SESQUIALTERA IN THE COLOMBIAN BAMBUCO: PERCEPTION AND ESTIMATION OF BEAT AND METER

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ABSTRACT

The bambuco, one of the national rhythms of Colombia, is characterized by the presence of sesquialteras or the superposition of rhythmic elements from two meters. In this work, we analyze sesquialteras in bambucos from two perspectives. First, we analyze the perception of beat and meter by asking 10 Colombian musicians to perform beat annotations in a dataset of bambucos. Results show great diversity in the annotations: a total of five different meters or meter combinations were found in the annotations, with each bambuco in the study being annotated in at least two different meters. Second, we perform a beat tracking analysis in a dataset of bambucos with two state-of-the-art algorithms. Given that the algorithms used in the analysis were designed to deal with the rhythmic regularity of a single meter, it is not surprising that tracking performance is not very high (≃42% mean F-measure). However, a deeper analysis of the onset detection functions used for beat tracking, indicate that there is enough information on the signal level to characterize the bi-metric behavior of bambucos. With this in mind, we highlight possibilities for computational analysis of rhythm in bambucos.

1. INTRODUCTION

The focus of this work is the bambuco, one of the national rhythms of Colombia characterized by the superposition of musical elements in two meters, 3/4 and 6/8. This phenomenon is called *sesquialtera*, and while it is not unique to the bambuco [1, 2], this work focuses on perceptual and computational aspects particular to the Colombian bambuco. Our goal is to better understand how meter in bambuco is perceived by cultural insiders. To do so, we conducted a study where Colombian musicians were asked to tap the beat of a selection of bambucos (Section 2.1). We then investigate whether computational tools can help ethnomusicological investigations on tendencies of bambucos to follow a given meter. We extracted beat information from a bambuco dataset using state-of-the-art algorithms and evaluate tracking performance (Section 2.5).

The contributions of this work are summarized as follows: (1) To the authors' knowledge, this paper presents the first study on meter perception in bambucos. (2) We present an objective evaluation of computational tools for rhythm analysis on bambucos, and highlight analysis possibilities for future research. (3) All the data including audios, transcriptions, annotations, and code have been made publicly available to enable future research on the topic.

1.1 The bambuco

There are references about the presence of bambuco in Colombia dating back to the mid 19th century; however, despite numerous discussions about its origin and musicological characteristics, there is no clarity today about the real origin of this music: Is it indigenous, African or Hispanic? Is it urban or peasant mestizo? Despite this uncertainty, the reality is that little by little bambuco became a regional and musical symbol of identity. Like all the great Latin American genres that fulfilled this purpose towards the end of the 19th century and the first half of the 20th (e.g. Habanera, Tango, Chacarera), to become a worthy representative of this imagined regional identity and of those who coined it, the bambuco had to undergo a

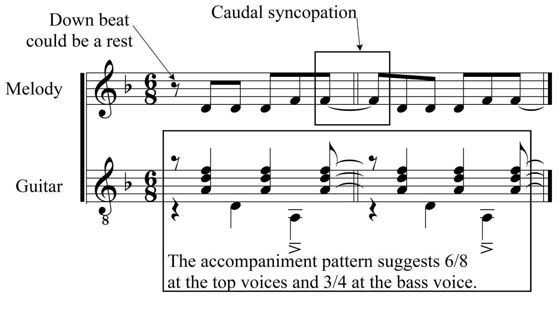


Figure 1: Bambuco example showing the downbeat, caudal syncopation and a guitar accompaniment pattern.

transformation process referred to as “whitening” [3]. This whitening can be understood as a progressive adherence to the bourgeois ideal of chamber music. This particular process has been studied by the Colombian ethnomusicologist Santamaria in [4]: “When relocating to the city since the mid-19th century, the bambuco progressively stopped being popular dance music and became music to be performed and listened to in an atmosphere of literary or concert gatherings”.

Bambucos show musical elements typical of ancient Spanish-Iberian and Colombian peasant dances, typified as sesquialteras, whose main characteristic is a bi-metric behavior (3/4 - 6/8) within the melodic line or between the melodic line and the bass line. This behavior can be observed in the example in Figure 1 where the guitar accompaniment has elements from both 6/8 and 3/4. Another characteristic element of bambucos is the presence of *caudal* syncopation in its phrases (sixth eighth note tied to the first eighth note of the following measure -see Fig. 1) which can result in the perception of a delay or a harmonic anticipation [5]. Another element of bambucos which adds to its rhythmic complexity is the characteristic accentuation of the third pulse in the accompaniment patterns in 3/4, which leads to the perception of a downbeat that is not the first pulse of the bar.

Of the instruments that usually participate in the performance of this type of bambucos [1] (such as guitars, tiples, and bandolas [2]), the main role of the rhythmic accompaniment is usually delegated to the tiple. The tiple is a plucked string instrument slightly smaller than a guitar, with 12 strings grouped in four tripled courses. One of the instrument’s most characteristic idiomatic playing techniques is the *aplatillado* which is achieved by bringing the nails closer to the strings to alter their timbre. With an alternating up and down strumming and the *aplatillado* (see Figure 2), textural elements are generated that can sometimes interfere with rhythm perception. This is similar to what happens in the charango (traditional string instrument) in certain Bolivian music [6].

Ramón y Rivera [7], proposed the term "free rhythm" in the context of Latin American music to refer to a certain elasticity in the unit of time, in breathing and in the execution of rhythmic groups, as opposed to a rhythmic reference subject to a measure or bar. This rhythmic freedom is observed in the set of recordings that are part of this study and that account not only for particularities of the genre, but also for a historical moment of the recordings not rigorously subject to a metronomic guide. Additionally, tempo and micro-timing in bambuco appear to work in general in a flexible way, with even subtle differences between timing of the melody and that of the various elements of the accompaniment. These freedoms could be associated with the rubato of European music or with the floating rhythm of jazz; however, it is a different phenomenon that contributes to the rhythmic complexity of bambuco and its perception [3].

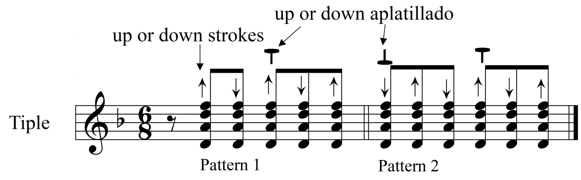


Figure 2: Tiple accompaniment patterns

The different levels of complexity described in this section become critical elements when developing computational tools for musicological analysis of these music traditions.

1.2 Beat and meter perception

The perception of meter and beat in music is directly associated with the perception of regularity. It is precisely this regularity that allows the listener to create expectations about the musical events in a given time span [8]. While beat perception is mostly linked to a perceived periodicity, meter is additionally linked to an accentuation pattern that differentiates, for example, beats from downbeats. Based on these ideas, Western music theory defines a hierarchical relationship between beats, measures (bars), and meter (see Figure 3). For certain musical traditions where a unique meter cannot always be clearly defined (such as the bambuco but also Bolivian Easter songs [6], the Southern Eve dance drumming of the Guinea Coast [2], among others), Western music theory (and music notation) can often fall short in providing an accurate representation of these traditions. In the particular case of the Colombian bambuco, its correct music notation has been the source of many academic discussions [3]. Besides the superposition of 3/4 and 6/8 meters, bambuco’s characteristic accentuation pattern (due to caudal syncopation and the accentuation of the third beat in 3/4 by the accompaniment - see Section 1.1) adds another layer of complexity as the traditional definition of downbeats (Figure 3) do not hold in the case of bambuco.

Of particular interest in this context is the work by Stobart et al. [6] on rhythm perception of Bolivian Easter songs. The study outlines how cultural outsiders perceived

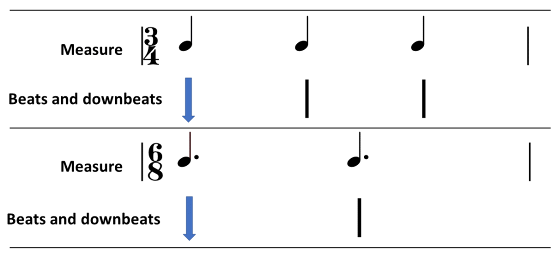


Figure 3: Hierarchical relationship between meter, measures (bars) and beats as defined in Western music theory. In both 3/4 and 6/8, the beats are indicated with vertical lines, and the downbeat with a blue arrow.

[1] More information available: https://acmus-mir.github.io/publication/ismir2020/
[2] Instrument descriptions: https://acmus-mir.github.io/andes-music/

these songs as anacrustic 6/8 rhythms, while footfalls of locals dancing to the rhythm of the music indicated a 2/4 rhythmic perception. The authors highlight that accentuation patterns of the charango (traditional string instrument) accompaniment as well as stress patterns in the local language *Quechua* in which the songs are sung, are possible causes of the differences in perception.

1.3 Music Information Retrieval (MIR) approaches for rhythm analysis

The computational analysis of musical beat has been widely addressed in the literature, predominately applied to Western popular music [9] but also applied to non-Western music [10, 11]. While beat tracking accuracy for Western popular music can already be very high, beat tracking of non-Western music presents many more challenges, and performance highly depends on the rhythmic complexity of each music tradition. In the particular case of Latin American music, work on computational analysis of rhythm has either focused on understanding characteristic patterns in micro-timing that implant local rhythms their unique rhythmic feel (e.g. Brazilian Samba [12], and Uruguayan Candombe [13]), on using rhythmic pattern templates for beat tracking (e.g. Afro-Cuban rhythms [14], and Uruguayan Candombe [15]) or on genre classification [16].

To the authors' knowledge, an in-depth computational analysis of rhythm in the Colombian bambuco has never been performed. This motivated the preliminary beat tracking evaluation where the goal was to understand how state-of-the-art tools for beat tracking perform when meters superpose in music. However, we approach this evaluation not with the expectation that the algorithms will succeed in tracking rhythmic patterns they were not originally designed to track; we approach this evaluation with the goal of understanding the potential of these techniques to be expanded into meaningful musicological analysis tools for bambucos and music from the Andes in general.

2. BAMBUCO ANALYSIS

2.1 Dataset

The data used in this study is part of the ACMUS-MIR dataset (V1.1), [3] a collection of annotated music from the Andes region in Colombia [17]. To evaluate beat tracking performance, all the bambucos in the **Rhythm Set** of the ACMUS-MIR dataset were used (N=73). From the 73 bambucos, a smaller selection of 10 bambucos were used in the perceptual study (see Table 1 for details). [5] The 10 bambucos in the perceptual study were chosen as they clearly exemplify the bi-metric behaviour of the bambuco genre, and include a diversity of instrumental formats (duets, trios, wind orchestra). Additionally, the majority of the tracks were composed by Luis Uribe Bueno, a representative composer and performer of bambuco in Colombia.

[3] ACMUS-MIR: https://zenodo.org/record/3965447

2.2 Participants

A total of 10 Colombian participants took part in the perceptual study (8 male, 2 female, ages 25-50), all of whom had been exposed to bambuco music throughout their lives (cultural insiders). All the participants had musical training, and were either university music students or professional musicians: five guitarists, two bandola players, two pianist, one flutist, one singer. The majority of the participants had previous experience performing bambucos within their musical practices.

2.3 Survey

As part of the perceptual study, each participant also answered a short survey consisting of three questions: (1) Which musical elements guided you when tapping the beat? (2) Was there any element that made the annotation process difficult? and (3) Do you have any observations about the tempo in these bambucos? [1]

2.4 Annotations

2.4.1 Beat

For the perceptual study, the 10 participants were asked to tap the beat to the selection of 10 bambucos using the computer keyboard in Sonic Visualiser. [4] Participants were given freedom to tap the beats that felt more natural to them. No indications about meter were given to the participants to avoid biasing them. Two sets of annotations were recorded: (1) Beat annotations tapped while listening to the audio (without any visual information) without allowing corrections by the participants (***Audio Only***). (2) Participants were allowed to modify their initial beat annotations in Sonic Visualiser using both audio information and a visual representation of the audio waveform. Participants were allowed to make as many corrections as necessary for them to be satisfied with their annotations (***Audiovisual + corrections***). If participants were satisfied with the ***Audio Only*** annotations, the correction step was not performed. [5]

For the computational beat tracking analysis, the annotations from the **Rhythms Set** of the ACMUS-MIR (V1.1) dataset [3] were used. With the awareness that in many cases a unique meter in bambucos cannot be defined, beat annotations in the dataset were performed independently for the two predominant meters, 3/4 and 6/8. For the 73 bambucos, these two sets of annotations were used, each assuming a unique underlying meter [17].

2.4.2 Melody, bass and chord annotations

The melody line and the bass of each bambuco in the perceptual study were transcribed by four professional musicians in Colombia. The transcriptions in MIDI format were manually aligned to the audio signal resulting in time-aligned transcriptions. The chord progression of each bambuco was also annotated (see Fig. 4 for an example). [5]

[4] https://www.sonicvisualiser.org/

[5] Audio and annotations: https://zenodo.org/record/3829091#.Xxd3IZ7TuUk

Title	Composer	Tempo 3/4 [bpm]	Tempo 6/8 [bpm]	Duration [sec]	BLIND REVIEW IDs
Mimí	Unknown	181	121	19.4	rh_0001
Campanitas de mi pueblo	Luis Uribe Bueno	154	102	18.8	rh_0002
El espinaluno	Carlos A. Rosso Manrique	213	142	16.4	rh_0003
El marco de tu ventana	Luis Uribe Bueno	130	89	13.9	rh_0038
Baile de ranas	Luis Uribe Bueno	153	102	16.5	rh_0039
Bambuco instrumental	Luis Uribe Bueno	192	128	15.1	rh_0067
Bambuco instrumental	Luis Uribe Bueno	195	128	20.1	rh_0079
Bambuco instrumental	Luis Uribe Bueno	199	132	17.0	rh_0080
Bambuco instrumental	Luis Uribe Bueno	169	113	25.5	rh_0100
Bochicaniando	Luis Uribe Bueno	184	123	25.6	if_0172

Table 1: Selection of bambucos from the ACMUS-MIR dataset used in the perceptual study. Each segment corresponds to a complete musical idea or phrase taken from the original recording. Due to the superposition of 3/4 and 6/8 meters in these bambucos, tempo annotations for both meters are presented.

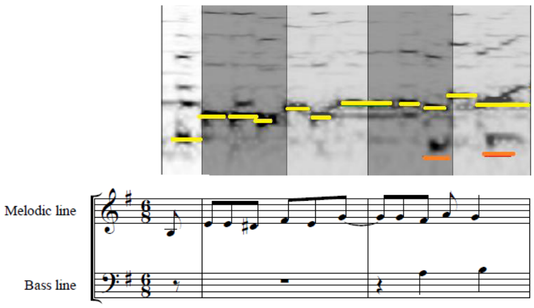


Figure 4: Example transcription of the first two measures of track rh_0067. Conventional music notation and their MIDI representation is displayed.

2.5 Automatic beat tracking

For beat tracking evaluation, two state-of-the-art algorithms were used to predict the beat positions. The first set of beat tracking estimations was obtained using Madmom. [6] In the context of the Madmom library, we specifically used a multi-model approach that uses recurrent neural networks to track beats [18]. The second algorithm used for beat estimation was the Multi-Feature Beat tracker (MultiBT) [19] implemented in Essentia. [7] This algorithm selects between beat estimations from a single beat tracking model with diverse input features. Given the bi-metric characteristics of bambucos, independent ground-truth annotations assuming either a 3/4 or 6/8 meter were used (see Section 2.4.1).

For evaluation we use a subset of metrics from the standard evaluation methods described in [20]. Among all the proposed metrics, we chose the F-measure (F1), along with the continuity measures originally defined in [21, 22]. This allows us to analyze both the ambiguity associated with the annotated metrical level and the continuity in the beat estimates. The F-measure (F1) is a generic score often used in information retrieval. For beat tracking, it is common practice to use a ± 70 ms tolerance window around annotations to consider a beat prediction as correct. The F-measure takes into consideration the number of correct beats, the number of false positives (extra detections), and the number of false negatives (missed detections). Under this metric, completely unrelated beat sequences typically score around 25% by virtue of beats arbitrarily falling within the range of tolerance windows.

Continuity-based evaluation considers regions of continuously correct beat estimates relative to the length of the audio signal. This is the case of the Correct Metrical Level Continuity **(CMLc)** measure, which computes the ratio of the longest continuously correct segment to the length of the input. By definition, continuity is defined using a tolerance window of $\pm 17.5\%$ around each annotation, considering an estimation as correct if it falls within this window. To include the effect of beats in other segments, a less strict measure considers the total number of correct beats at the correct metrical level without the continuity criteria (**CMLt**) [20]. Lastly, to account for ambiguity in the metrical level, two additional metrics consider beats tapped at double or half the annotated metrical level, with the same continuity criteria as before. This conditions are considered *allowed* metrical levels resulting in the Allowed Metrical Level Continuity (**AMLc**) metric and its less strict alternative (**AMLt**) [20]. [8]

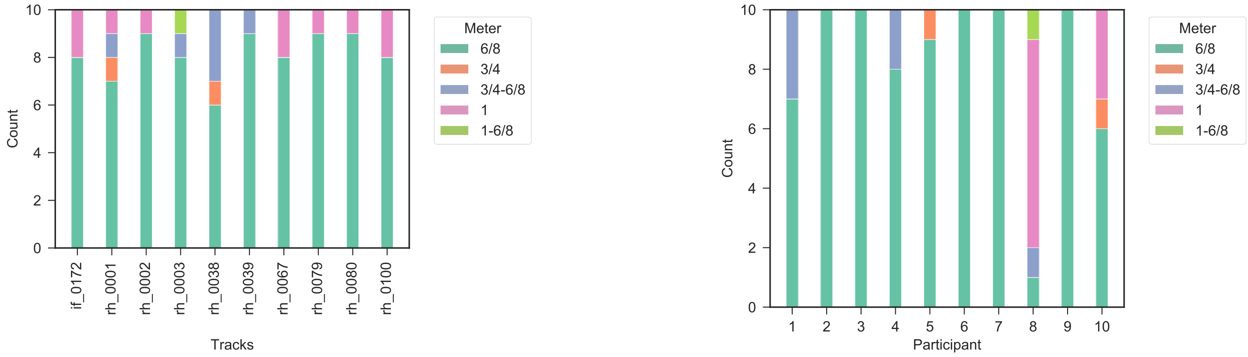
3. RESULTS AND DISCUSSION

3.1 Meter perception in bambucos

The beat annotations obtained from the 10 participants (Section 2.4.1) were analyzed by three musicologists in Colombia to determine the underlying meter(s) perceived by each participant in each track. [5] Even though participants were given freedom to tap beats that felt natural to them, each annotation can be directly mapped back to a given meter. This can be understood by looking at Figure 3: If a participant taps three beats per bar, these annotations are mapped back to a 3/4 meter. Conversely, if a participant taps two beats per bar, the underlying meter is assumed to be 6/8. In total, five different meters or meter combinations were observed: 3/4 meter, 6/8 meter, a combination of 3/4 and 6/8, "one count" annotations where participants annotated the first beat of the measure (blue arrows in Fig. 3

[6] https://madmom.readthedocs.io/en/latest/
[7] https://essentia.upf.edu/

[8] Code available: https://github.com/ACMUS-MIR/publications-resources/tree/master/ISMIR2020



(a) Perceived meter aggregated per track

(b) Perceived meter aggregated per participant

Figure 5: (a) Perceived meter aggregated per track over the 10 participants. (b) Perceived meter aggregated per participant over the 10 tracks. Five distinct meters or meter combinations were observed.

which correspond to the downbeats in Western traditions but are not the accentuated beat in bambucos), and a combination between 6/8 and "one count" annotations. These five alternatives are denoted "3/4", "6/8", "3/4-6/8", "1", and "1-6/8", respectively.

Figure 5a shows a summary of the annotations aggregated per track from the revised annotations (***Audiovisual + corrections***). It can be seen that for each of the 10 bambucos, at least two different meters or meter combinations were perceived. The 6/8 meter proved to be predominant in the annotations. It should be noted, that as of today, bambuco is written as a convention in 6/8, and hence, there might be a tendency in trained musicians to default to 6/8.

Similarly, Figure 5b shows a summary of the revised annotations aggregated per participant. It can be seen that five of the 10 participants annotated all the tracks in 6/8 meter. Two of the participants perceived "6/8" and the "3/4-6/8" combination, and two participants perceived a "3/4" meter. Of particular interest in participant eight (p8), who predominantly annotated the bambucos in "1". This is interesting in the sense that this is the only type of annotation that removes the ambiguity in meter perception as the first beat coincides in "6/8" and "3/4" (see Fig. 3). The practice of counting music in "1" is often related to music in fast tempi, where counting all beats in a bar might no longer be comfortable. However, this is not the case here. Table 1 shows the tempo distribution of our bambuco dataset. The fastest bambuco in our dataset is rh_0003, which is mostly annotated in "6/8", with p8 choosing the "1-6/8" alternative in this case. Participant p8 annotated seven bambucos in "1", all of them with slower tempi than rh_0003.

From the 100 annotation instances in this study (10 tracks x 10 participants), a total of 10 instances showed different meters when comparing the (***Audio Only***) annotations with the revised annotations (***Audiovisual + corrections***). Three instances were modified from "3/4-6/8" to "6/8", two instances were modified from "6/8" to "3/4-6/8", two from "3/4" to "6/8", two from "6/8" to "1", and one from "6/8" to "3/4". These results further indicate the dynamic nature of meter perception in bambucos.

The responses from the participants in the survey show a tendency to use harmony, as well as a tendency to rely on parts of the musical discourse that are close to their personal experience (guitar or tiple players, for example, focused more on the accompaniment patterns of the guitar and the tiple). According to the participants, the main difficulties of the analysis process, in addition to flexibility in tempo, were the conception of the phrasing present in the sample, the ritardandos and accelerandos performed between different parts of the musical texture (melody and accompaniment), and the quality of the recordings. Finally, the participants observed that the tempo in these recordings behaves in an organic way, far from the metric rigor typical of the practices of current academic musicians. This is no longer frequent in the way the bambuco is performed today. This transformation could be related to the changes in recording techniques and the prescriptive function of the academic institutions and the musical events in which this type of music circulates.

	Algorithm	**F1**	**AMLc**	**AMLt**	**CMLc**	**CMLt**
$\frac{3}{4}$	Madmom	75.06	60.76	77.05	50.89	64.27
	MultiBT	42.79	23.32	25.24	12.43	14.33
$\frac{6}{8}$	Madmom	41.13	9.23	10.71	5.64	5.72
	MultiBT	45.15	42.87	51.76	32.38	35.54

Table 2: Beat tracking evaluation metrics obtained with Madmom and MultiBT. Results are presented using two sets of ground-truths: 3/4 and 6/8. All metrics presented have a maximum score of 100%.

3.2 Beat tracker performance on bambucos

Two independent evaluations are presented in Table 2 for each of the two beat tracking algorithms. The top row presents results obtained when ground-truth annotations assuming an underlying 3/4 meter are used. The bottom row presents results with ground-truth annotations in 6/8. Metrics that enforce continuity (CMLc and AMLc) are in all cases lower than their less strict counterparts (CMLt and AMLt). Additionally, metrics that allow estimation in different metrical levels (AMLc and AMLt) are also higher than the ones that enforce a correct one (CMLc and CMLt).

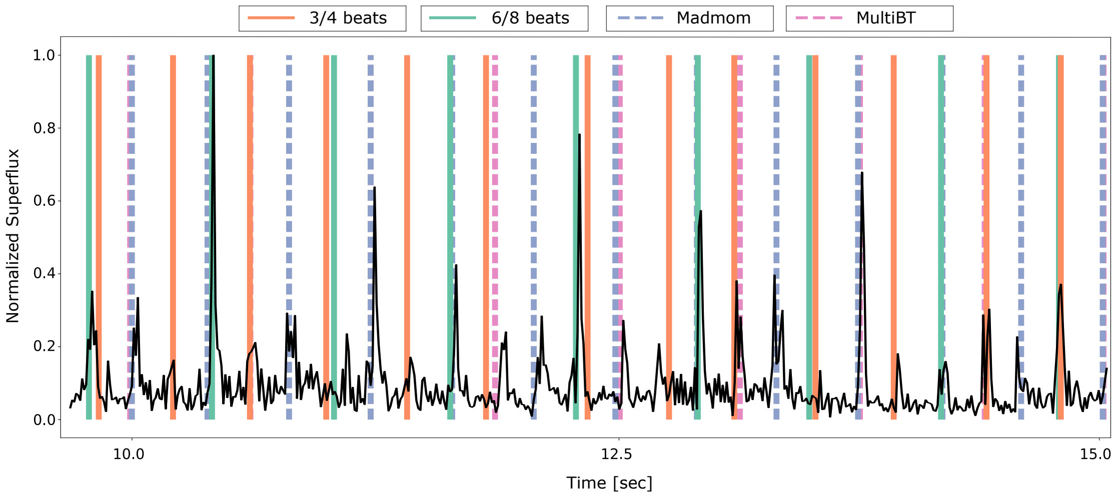


Figure 6: Onsets detection function extracted using *Superflux* on a segment of track rh_0002. Ground-truth annotations in 3/4 and 6/8 are shown, as well as beat estimations obtained with Madmom and MultiBT.

These results indicate that in certain occasions, the algorithms are tracking a higher metrical level, detecting the first beat of the bar as the underlying beat (similar to the "1" annotations in the perceptual study). As previously mentioned, this is the only beat where 6/8 and 3/4 coincide. When focusing on those metrics that only consider the correct estimations and not the false positives and false negatives, namely AMLc, AMLt, CMLc and CMLt, Madmom appears to be consistently better at estimating beats in 3/4 than in 6/8. In contrast, MultiBT shows better performance for 6/8 for the same set of metrics.

Evaluation results confirmed our initial hypothesis that the bi-metric nature of our dataset can be challenging for the beat tracking algorithms. However, to better understand the potential of beat tracking algorithms when working with our dataset, we analyzed the onset detection functions, as obtained by the spectral flux or the superflux, [6] of the 10 bambucos in our dataset. [8] Onset detection functions are intermediate signal representations often used in beat tracking algorithms that highlight time instants of the signal where onsets might be present. A peak in the onset detection function suggests that there is a high probability of an onset occurring in that position. With this analysis, the goal was to understand whether enough information could be found on the signal level to characterize the bi-metric behaviour of bambucos. Figure 6 shows a segment of the onset detection function obtained with Superflux on track rh_0002. The ground-truth beat annotations in 6/8 and in 3/4 are also displayed for reference. It should be noted that the annotations in 3/4 and 6/8 were extracted independently by different annotators, and hence the downbeats (which in theory should coincide) do not exactly overlap in all cases. Strong peaks in the onset detection function can be observed in most beat positions from the ground-truth annotations (solid orange line (3/4) and solid green line (6/8) lines). This suggests that regardless of the rhythmic complexity, there is information that can be exploited to characterize the metric behavior of bambucos. For reference, the beat estimations obtained by Madmom and MultiBT (dashed lines) are also shown in the figure. The complexity of the task is further confirmed by the fact that, not surprisingly, the estimations obtained by the Madmom and MuiltiBT also tend to overlap with peaks in the onset detection function.

4. CONCLUSIONS

This work presented an analysis of beat and meter in the Colombian bambuco, a rhythm characterized by the presence of musical elements from two different meters. Our perceptual study confirmed that even for human listeners, there is not an unique understanding of the rhythmic structures of the genre. Even though current conventions assume a 6/8 meter when writing bambucos, our perceptual study confirmed that reality is much more complex than that. A total of five metric alternatives were found in the annotations produced by the participants in the study. Not surprisingly, results from the computational analysis confirmed that beat tracking models developed to deal with the regularity of a unique meter, do not fully characterize the complex rhythmic interactions in bambucos. However, our analysis of onset detection functions suggests that there is relevant information in these signal representations that could be leveraged for musicological analysis of bambucos. It is clear from the findings in this study that the development of tools for rhythm analysis of bambucos –or of any other music tradition that shares similar rhythmic properties– cannot be approached from a binary decision (right/wrong) perspective. This calls for rhythm analysis tools with an exploratory nature, where the existence of several truths is permitted, and the choice of the most relevant one is both task- and context-dependent. Our hope is that this study as well as the data and annotations collected in it, will serve as a preliminary step in the development of computational tools for musicological analysis of bambucos and Andean music.

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