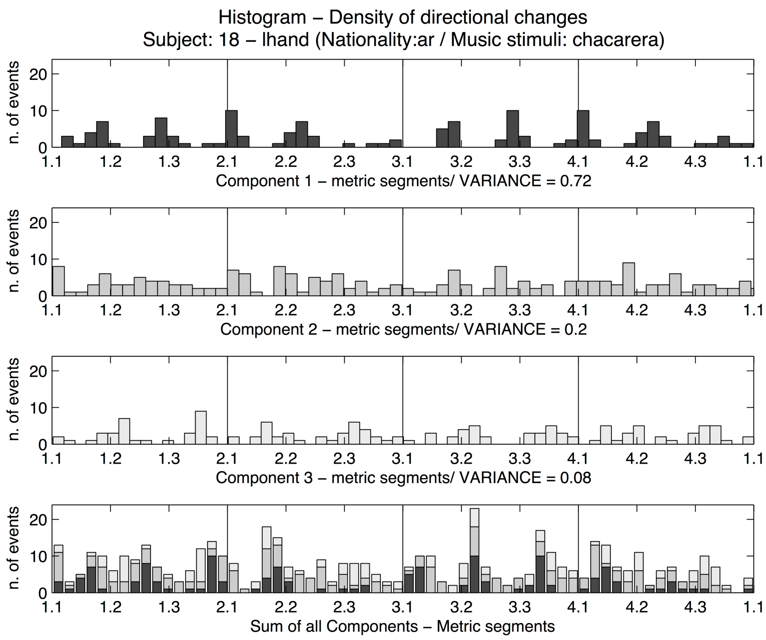


Fig. 9. Density of directional events across 1 bar of chacarera (12/8), for subject 18 (left hand).

Discussion

Three analytical strategies were applied to the study of the kinematic and kinetic cues involved in the configuration of the morphology of movement. The interest was placed on two cases of study about two musicians (one Argentinian and one Brazilian) who were required to produce free movements, organized around a repetitive pattern for as long as 60 seconds, synchronizing with a rhythmic fragment of chacarera.

Our analytical approach employed the state-of-the-art motion capture technology. The accomplished analyses face, on the one hand, a number of challenges and, at the same time, offer a window of inquiry that helps to look further into the particularities and idiosyncrasies of the individual experience of music and dance within culture. The analysis of all kinetic and kinematic variables that define topological and morphological features of movement, requires careful attention to the translations between modalities and components involved.

The analysis realized allowed the following accomplishments:

1. Inference of the polyrhythmic structure of chacarera from the kinetic configuration of velocity profiles in both hands (Case 2)
2. Organization of accented structures, based on the increment and/or decrement of energy (Case 1)
3. Determination of the incidence or interrelation of dimensional components (PCA components) in the articulation of metric stress (Case 2).

Both participants belong to two different cultural environments, however they reported familiarity with the Argentinian style. Familiarity of the Brazilian participant is evidenced in the subject´s entrainment to the beat. The movement profile emergent from the density of directional changes analysis is cancelled in the histogram of movement profile from the sample of all Brazilians participants that took part in a cross-cultural experiment [21] being nevertheless similar to the histogram of movement profile of the sample of all Argentinian subjects from the above mentioned study, accounting for the capacity of basic temporal patterns to shape embodied attunement in cross-cultural communication.

The morphology of movement conveyed by the Argentinian participant, on the other hand, reveals a metrical complexity that is typical in chacarera style, and that was not evidenced by the Brazilian participant. This particular stylistic feature is related to the combination of binary and ternary metric organization in the temporal structure of the rhythmic fragment. It seems that in the process of enculturation, familiarity is a necessary but not sufficient condition to account for the complexity embodied in gestural action-oriented ontology of stylistic communication. Gesture seems more related to communication of other structural and/or stylistic components rather than just to a precise synchronization to the beat.

Therefore, accomplishment of case studies is together with other inquires in the field of systematic musicology a useful tool to gain further knowledge on the embodied cultural practice of meaning in music.

Application of these strategies, to the extent that they represent third person analytical tools, is useful to tackle the challenge of understanding the non-propositional embodied meanings that can be combined with methodological perspectives of first and second person descriptions, in order to reach a more comprehensive account of human experience of movement in music.

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