Mapping idiomatic elements in the morphology of dance gestures

Meter, gender and cultural idiosyncrasies in the samba dance and music

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Abstract

How are dancers and musicians dealing with style? How do they perform music and dance styles that are so associated with their culture, community and time? Music and dance cultures evolved from entangled transformation vectors into styles that mark a culture. The styles reflect gender roles, socio-economic (and geographic) differences, but they also reflect aspects of the bodies that express the movements, and aspects of the musical structures that support their functioning in the social context. Style is idiomatic. In this paper we study idiomatic expressions of style by mapping them into a universe of Afro-Brazilian dances and music styles. We collected the trajectories of 30 samba dances using motion-tracking technologies and analyzed the periodic structure of the gesture’ trajectories. The information from the shape of the gesture was used to trace comparisons and generate a dissimilarity map. From this map we used data visualization methods (MDS) in order to test how the classes of gender, origin and musical metrical structure were discriminated. The results show relevant traces of idiomatic differences in different degrees of significance. We discuss hypotheses for the emergence of these traces and how the interaction between music and dance could support cues of dance and music styles.

Resumen

¿Cómo los bailarines y músicos manejan el estilo? ¿Cómo realizan estilos de música y danza que están tan ligados a su cultura, la comunidad y tiempo? Culturas de música y danza evolucionaron a partir de vectores entrelazados de transformación en estilos que marcan la cultura. Los estilos reflejan los roles de género, las diferencias socio-económicas (y geográficas), pero también reflejan aspectos de los cuerpos que expresan los movimientos y aspectos de las estructuras musicales que apoyan su funcionamiento en el contexto social. El estilo es idiomático. En este trabajo se estudian las expresiones idiomáticas de estilo mediante la asignación de ellos a un universo de danzas afro-brasileñas y estilos musicales. Recogemos las trayectorias de movimiento de 30 bailes (samba-no-pé) por medio de tecnologías de captura de movimiento y analizamos la estructura periódica de estas trayectorias. La información sobre el gesto fue utilizada para trazar comparaciones entre cada baile y producir un mapa de disimilitud. A partir de este mapa fueron utilizados métodos de visualización de datos (MDS) con el fin de probar el efecto de clases de género, origen y estructura de metros musical en la discriminación por características morfológicas. Los resultados indican características relevantes que sugieren explicaciones para las diferencias idiomáticas en diferentes grados de importancia. Al final se discuten las hipótesis de la aparición de estos rasgos y cómo la interacción entre la música y la danza podía apoyar elementos de estilos de danza y música.

Resumo

Como bailarinos e músicos lidam com o estilo? Como eles executam estilos de dança e música tão associados com sua cultura, comunidade e tempo? Culturas musicais s coreográficas evoluíram a partir de intrincados vetores de transformação em estilos que marcam a cultura. Os estilos refletem papéis sócios de gênero, diferenças socioeconômicas (e geográficas), mas eles também refletem aspectos dos corpos que expressam os movimentos e aspectos das estruturas musicais e seu funcionamento no contexto social. O estilo é idiomático. Neste artigo estudamos as expressões idiomáticas de estilo por meio de seu mapeamento dentro do universo de dança e música afro-brasileiras. Coletamos os trajetórias de movimento de 30 danças (samba-no-pé) utilizando tecnologias de captura de movimento e analisamos a estrutura periódica destas trajetórias. A informação sobre o gesto foi utilizada para traçar comparações entre cada dança e produzir um mapa de dissimilaridade. A partir deste mapa foram utilizados métodos de visualização de dados (MDS) a fim de testar o quão forte as classes de gênero, origem e estrutura métrica musical foram discriminados pelas características morfológicas. Os resultados indicam traços relevantes de informações que sugerem explicações para as diferenças idiomáticas, em diferentes graus de importância. Discutimos hipóteses para o surgimento desses traços e como a interação entre música e dança poderia apoiar elementos de estilos de dança e música.

Introduction

Dances flourish as profuse collective and individual expressions in many different sociocultural contexts, at different levels of expertise, age or motor coordination capacities. The striking diversity of dance and music in culture includes dances to be performed in the darkness, dances for mourning, dances for courting, dances for worship (Hanna et al., 1979) and a number of popular dances discriminated and recognized as specific types of dance, or styles of movement. These styles convey recurrent characteristics that are systematically attached to cultural identities (Cohen-Stratyner, 2001; Desmond, 2000). How do individuals deploy cultural signatures by means of such sophisticated patterns of movement? How do different movement signatures express idiomatic/stylistic elements?

There are few approaches to these questions in the literature. Examples of scientific studies looking at movement patterns and its relationship with style are marginally represented across the fields of study of biomechanics (see Krasnow, Wilmerding, Stecyk, Wyon, & Koutedakis, 2011, for a extensive survey), computer vision (Camurri, Lagerlöf, & Volpe, 2003; Camurri, Mazzarino, & Volpe, 2004; Srivastava & Sural, 2007), dance studies (e.g.: Jackson, 2001; Szwed & Marks, 1988) and more recently musicology (Naveda, 2011; Shifres, Pereira Ghiena, Herrera, & Bordoni, 2012; Toiviainen, Luck, & Thompson, 2010). Other relevant contributions include walking and its influence on musical preferences (Styns, van Noorden, Moelants, & Leman, 2007; Van Noorden, G’voy doy, & Leman, 2010; Zhang, Wu, & Ruan, 2009), the influence of movement stimuli to the perception of rhythm (Phillips-Silver & Trainor, 2005), musical expression (Maes & Leman, 2013) and the neuroscience of dance (Brown, Martinez, & Parsons, 2006).

In this study, we investigate how dance style is rendered a collection of shapes of gestures organized by the musical meter. We analyze movement trajectories by means of representations of repetitive gesture movements that take into account the relation of movement profiles to the musical meter. We concentrate on the type of dances within the field of popular and urban dances, which allows two important assumptions:

“(1) that the morphology of the dance gestures depends on temporal regularities in music and that (2) the morphology of the gestures accounts for expressive characteristics of personal or cultural styles of movement in dance.

In the following sections we describe the methodology for the analysis of full body motion capture data of dance performances and a study case realized in the context of Afro-Brazilian samba.” (Naveda & Leman, 2013, p. 1)

Methodology

The methodology involves three parts: (1) recording of movement data (2), analysis of gesture patterns and (3) classification and discrimination. Each of these parts involves a combination of approaches that allows the representation of music and dance and the exploration of the dissimilarities within the universe of dances. Since there are many technical details and interdisciplinary topics involved in the methods, the methodological procedures will be briefly described and referenced in the text. Figure 1 displays a schema of the methodological workflow.

Procedures

Fifteen Brazilian dancers participated in this study. All subjects danced two sequences of samba-no-pé dance style accompanied by music stimuli at tempi 80 BPM (53% the of excerpts, 16 recordings) and 120 BPM (47% of excerpts 14 recordings). The stimuli consisted of sequences of looped samples of a samba percussion ensemble (surdo, tamborim, and caxixi) recorded in Brazil by professional musicians. All participants were professional samba dancers with more than 5 years of experience. 60% of the subjects (18 recordings) belonged to the cultural background of the “Rio de Janeiro” samba while 40% (12 recordings) belonged to the background of “Bahian” samba (State of Bahia, Brazil). 60% of the subjects (18 recordings) were female while 40% were male dancers (12 recordings).
Recordings

The dance performances were recorded using a motion capture system (Optitrack/Natural Point) consisting of 8 cameras positioned around a squared aluminum structure (4 x 4 meters) and a computer workstation. Each recording session was 60 s in length and was recorded at a frame rate of 60 Hz, interpolated to 100 Hz in the editing phase. The motion capture recordings were synchronized with the audio stimuli using low-latency audio trigger (10 ms of latency) connected to an infrared light signal. The dancers wore a dance suit with 34 reflective markers attached to it. The recording sessions were edited in the Arena software (Natural Point) and exported as C3D files. The files were imported into Matlab using the MoCap toolbox (Toiviainen & Burger, 2011). The calculation of basic joint positions of the body, filtering of raw vectors, normalization and part of the visualization functions were also based on the MoCap toolbox for Matlab. The motion capture recordings were segmented in 16-beat sequences along with the musical annotation (beat and ¼ beat time points and related categories of meter) and only the most homogeneous segments of the 16-beat sequences were selected.

Gesture analysis

In this study, the methodology for gesture analysis must provide a representation of the gesture that is both sensitive to musical and chorographical structure and capable of reflecting the idiosyncrasies of different dance styles. The Basic Gesture approach, which was developed and detailed in previous studies (see Leman & Naveda, 2010), provides a method that responds to these conditions. This analytical approach allows for the reduction of raw trajectories of dance movements in representations that convey the repetitive profile of the gestures for each period of the metrical structure (in this case, samba music, played at 2/4). Hence, the approach uses information of metrical levels of the music to uncover musically relevant patterns in dance. The procedures involve (1) normalization, (2) principal component analysis (PCA), (3) periodicity analysis and will be briefly described in the next subsections.

Normalization: body size, body orientation and PCA

In order to prevent the analysis from the effect of the magnitude of different bodies we normalized the maximum distance between the lowest sample of the feet and the highest sample of the head (2 dimension) to 1,70 m, for all dancers. The whole body rotation and transla-
tions were also normalized with respect to a referential point and orientation of the dancers’ body (the point is defined as the centroid of the body across markers and the orientation as a frontal view with respect to the left and right hips). This normalization prevents the analysis from the effect of whole body translations and rotations and also provides a better contextualization of the movements of the dancer in the space.

The Principal Component Analysis (PCA) helps to improve the analysis of each gesture by measuring how dancers use the dimensions in the space and by rotating the trajectories to an angle that reveals the best perspective of the gesture variance (and not the frozen perspective of the recording system). The PCA was applied to each joint trajectories (3 dimensions), which determined the dimension (or coordinate) that captures the largest variance. In short, it normalizes the coordinate system to the dimensions where the variance of the gesture is greater (see Jolliffe, 1986, for a detailed description of the theory behind PCA).

**Periodicity analysis: Basic Gesture approach**

The Basic Gesture approach is based on the Periodicity transforms from Sethares & Staley (1999) and previous work of the authors (Naveda & Leman, 2008, 2009). In this type of transform, the pattern of trajectory is projected onto a “periodic space” and results in a set of periodic bases, periods and energy levels. The main principle is to use the periods of the musical meter to retrieve the bases (or the periodic patterns) of the dance movements in space. First, the periodicity analysis is applied to the first principal component retrieved in the PCA analysis. The strongest periodic elements related to the metrical levels are then propagated to the remaining components (dimensions of the trajectories) for the extraction of periodic patterns.

This process generates renditions of patterns of repetitive movements for each joint of the dancer in relation to each metric level of the music. For each metrical level, or each element of the metrical grid, there is resulting repetitive pattern. In this study, we only use the profiles of the metrical level 2-beat, which corresponds to the main metrical level of the samba music. The periods of the metric structure of the music being danced were previously analyzed using manual annotation of the stimuli.

**Results of the gesture analysis**

Figure 2a shows an example of results provided by the Basic Gesture analysis for the excerpt 4. The collection of gestures displayed the first graph (Figure 2a) informs about the morphology of the repetitive dance gestures. It shows how movements are deployed in repetitive patterns along a musical cycle of 2-beats and how these gestures and their magnitudes are distributed in the dancer’s body. The bar graphs displayed in the right side stick figure in Figure 2a indicate the magnitude of the periodicities for each musical metric level. Notice that periodicities in 2- and 4-beat levels are stronger, which agrees with binary metrical structure reported for samba music (Browning, 1995; Sandroni, 2001). Figure 2b illustrates how the temporal subdivision of the metric levels (hereafter referred as metric cues) can be projected as 3-dimensional points along the gesture representation in space.

Figure 3 shows a set of Basic Gesture patterns for the right hand, for all dancers. The patterns exhibit a huge diversity of shapes and choreographical relationships with metrical levels of music. These results form the main feature that was used to classify the dancers in the next sections.

**Classification and discrimination**

How to map the styles of dance in the territory of choreographies? In this section, we provide method for deriving a numerical distance reflecting the dissimilarity between the collections of Basic Gesture’s shapes (as seen, for example, in Figure 3). These distances provide the basis for the elaboration of maps of choreographies, which will be further discriminated by classes that represent dance styles.

**Measuring the distance between gestures: Procrustes analysis**

The Procrustes analysis is a statistical technique that provides a measure of the dissimilarity between shapes after removing its rotational and scale components. It has been used to compare shapes in studies about walking patterns (Wang & Spelke, 2002), signature recognition (Fan, Hastie, & Kishon,
Figure 2: (a) Basic gesture representation of the patterns for 16 body joints and energy levels retrieved for each metric level. (b) Basic gesture representations for the right hand and metric cues projected onto the gesture. These cues indicate the position and the time of each metrical accent projected onto the gesture itself.

Figure 3: Set of basic gesture patterns for 30 dancers, right hand. The viewpoints on the 3-dimensional shapes are rotated to the perspective of the first two main eigenvectors (after the PCA). The number after the letter E indicates the number of the excerpt, the number after the D the reference of the dancer. Information inside the parenthesis indicate gender ([m] male, [f] female), tempo (beat-per-minute) and origin (BH = Belo Horizonte, SA = Salvador).
1992) among others (Goodall, 1991; Rohlf, 1999). The dissimilarity between each gesture (or simply the Procrustes distance the between shapes) is calculated using the points formed by metric cues projected on the gesture (see Figure 4). These points are distributed in 1/8-beat steps along the spatiotemporal trajectory. For each gesture, the total distance $d_t$ was calculated as the mean of the Procrustes distances $d(1)$ and $d(2)$. Figure 4 illustrates this process. Since different parts of the body contribute with different weights to the perception and performance of movement, we applied a weighting procedure to the Procrustes analysis. This procedure takes into account the ratio of the area occupied by the gesture divided by the sum of all gestures’ areas, which generates a factor that gives more importance to the effect of large gestures.

**Building a map: Multidimensional scaling (MDS)**

We applied a multidimensional scaling algorithm (MDS) that allows building a graphical representation from the matrix of Procrustes distances between dance gestures. The test of goodness-of-fit of the MDS solutions resulted in acceptable solutions (acceptable stress factor) for 4 dimensions. For the sake of illustration, the resulting maps are displayed in 2-dimensional plots in Figures 5 and 7. Note that the absence of 2 dimensions in the graphs will make the 2D representation contrast with some results. The maps inform about how close the choreographies are in relation to each other. The strength that unifies or separates each class of characteristics of the dancers will be analyzed by defining the “boundaries” in this map, as explained in the next section.

**Tracing boundaries: Discriminant analysis applied to MDS maps**

The MDS provides an explorative data visualization of the organization of the gestures of all dance excerpts in maps (often called perceptual maps). But how can we discriminate the characteristics of the dancers and dance excerpts in these maps? We conducted four discriminant tests using quadratic discriminant analysis (QDA, see Jain, Duin, & Mao, 2000), which tries to identify classes by tracing a (quadratic decision) boundary between the points. By training the QDA with known categories of the data (e.g., male-female) we measured the percentage of points (in our case, choreographies) that were predicated in a delimited region of the map and the percentage of points that violated the predicted boundaries (errors or non-predicted points). In short, the more a class of choreography is grouped in a delimited region of the map, the more the class is likely to be recognized by the morphology of the gestures. The percentage of errors of classification provides a rough measure of how a characteristic/class (e.g., male, female) is recognized by the morphology of the dance gesture.

In this study, the discriminant tests respond to three scenarios. In the first two tests we classified the points of the distribution provided by
the MDS with characteristics of (1) origin and (2) gender. In the last test, (3) we performed the processes classification and discrimination for each 1/4 beat segment of the gestures. The results of these tests will be displayed and discussed in the next section.

Results and discussion

**Discrimination: Choreographic origin**

Figure 5 displays the results for the analysis of discrimination of choreographic origin. This analysis tests if the origin of the dancers (in this case, the cities of Belo Horizonte or Salvador) is reflected in the distribution of the choreographies. The graph shows the MDS map that was built from the matrix of dissimilarities between full-body choreographies, here represented as data points. The numbers above the markers indicate the excerpt and different markers indicate the class of the choreography in each scenario (e.g.: “o” for dancers from Belo Horizonte and “+” for dancers from Salvador). Above the graph it is displayed the characteristics of the “medoids” and “poles”. Medoids represent the choreography close to the mean of a class. Poles indicate the most dissimilar choreographies between both classes. Further indications inform about the profile of the subject who performed the dance: gender (m. or f.), choreographic origin (BH or SA) and the tempo of the dance (t80 for BPM=80 and t120 for BPM=120).

The percentage of errors in the classification seen in the legend of Figure 5 (excerpts incorrectly classified are indicated by “x” markers, or “errors”) denotes the level of discrimination of each class.

The large error (17%) of the SA class (representing the choreographic matrix of the city of Salvador, in Bahia) indicates that the gesture shapes of the dances from SA were not easily discriminated by the morphological similarities of their gestures.

**Figure 5**: Results of the discriminant analysis using the original division between choreographic origin (BH for Belo Horizonte and SA for Salvador). In order to illustrate the distribution in a legible graph, only the first two dimensions of the MDS map were represented.
The largest distance between choreographies (pole 1 and pole 2) was found between elements of the SA and BH choreographies. The results indicate that the choreographies from the BH origin show a small error (6%) and seem to be more discriminated, more compacted in the space of gesture dissimilarities.

The medoids M1 (excerpt 20) and M2 (excerpt 16) indicate the choreographies that have the smallest distances to the mean of all elements within the discriminated class. They represent the closest renditions of the “choreographical model” of BH and SA styles. However, it does not mean that they convey the model of samba style for these groups. They only provide cues to understand the frames of reference used by the limited universe of dancers and dances at the time of the recordings.

**Discrimination: Gender**

Figure 7 displays the result of the discrimination test for male and female classes. The results indicate that 50% of the male dances could not be discriminated from female dancers. The most dissimilar pair of choreography is characterized by a female pair of dances (excerpts 12 and 13), dancing at 80 and 120 BPM, both in SA style, which reinforces the apparent variability of the SA style. The medoids indicate that the models for male and female dances are close to the BH style, at 120 BPM. The shapes of the medoids of the male (excerpt 29) and female (excerpt 23) classes are displayed on Figure 6.

The major difference between gestures of male and female medoids seem to suggest a contrast between round and large shapes for female gestures, and a more direct, line-like shapes of the male gestures. This information can be easily seen in the graphs of the Figure 6 although the high error of discrimination of the male choreographies decreases the relevance of the information. Subdivisions of the male class in other sets of classes (e.g.: male-BH and male-SA) and more subjects may help to understand the sources of variability in the shapes of the gestures.

![Figure 6: Basic Gesture curves for the Excerpts 16, 20, 23 and 29, referenced in the discussion of results.](image-url)
Discrimination: from gesture segments to classes of origin, gender and tempo

In the last sections we analyzed the results of discriminating classes of gender and origin by taking into account the whole 2-beat gesture pattern. But how do segments of these 2-beat patterns affect the results of discrimination? Is there a “part” of the meter or the gesture that is likely to exhibit more idiosyncratic patterns? In order to answer to this question we repeated the classification and discrimination analyses described in the methodology for each 1/4-beat segments across all gestures. We measured its impact in errors of the discrimination of classes of origin, gender and, additionally, musical tempi (80 and 120 BPM), as displayed in Figure 8. In order to improve the Procrustes analysis each 1/4 beat segment was represented by 4 points along the gesture profile (1/16-beat points).

Figure 8 shows the percentages of errors of discrimination for each 1/4 beat segment of the Basic Gestures (all gestures of all body parts). The classes of origin seem to be homogeneously discriminated across the gesture segments although there is a positive effect (more discrimination, less errors) at the 1.5 beat position. This may reflect the apparent variability of the morphology of the choreographies from Salvador (SA), also reported in previous results.

The discrimination of gender classes shows curious pattern where the female class is better discriminated (less errors) across the segments (except at 1.25 beat position) and male classes less well discriminated (more errors) at “strong” metrical positions. We could not find any clear hypothesis for this effect, apart from being a result of the apparently well discriminated characteristics of the female choreographies, reported in Figure 7.

The discrimination of tempo classes follows another interesting path. Fast dances (120 BPM) exhibit considerably less discrimination at the strong beat points (positions 0 and 1), which often signalize a change of directionality (see examples in Figure 3). By reaching these beat points at higher velocities (due to the higher BPM) dancers may have had their movements randomly disturbed by the increasing muscular control necessary to cope with the kinetic demands of the mass of the limbs and expressive kinematics of the gesture directionality. Slow dances (80 BPM) exhibit the opposite effect. At strong beat positions slow dances show more discrimination (less errors), which may indicate that stylistic movement are performed at these positions. In between beat points, the lower velocity patterns may have released the dancers to
make use of free movements, which may have generated more variability and less discrimination.

Finally, in the last half beat (1.5-1.75 beat positions) we observed more discrimination in all classes. This seems to indicate a sort of idiomatic preparation for the re-start of the metrical cycle (which somewhat reminds the preparatory movements of conductors). At this point, dancers seem to prepare the impulse to the strong beat (position 0) by systematically performing idiomatic elements that work positively for class discrimination (in special the classes of origin).

**Conclusion**

The methods applied in this study provide an exploration and visualization of the relationships between dance, music, profiles of the dancers and morphology of the gesture. Although it is difficult to raise any sort of classical generalization due to the small number of samples and the huge variability found in the data, the results demonstrated an intriguing relationship between profiles of dancers and morphological structure of the gestures, in our universe of dances.

More specifically, in looking at the regional origin of the dance, the results show that styles such as the dances from Salvador might be characterized by variability, which contrast with the traditionalistic/conservationist perspective of “frozen” objects or “uniqueness” of cultural heritage (Desmond, 1994). The same applies to the results of the male dances, which could not be easily discriminated in our dataset. In contrast, the good discrimination of female dances may support the hypothesis that female dances incorporate gender roles that resulted in a well-defined display of dance in the development of samba dances. The profuse examples of construction of gender roles and sexual objectification of women in narrative of samba culture (Browning, 1995) may have been mirrored in the construction of a specific gestural display. However, more samples would be needed to fully support this conclusion. What we observed here is more a trend rather than an established fact.

The rich profile of gesture signalizations present in the results of discrimination for gesture segments (Figure 8) shows that the structure of meter is not a simple isochronous time structure, if framed in the universe of dance-music phenomena. Each portion of the macro metrical structure (in this case, 2-beats) is attached to different designs of idiomatic elements that manipulate directionality, expectancy and variability. The results indicate that the metrical properties present in the movement gestures mirror strategies present music performance and musical expressivity mentioned in the literature (see, for example Kronman & Sundberg, 1987). In addition, they
support hypotheses on closer relationships between musical meter and dance (see the discussion in Naveda & Leman, 2011). In this perspective, the musical or choreographical meter seems to incorporate both chronological and kairotic properties: time incorporates both linear (chronological) and non-linear, qualitative functions (kairotic) in the gesture display. In other words, the dance style may offer a blueprint to organize music and dance according to a flexible chronological structure at the same time it spreads meaningful expressive signals, function and qualities.

To sum up, we can say that despite the huge variability and density of data structures presented in the full body analysis some interesting insights on the structure, function and relationships between dances, music and context could be observed. However, more comprehensive methods for statistical analysis and data visualization are required to improve the level and relevance of the analyses and to cope with the variability and ubiquity of popular dances and music.

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References

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Notes

1 In this study the metrical grid is composed of multiples and subdivisions of the beat composed of the following multiples: \( \frac{1}{4}, \frac{3}{8}, \frac{5}{16}, \frac{1}{2}, 1, 1.5, 2, 3, 4 \).

2 The Procrustes analysis was calculated using the Matlab algorithm with the same name, whose theory is referenced in Kendall (1989) and Bookstein (1997).

3 For details concerning the MDS technique see Wickelmaier (2003).

4 For the metric scaling of the MDS method, we used the criterion of squared stress, normalized with the sum of the 4th powers of the dissimilarities.

5 Medoids are representative objects of a data set or a cluster that are close to the "mean". More specifically they are the data point in which the average dissimilarity to all the objects in the cluster is minimal.

6 Poles are pairs of representative objects that exhibit the maximum distance between each other in the data-set.

7 In the Western music theory, it is considered that the strong metrical positions take the largest subdivisions of the macro metric levels. For example, for a 2 beat metric level, beat and half-beat positions are stronger than 0.25, 0.75, 1.25 and 1.75 positions.