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Measuring Similarity between Flamenco Rhythmic Patterns

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Abstract

Music similarity underlies a large part of a listener's experience, as it relates to familiarity and associations between different pieces or parts. Rhythmic similarity has received scant research attention in comparison with other aspects of music similarity such as melody or harmony. Mathematical measures of rhythmic similarity have been proposed, but none of them has been compared to human judgments. We present a first study consisting of two listening tests conducted to compare two mathematical similarity measures, the chronotonic distance and the directed swap distance, to perceptual measures of similarity. In order to investigate the effect of expertise on the perception of rhythmic similarity, we contrasted three groups of participants, namely non-musicians, classically trained percussionists and flamenco musicians. Results are presented in terms of statistical analysis of the raw ratings, phylogenetic analysis of the dissimilarity matrices, correlation with mathematical measures and qualitative analysis of spontaneous verbal descriptions reported by participants. A main effect of expertise was observed on the raw ratings, but not on the dissimilarity matrices. No effect of tempo was observed. Results of both listening tests converge to show that the directed-swap distance best matches human judgments of similarity regardless of expertise. The analysis of verbal descriptions indicates that novice listeners focused on 'surface' features, while musicians focused on the underlying rhythmic structure and used more specialized vocabulary.

1. Introduction

Musical discourse progresses through transformations of musical material. For such transformations to be meaningful to a listener, there must be an underlying notion of musical similarity so that the musical progression may be perceived and assessed. Such a notion is acquired through exposure to music within a specific cultural context. Among the musical parameters that undergo transformations rhythm is one of the most prominent. Therefore, the study of musical similarity, and in particular of rhythmic similarity, bears some relevance. There is a large body of literature on the perception of rhythm structure in music (e.g. Gabrielsson, 1973; Honing, 2002; Lerdahl & Jackendoff, 1985). However, as paradoxical as it may seem, rhythmic similarity has received scant research attention in comparison with other aspects of music such as melodic or harmonic similarity (see Hewlett & Selfridge-Field (1998) and the references therein for a review on melodic similarity). Studies on rhythmic similarity can be found in Toussaint (2004) from a symbolic point of view, and Foote et al. (2002), from an audio point of view.

Many measures of rhythm complexity have been proposed (Gómez et al., 2007), but very few have been compared to perceptual human judgments, a situation that may raise objections to their validity. Much the same can be said about rhythmic similarity measures. In fact, to our knowledge, none of the measures proposed so far have been tested on subjects. In this paper we present two experiments conducted to compare two mathematical similarity measures, the chronotonic distance and the directed swap distance, to actual perceptual measures of similarity. Of interest, too, is the set of rhythms chosen to carry out our study. Because of its rhythmic vitality and use of rhythm as unifying principle, and also because of the lack of systematic research concerning the genre, we have chosen our set of rhythms from flamenco music. In our experiments we investigated

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which mathematical measure best matches human judgments. We presented the listeners a set of flamenco rhythmic patterns, which will be described below in detail, and asked them to rate their similarity. In order to investigate the effect of expertise on the perception of rhythmic similarity, we contrasted three groups of participants: non-musicians, classically trained percussionists (both recruited in Canada) and flamenco musicians (recruited in Spain). Indeed, previous research on rhythmic perception has highlighted differences between novice listeners and musicians in their ability to label perceived differences as well as strategies for representing musical structures (see Duke, 1994, for a review). As we shall see, novice listeners tend to focus on 'surface' features, while musicians tend to focus on the underlying rhythmic structure and develop a specific vocabulary. Moreover, statistical tests to determine the correlation between similarity measures have been carried out. Finally, we used phylogenetic trees to visualize our results.

1.1 Flamenco music

Flamenco music is the result of a complex amalgam of several musical traditions coming from diverse geographical origins and forged over centuries of musical practice. Several authors have highlighted a wide variety of influences for flamenco, namely the influence of liturgical music, the marks of the Moorish music, the footprint of Jewish music, the more modern influence of South American music, and above all, the strong personality of Gypsy music (see Hernández-Jaramillo (2002) and Cruces (2002) for more details on the musical and historical origins of flamenco music). As for geographical origins, although flamenco music originated in Andalusia, it soon received influences from musical traditions from other areas such as Castilia, Murcia, Extremadura or South America. By the late eighteenth century, flamenco music was characterized by unique features that constituted its identity and distinguished it from local folk music. Its evolution has continued through to the present day.

According to Fernández (2004, p. 32), one of the most distinctive characteristics of flamenco music is the richness of its rhythmic structures. Flamenco rhythm permeates its harmonic and structural elements, and is one of the main features used to distinguish flamenco styles. Most flamenco styles are accompanied by hand clapping, where rhythmic patterns are performed by changing the clapping intensity and timbre (or playing mode). The main function of those clapped rhythms is to provide a metrical reference, that is to structure the time by establishing how it is divided and set the distribution of accents. In flamenco music, all pulses are played with a clap, but non-accented pulses are played with a soft clap and accented pulses are played with a strong clap. There are five ternary metrical patterns and only one binary pattern (namely, [. x x x], described in box notation). In our experiments we only utilized the ternary metrical patterns, shown below in box notation. Here an 'x' means a loud clap and '.' a soft clap.

(1) Fandango [x . . x . . x . . x . .]
(2) Soleá [. . x . . x . x . x . x]
(3) Bulería [. . x . . . x x . x . x]
(4) Seguiriya [x . x . x . . x . . x .]
(5) Guajira [x . . x . . x . x . x .]

Each pattern has been labelled with a style that uses it as a metrical reference, but, as a matter of fact, many styles can use the same pattern. For example, the fandango pattern is used by the sevillana.

The origin and evolution of the different flamenco styles (*palos*) and variations have been studied in different disciplines, including ethnomusicology, literature and anthropology (see Diaz-Bañez et al., 2005, for a review). We refer the reader to Fernández (2004) for an account of flamenco genres, including musical features and criteria for style classification. Rhythmic similarity and its possible use as a tool for classifying styles and variants among performers have always spurred great interest among flamenco scholars.

1.2 Mathematical measures of rhythmic similarity

In computational music theory, measuring the similarity between rhythms is a fundamental problem with many applications such as music information retrieval and copyright infringement resolution. Toussaint (2006) reviewed computational methods for evolutionary musicology using approaches derived from bioinformatics (phylogenetic analysis), where musical sequences are modelled as sequences of symbols.

In this paper the validity of two mathematical measures proposed in Diaz-Bañez et al. (2005) were tested from a perceptual point of view. The measures are the chronotonic distance and the directed swap distance. The chronotonic distance is based on histogram representation, specifically on the so-called TEDAS representation (Gustafson, 1998). The vertical axis displays the inter-onset intervals, while the horizontal axis shows where the onsets occur. The result is a histogram representing the pattern that contains both pieces of information; see Figure 1 below. The distance between two rhythmic patterns is obtained by computing the area between the two given histograms. Figure 1 shows the histograms corresponding to fandango and bulería; the area of the ruled regions in the third graph is the chronotonic distance between the two rhythmic patterns. Considering the example given in Figure 1, if the area of the ruled regions is added up, the result is 14, which is the chronotonic distance between fandango and bulería.

The directed swap distance is computed by counting the number of swaps (exchanges between adjacent accented positions) needed to transform one pattern into the other and then summing them all up. More formally, if P and Q are two patterns with the same number of pulses, where P, say, has more onsets than Q, then the directed swap distance between P and Q is the minimum number of swaps to convert P to Q under the following constraints: (1) each onset of P must move to an onset of Q; (2) each onset of Q must receive at least an onset from P; (3) no onset may travel across the boundary between the last and the first onset. See Toussaint (2004) for a detailed explanation of this measure. To illustrate, let us look at the directed-swap distance between seguiriya and fandango illustrated in Figure 2. Here the number of swaps needed to transform seguiriya to fandango is 4; notice that two onsets in the seguiriya have been transformed into one onset in the fandango.

In a previous study, Diaz-Bañez et al. (2005) identified a rhythm from a phylogenetic tree as a hypothetical ancestral rhythm (it appeared on one of the central nodes of the phylogenetic tree). The pattern was [x . . x . . x . . x x .] and, in fact, such a pattern exists: it is the main pattern for the fandango de Huelva (Solo Compás, 1998). Notice that the pattern was obtained under a temporal interpretation of the tree. So far this hypothesis has not been examined in depth by flamenco musicologists so as to confirm it or reject it. In our study we incorporated the 'ancestral' rhythm because we deemed it interesting to collect perceptual ratings for this pattern and compare it to the rest of the patterns. We also denote it as the 'ancestral' pattern, but further research is required to investigate the role it actually played in the evolution of flamenco patterns. In general, computing ancestral nodes on a phylogenetic graph is a difficult problem in computation and is still under investigation. Diaz-Bañez et al. were able to compute the ancestral pattern for the directed swap distance because of the small number of patterns involved.

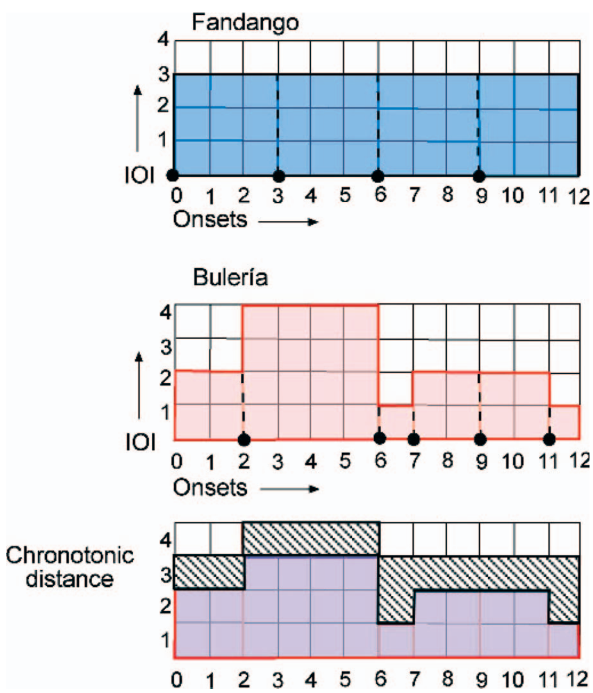

Fig. 1. Chronotonic distance.

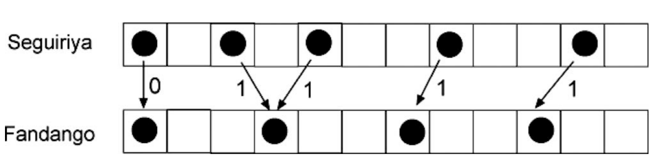

Fig. 2. Directed swap distance.

Distance matrices obtained for both measures are shown in Tables 1 and 2.

Based on these two measures, dissimilarity matrices were derived and a phylogenetic analysis of the five flamenco patterns was reported by Diaz-Bañez et al. (2005). The program used to construct the phylogenetic graphs for the distance matrices was SplitsTree (Huson & Bryant, 2006) and the algorithm NeighborNet (Bryant & Moulton, 2004). The phylogenetic algorithm outputs a plane graph embedding the set of rhythmic patterns where the distance on the graph reflects as closely as possible the true distance between the corresponding rhythmic patterns in the matrix. Distances in the matrix are represented by the distance between nodes in the

Table 1. Dissimilarity matrix for the chronotonic distance.

	Soleá	Bulería	Guajira	Seguiriya	Fan-dango	Ances-tral
Soleá	0					
Bulería	6	0				
Guajira	4	8	0			
Seguiriya	8	12	8	0		
Fandango	10	14	6	6	0	
Ancestral	8	12	4	6	4	0

Table 2. Dissimilarity matrix for the directed swap distance.

	Soleá	Bulería	Guajira	Seguiriya	Fan-dango	Ances-tral
Soleá	0					
Bulería	1	0				
Guajira	7	8	0			
Seguiriya	11	12	4	0		
Fandango	7	8	2	4	0	
Ancestral	6	7	1	7	1	0

graph along the edges of the graphs (neither the orientation of the edges nor the Euclidean distances between nodes in the plane is relevant). The LSfit index is a measure of the goodnes-of-fit of the graph. If the index is very close to 100%, then the graph represents the distance matrix faithfully; otherwise, the graph is of little value. The trees corresponding to the directed-swap distance and the chronotonic distance are presented in Figures 3 and 4, respectively, along with the LSfit values.

2. Experiment 1

Experiment 1 was conducted as a first attempt to compare the two mathematical measures described above to perceptual judgments of rhythmic similarity on the five most common flamenco rhythmic patterns. The mathematical measures considered here have been designed to only keep track of note-value changes in rhythmic patterns. Thus, in this first investigation, we compared them to perceptual judgments of synthetic MIDI-generated patterns. By doing so, the emphasis was put on note-value differences rather than expressiveness or timbral features that could be used to rate highly expressive, rich-timbre renditions of these rhythmic patterns. That being said, we have tried to preserve the most essential rhythmic characteristics of flamenco music in the MIDI-generated patterns, namely: (1) the hand-clapping sound (although MIDI-generated); (2) the clapping on all the pulses; (3) the combination of soft and loud (accented) claps in the hand clapping.

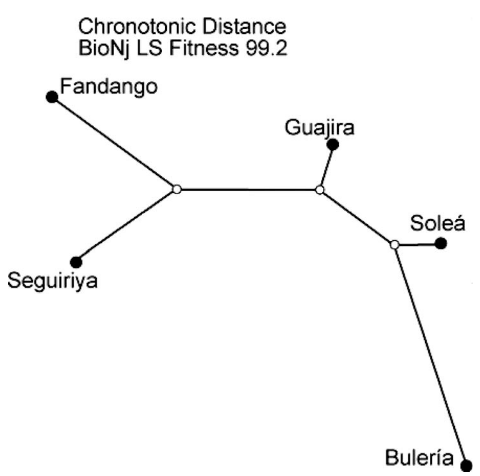

Fig. 3. Directed-swap tree.

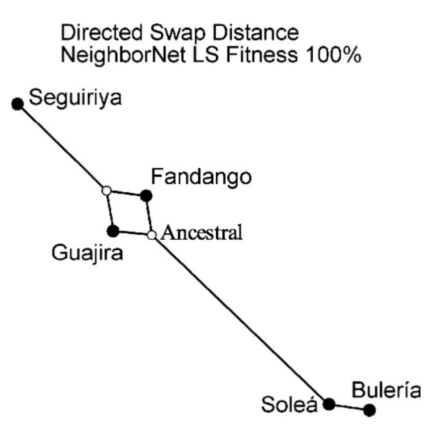

Fig. 4. Chronotonic tree.

2.1 Participants

Twelve participants (mean age: 25, S.D. 4) with an average of 3 years of musical training were recruited from the student population at McGill University. They received 10$ for their participation.

2.2 Stimuli

The sound files were generated using the music notation software Finale. The output was MIDI-generated sounds of hand clapping (channel 10, key 39) produced through the native instruments audio unit of Finale. The rhythms were generated at three different tempi: 50, 70 and 90 dotted quarter notes per minute (or 400, 285 and 222 ms between consecutive claps, respectively). There was a clap every eighth note, some soft, some loud. The MIDI velocity of all soft (non-accentuated) claps was set to 80. The loud (accented) claps were generated by setting the MIDI velocity to 125% of the original value.

2.3 Procedure

The graphical interface was programmed in Java on a MacPro computer. The experiment took place in an acoustically treated room. Sounds were presented over headphones (AKG 240) after digital-to-analogue conversion and amplification (Motu 828 MKII). The experiment consisted of three blocks corresponding to the aforementioned tempi. In each block, participants were first asked to listen to the five rhythmic patterns presented in the experiment to become familiar with the range of variation. After three randomly chosen practice trials, they were asked to rate the similarity for all possible non-identical pairs of the five patterns (ten pairs). Each combination occurred twice within a block, resulting in 20 trials in total per block. The order of presentation was randomized across trials within each block. The order of presentation of the three blocks was counterbalanced across participants using a Latin square design. Dissimilarity ratings were made by using a slider on a scale presented on the computer screen with end points labelled 'very different' and 'very similar'. Scale values were digitized on a 0 to 100 scale. Listeners were allowed to listen to the patterns as many times as desired before entering their ratings, but each pattern was presented only once (i.e. the patterns were not looped). They were requested to keep their rating strategy as constant as possible. After the experiment, they were asked to freely describe the differences between the presented patterns and explain how they made their ratings.

2.4 Statistical analysis

A three-way (Tempo × ComparisonPair × Repetition) repeated measure ANOVA, conducted with SPSS, revealed no significant effect ($F < 1$ for Tempo and ComparisonPair, $F(1,11) = 4.4$ for Repetition), that is, no significant differences were observed across tempi, stimuli combination, or order of presentation of the stimuli combination (since each combination was presented twice).

2.5 Phylogenetic analysis

A dissimilarity matrix was created for each participant based on the ratings. Values corresponding to the same pair of patterns (each pair was presented twice in counter-balanced order) were averaged for each participant to obtain symmetric matrices. A global dissimilarity matrix was obtained by summing individual matrices across the 12 participants. In this first experiment we did not include the ancestral pattern. In order to better quantify the correlation between the matrices we performed Mantel (1967) tests. A straightforward correlation analysis of two distance matrices cannot be carried out because the distances in the matrices are not independent. The Mantel test provides a way to overcome this difficulty. The rationale behind the Mantel test is that, if there is no correlation between the matrices, then random permutation of their rows and columns will produce equally likely low correlation coefficients. Thus, the test performs random permutations of the rows and columns of the matrices and computes the normal correlation coefficient; after that, it counts the proportion of those permutations that led to high correlation coefficients. A hypothesis testing is then computed to determine the final correlation of the distance matrices. We began by carrying out Mantel tests to assess the relationship between the matrices corresponding to the three different tempi using the zt software tool (Bonnet & Van de Peer, 2002). The correlations between the matrices were all very high ($r > 0.8$) and significant ($p < 0.02$). Specifically, the results are the following: for slow and medium tempi: $r = 0.82$ and $p = 0.016$; for medium and fast tempi: $r = 0.92$ and $p = 0.008$; for slow and fast tempi: $r = 0.92$ and $p = 0.008$.

Subsequently, and given the lack of significant effect of tempo in the ANOVA, we collapsed the results across tempi by summing the matrices corresponding to the different tempi. The SplitsTree program (Huson & Bryant, 2006) was used to construct the phylogenetic tree for the overall matrix, presented in Figure 5.

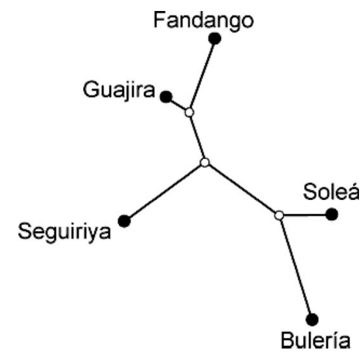

Fig. 5. Phylogenetic tree for 12 non-musicians in Experiment 1 (LSfit = 99.56).

2.6 Comparison with mathematical measures

Guajira and fandango always form one cluster, soleá and bulería form another cluster, and seguiriya is isolated from the others. Bulería comes out as the most different from all the rhythms, according to the chronotonic distance, and guajira and fandango come out as the two most similar according to the directed swap distance.

We also carried out Mantel tests to determine the correlation between the overall matrix for the perceptual judgments and the matrices obtained with the mathematical measures, namely, for the directed swap distance and the chronotonic distance.

- Perceptual judgments and directed swap distance: $r = 0.76$ and $p = 0.03$.
- Perceptual judgments and chronotonic distance: $r = 0.66$ and $p = 0.017$.

It can be seen that correlation is higher for the directed swap distance than for the chronotonic distance, both being significant. As it can be seen, human judgment matches the similarity measures using the directed swap distance more than that using the chronotonic distance, both in terms of clusters and most distinct rhythmic pattern (seguiriya).

3. Experiment 2

Experiment 2 was designed to extend Experiment 1 in three ways. First, the differences between novice listeners, classically trained musicians and flamenco musicians are investigated. Second, we analyse the verbal data used by participants to describe the differences between the different patterns and the strategy used to compare them. Third, we added the possible ancestral rhythm identified by Diaz-Bañez et al. (2005), which is positioned in the central position of the phylogenetic graphs derived from the mathematical measures of rhythmic similarity.

3.1 Participants

Sixteen non-musicians (mean age 27.2, SD 7.4) with an average of 3.9 years of musical training were recruited from the student population at McGill University in Montreal, Canada. Twelve classically trained percussionists (mean age 24.6, SD 7) with an average of 14 years of musical training were recruited from the Schulich School of music at McGill University. Seven flamenco musicians (mean age 31.8, SD 8.6, four guitar players, two singers and a percussionist) with an average of 13 years of musical training were recruited from the teacher and student population at the Escola Superior de Música de Catalunya (ESMUC) in Barcelona, Spain. All participants received a nominal fee for their participation.

3.2 Stimuli

As in Experiment 1, participants listened to the MIDI-generated patterns using Finale (using the same hand clapping sounds from the standard percussion kit with the same parameters). In addition to the five patterns used in Experiment 1, we added the ancestral rhythm [x . . x . . x . . x x .], resulting in six patterns. The rhythms were generated at two different tempi, namely 70 and 90 dotted quarter notes per minute, respectively denoted Medium and Fast in the figures. The procedure was the same as in Experiment 1: after three randomly chosen practice trials, participants were asked to rate the similarity for all possible non-identical pairs of the six patterns (15 pairs), presented in random order. Every pair occurred twice within a block in counterbalanced order, resulting in 30 trials in total per block. The stimuli were blocked by tempo condition following a Latin-square design. The within block order was randomized. In addition to similarity ratings, participants were asked to freely describe the differences between patterns presented in each trial, as well as their strategy for evaluation similarity.

3.3 Statistical analysis

A four-way (Expertise × Tempo × ComparisonPair × Repetition) repeated measure ANOVA, conducted with SPSS, revealed significant main effects of Expertise ($F(2,29) = 3.6$, $p = 0.04$) and ComparisonPair ($F(9,21) = 36.2$, $p < 0.001$). No other significant effects were observed. For the main effect of expertise, classically trained percussionists gave the lowest ratings (average of 42 out of 100), i.e. judged patterns as more different, followed by flamenco musicians (average of 46 out of 100) and non-musicians (average rating of 54 out of 100). *Post hoc* tests revealed a significant difference between non-musicians and classically trained percussionists ($p = 0.017$), but no significant differences were found between the two groups of musicians (percussionists and flamenco musicians) or between non-musicians and flamenco musicians.

3.4 Phylogenetic analysis

As in Experiment 1, no significant difference was observed between the two tempi in the ANOVA. Mantel tests were performed to assess the relationship between the matrices corresponding to the two different tempi. The correlation between the matrices was very high ($r > 0.85$) and significant ($p < 0.03$). Specifically, the results are listed below:

- non-musicians: medium and fast tempi: $r = 0.92$ and $p = 0.005$;
- percussionists: medium and fast tempi: $r = 0.95$ and $p = 0.001$;
- flamenco musicians: medium and fast tempi: $r = 0.85$ and $p = 0.028$.

Subsequently, we collapsed the results across tempi. The SplitsTree program (Huson & Bryant, 2006) was used to construct the phylogenetic tree for the overall matrices. The results are presented in Figures 6, 7 and 8

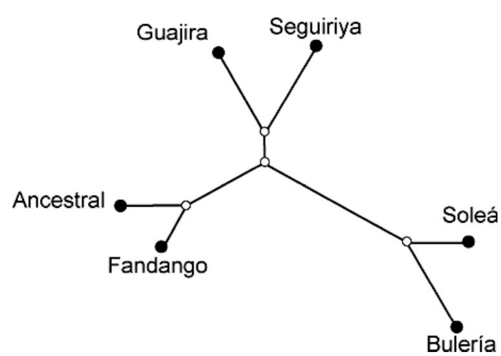

Fig. 6. Phylogenetic tree for 15 non-musicians in Experiment 2 (LSfit = 95.72).

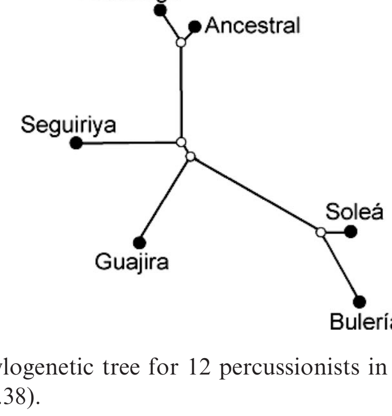

Fig. 7. Phylogenetic tree for 12 percussionists in Experiment 2 (LSfit = 97.38).

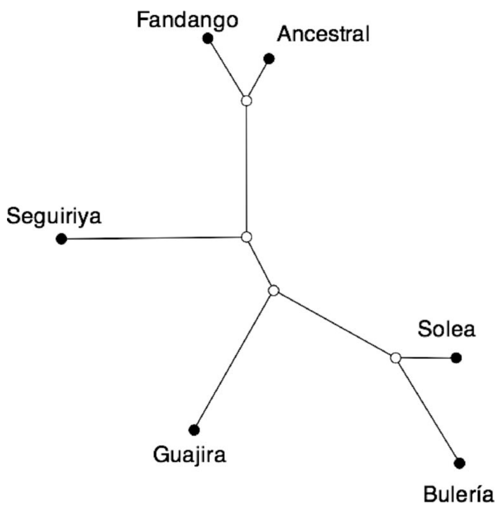

Fig. 8. Phylogenetic tree for 7 flamenco musicians in Experiment 2 (LSfit = 97.56).

below for non-musicians, classically trained percussionists and flamenco musicians (respectively). Three clusters emerge from the analysis, the first one contains fandango and ancestral, the second one contains guajira and seguiriya and the third one soleá and bulería, which both begin with soft claps resulting in anacrusis if the patterns were repeated. It is interesting to note that the ancestral was positioned in the middle of the phylogenetic graphs given by the mathematical measures, but it did not keep the same position in the phylogenetic graphs given by the perceptual measures, where it was grouped with fandango.

3.5 Comparison with mathematical measures

Mantel tests were performed to determine the correlation between the overall matrix for the perceptual judgments and the matrices obtained with the mathematical measures, namely for the directed swap distance and the chronotonic distance. The results are reported in Table 3.

In this case, it can be seen that the correlations are higher for the directed swap distance than for the chronotonic distance in the case of non-musicians and musicians as in Experiment 1 (they are both significant, with $p < 0.02$). As for the flamenco musicians, that was not the case as the correlation coefficient was higher for the chronotonic distance than for the directed-swap distance. There was a small difference between the r-value for musicians ($r = 0.61$) and flamenco musicians ($r = 0.69$), although the p-values of both are significant. The directed-swap distance only takes into account the distance between adjacent onsets. The chronotonic distance, however, not only considers the attacks, but also the inter-onset interval information. Indeed, the histogram associated with the chronotonic distance is composed of squares (but not rectangles) put together, whose height is exactly the inter-onset interval. A change of position of an onset also implies a change of the inter-onset interval. From this point of view, the chronotonic distance embeds more information than the directed-swap distance. It seems that the two first groups of subjects mainly rely on the adjacency, whereas the flamenco musicians seem to use more information besides note proximity. Interestingly enough, we observe that in their verbal comments musicians and flamenco musicians often talk about groups of 2 and 3 (see the analysis of verbal comments below). As a matter of fact, it is possible that flamenco musicians use extra information associated with the rhythms themselves irrespective of the chronotonic distance. Therefore, further experiments should be carried out in order to elucidate this point.

Table 3. Mantel tests for correlation between dissimilarity matrices in Exp. 2.

	Directed-swap distance		Chronotonic distance	
Mantel tests	r	p-value	r	p-value
Non-musicians	0.8	0.004	0.59	0.001
Percussionists	0.78	0.008	0.71	0.0014
Flamenco musicians	0.61	0.017	0.69	0.0014

3.6 Effect of expertise

In addition, to investigate the effect of expertise, Mantel tests were performed to compare the overall matrices for each group of participants. Very high correlations were observed ($r > 0.85$, $p < 0.002$). The results are reported below.

- Non-musicians and percussionists: $r = 0.96$ and $p = 0.001$.
- Flamenco musicians and percussionists: $r = 0.94$ and $p = 0.001$.
- Flamenco musicians and non-musicians: $r = 0.87$ and $p = 0.001$.

These results suggest that expertise did not have an effect on the perceptual organization of the rhythmic patterns. The analysis of the verbal comments was used to complement this observation by looking at the strategies used by the different groups of participants.

3.7 Analysis of verbal comments

Participants were asked which criteria they used to make their judgment and how they would describe the difference between each pair of patterns, besides general comments. We used the constant comparison technique from Grounded Theory (Glaser, 1967) to extract the emergent concepts from the free-format data. Occurrences within each concept are presented for each group of participants, concepts with only 1 occurrence were excluded from the analysis. Non-musicians based their judgments on whether the pattern started with an accentuated or non-accentuated beat (3 occurrences), 'fast and slow parts' (3 occ.), and by re-creating mentally a polyphonic pattern, by mentally superimposing the first pattern as they listened to the second pattern (2 occ.). Classically trained musicians, on the other hand, relied on groupings of 2's and 3's (6 occ.), the presence/absence of two consecutive accentuated beats (2 occ.), and whether the pattern started with an accentuated or non-accentuated beat (2 occ.). Musicians also used the superimposing strategy (2 occ.), but gave explicit comparison criteria somewhat similar to the directed swap distance, defined as the minimum number of position interchanges of adjacent 'x's and '.'s. Indeed, they seem to be matching each onset of one pattern to the nearest onset of the other pattern (3 occ.), as illustrated in the following quotation:

> I studied the first example's accents, and played them over again in my head while listening to the second example to see where it lined up and where it did not. If it rarely lined up and was completely off, the 2 rhythms appeared very different. If it lined up sometimes, they appeared slightly similar, and if they lined up at least 90% of the time I noted them as being very similar.

More detailed interviews will be conducted to further investigate this comparison strategy.

Flamenco musicians also determined a clear list of criteria, somewhat similar to those used by percussionists: namely whether the pattern started with an accentuated or non-accentuated beat (5 occ.), whether the pattern was shifted (4 occ.) and groupings of 2's and 3's (2 occ). The main difference is their knowledge of the patterns involved, identifying and referring to the different styles (*palos*) involved in the experiment (4 occ.). However, without a clear reference to the underlying meter (also expressed as the difficulty to establish the first beat without a reference to the harmony), they tended to identify three patterns as 'the same pattern shifted', rating them at 50%, between similar and dissimilar. Those patterns are the soleá, the seguiriya and the guajira, which share the same alternation of groups of 2 and 3, but starting at a different point within the metric frame of 12 claps. It should be noted that the percussionists who identified this particular feature used the same rating strategy. Another difference in the verbal data of flamenco and classically trained musicians and non-musicians is the vocabulary used to describe the criteria of segmentation; musicians had developed vocabularies and used formal terms to describe their strategies, whereas non-musicians used broader terms such as 'beats' (all 16 non-musicians) and 'rhythm' (5 occ.). The results of the qualitative analysis of verbal descriptors are summarized in Table 4.

4. Discussion

Our results indicate the *directed swap* distance proposed by Diaz-Bañez et al. (2005) closely matches human judgments of perceived similarity made by classically trained musicians. Results from Experiments 1 and 2 provide converging support for the directed swap distance for all groups of participants and all tempi. Few differences are noticeable between non-musicians, percussionists and flamenco musicians, and they are not big enough to lead to the definition of different categories. Significant differences were observed for the actual ratings but no significant differences were found across participants with different levels of expertise in terms of the resulting clusters. This finding could be interpreted as suggesting that when the input is abstracted away from the context, the underlying psychological perceptual mechanisms take over and dominate higher-level cultural effects.

Regarding the effect of expertise in Experiment 2, our results show that trained musicians and novices

Table 4. Summary of the qualitative analysis of verbal descriptors. An x indicates that the criterion was used by at least two participants in the corresponding group, an X indicated that it was used by more than half of the participants in this group.

	Strategy and criteria used to compare rhythmic patterns							
	Start with accent or not	Groupings of 2's and 3's	Superimposing patterns	Reference to palos (styles)	Patterns shifted	Fast and slow parts	2 consecutive accents	Directed swap strategy
Non-musicians	x		x			x		
Percussionists	x	X	X				x	x
Flamenco musicians	X	x		X	X			

organized the different rhythmic patterns in a very similar way, but using different cognitive processing strategies, as indicated by the qualitative data analysis. We observed a significant effect of expertise on the raw similarity ratings. The fact that non-musicians rate patterns as more similar to one another than musicians could suggest that musical training results in finer-grain discrimination abilities. In addition, the qualitative analysis of verbal descriptors revealed that percussionists could describe very explicitly the differences across patterns and the strategies they used to compare them and rate the similarity. However, we failed to observe an effect of expertise at the level of the phylogenetic analysis. We speculate that the lack of differences across our three groups of participants could be due to the restricted set of patterns, the fairly large differences across patterns, and the simplified nature of the MIDI-generated patterns used. However, further research would be needed to test this hypothesis on a wider range of rhythmic patterns, specifically by including variations on the main patterns used in the present studies, for which differences would be subtler. In addition, we intend to replicate these experiments by varying the instructions to ask participants to focus on specific comparison criteria. This would allow us to quantify the relative contribution of each criterion to the overall similarity and to compare the effect of expertise on each criterion.

Regarding the effect of tempo, we did not observe any significant effects of tempo, or interaction effect between tempo and expertise. This lack of effect may be seen as contradicting previous results (Duke, 1994), but it should be noted that in our experiments participants were always asked to compare patterns presented at the same tempo within an experimental block. That is, we did not introduce tempo variations within a given comparison.

Further research is needed to investigate the effect of repeating the patterns on perceptual measures of rhythmic similarity, specifically on the perception of the three 'shifted' patterns in relationship to the underlying metric structure. Repetition might indeed attenuate the impact of a beginning on soft claps, which could result in listeners grouping soleá closer to buleria than to the seguiriya/guajira. In addition, we will compare our findings with new listening tests using actual recordings of hand clapping in order to capture subtle variations in performance.

Furthermore, flamenco genres are mainly characterized by a particular rhythmic pattern, but other musical facets contribute to their identity (e.g. instrumentation, key and harmony). Hence further research is required to investigate rhythmic similarity of the analysed genres and its relationship to other musical facets (e.g. chord progression, dynamic variation, melodic contour), which may complement the perception of music similarity and the definition of different styles.

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