MOVING IN TIME: COMPUTATIONAL ANALYSIS OF MICROTIMING IN MARACATU DE BAQUE SOLTO

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ABSTRACT

"Maracatu de baque solto" is a Carnival performance combining music, poetry, and dance, occurring in the Zona da Mata Norte region of Pernambuco (Northeast Brazil). Maracatu percussive music is strongly repetitive, and is played as loud and as fast as possible. Both from an MIR and ethnomusicological perspective this makes a complex musical scene to analyse and interpret. In this paper we focus on the extraction of microtiming profiles towards the longer term goal of understanding how rhythmic performance in Maracatu is used to promote health and wellbeing. To conduct this analysis we use a set of recordings acquired with contact microphones which minimise the interference between performers. Our analysis reveals that the microtiming profiles differ substantially from those observed in more widely studied South American music. In particular, we highlight the presence of dynamic microtiming profiles as well as the importance of the choice of timekeeper instrument, which dictates how the performances can be understood. Throughout this work, we emphasize the importance of a multidisciplinary approach in which MIR, audio engineering, and ethnomusicology must interact to provide meaningful insight about this music.

1. INTRODUCTION

"Maracatu de baque solto", also known as "Maracatu rural", is a Carnival performance combining music, poetry, and dance, occurring in the Zona da Mata Norte region of Pernambuco (Northeast Brazil). Most inhabitants of this region, dominated by the sugar cane monoculture, are rural workers with very modest income, who invest most of their time and money to participate in the Carnival "desfile" (parade), taking place every year in Recife, the state capital. More than 100 groups of Maracatu de baque solto, of different sizes (ranging from 15-20 members up to 200 members) are currently active, each with their own headquarters ("sede") which are generally linked to individual families. A Maracatu performance is shown in Fig. 1.

Figure 1: Maracatu de baque solto "Leão de Ouro de Condado" during a Carnival parade in Tupaoca (Pernambuco), Feb. 28th, 2017. Photo credit: Filippo Bonini Baraldi.

Maracatu de baque solto differs from another Carnival performance with a similar name, Maracatu "de baque virado," not only in terms of its musical and choreographic features, but also because it has remained a very local cultural practice. Indeed, while Maracatu de baque virado, like other music from Pernambuco (e.g., forró, coco de roda, ciranda), has recently spread out nationally and internationally, Maracatu de baque solto (hereafter shortened to Maracatu) is only performed within a radius of about $100\,\mathrm{km}^2$ and is strongly linked to the local afro-indigenous spiritual and religious practices, specifically, the jurema-umbanda worship [1]. This local dimension explains why, barring a few exceptions, it remains a largely understudied cultural expression. To the best of our knowledge no in-depth analysis of its music has ever been realised.

Previous field research conducted in Condado, a small city located in the Zona da Mata Norte region, suggests that the protective function of Maracatu is locally expressed by two key concepts: "consonância" (consonance) and "fechar" (closure) [2, 3]. Consonance points to a particular way of behaving, of dancing together, and of producing sounds. It is associated with an idea of high interpersonal coordination, as opposed to the idea of "desmantelo" (fracture and breaking up). The expression "fechar o Maracatu" (closing the Maracatu) refers to various aesthetic strategies used to protect the individual and the community from the threats that are at stake during Carnival. The percussive nucleus of Maracatu plays as fast and loud as possible, saturating the acoustical space and "filling" each metrical position in order to avoid any silence. To this end, the study of systematic microtiming, i.e., intentional deviations from strict metronomic timing, can be a promising first step towards understanding Maracatu performances.

In December 2019, 13 members of a Maracatu group "Leão de Ouro de Condado" were invited to Lisbon. Several public performances were organised which culminated in a two-part event: a parade in which musicians and dancers moved through the streets, followed by a fixed location, outdoor performance. We focus on the recordings obtained from the latter, and perform an exploratory analysis of the microtiming in the percussionists' performances.

Our research is part of the emerging topic of computational ethnomusicology [4, 5], and falls within a growing body of work examining the role of microtiming and rhythmic structure and its relationship to groove and musical embodiment [6–10]. It also intersects with the existing MIR literature on the analysis of rhythm in South American music [11–16]. In our specific context, we face two prominent, interconnected challenges. In the absence of formal theories about Maracatu, there is little basis on which to pose research questions that computational analysis (e.g., using MIR techniques) could address. From a more practical perspective, the very nature of Maracatu performance: musicians in tight proximity to one another, playing very loudly, and moving between multiple adhoc external locations, creates technical difficulties for the high-quality signal acquisition necessary for temporally-precise analysis of musical timing.

Our methodology to address these challenges is to conduct the research from a strongly multidisciplinary perspective. We directly leverage technical expertise in audio engineering for signal acquisition, music signal processing and machine learning for computational rhythm analysis, and ethnomusicology to guide the interpretation of the findings based on long-term field research. By necessity, this leads to an exploratory approach concerning the presence and use of microtiming in Maracatu, where the computational analysis can be used as a means to infer new understanding about the musical practice.

To enable the isolated analysis of the microtiming of each percussionist, we use contact microphones attached to each individual instrument. We adapt a state-of-the-art approach for microtiming analysis [12] and investigate both "within-instrument" microtiming, where onset and beat information are specific to a given instrument, and "between-instrument" microtiming, where a "time-keeping" instrument provides the beat reference. Our main findings demonstrate that the choice of the time-keeper is critical and can change the interpretation of the performance. Furthermore, we observe microtiming profiles that change dynamically within given pieces of music, and between pieces of music. Thus, the notion of a single characteristic microtiming profile appears not to apply to the set of Maracatu recordings under investigation here.

The remainder of this paper is structured as follows. Section 2 provides an overview of the musical structure and instruments of Maracatu. Section 3 describes the signal acquisition process. Section 4 summarizes the microtiming modelling approach, with our main findings presented in Section 5. We conclude the paper in Section 6 with a reflection on the broader impact of the research.

2. MARACATU DE BAQUE SOLTO

Maracatu is a combination of various elements: two to four wind instruments (trumpet and trombone), played by "musicos" (musicians), and a nucleus of five percussionists called the "terno." During performances, the musicos and terno act in close cooperation with a poet (the "mestre de apito"). When the poet improvises short verses about 30 s in duration, the musicians remain silent and the dancers and public remain still. When the poet finishes his verses and blows his whistle ("apito"), the percussionists and the wind musicians play for about the same duration and everybody dances. During this time, the poet prepares his next verses. This alternating pattern remains throughout the performance, which may last up to eight hours.

Maracatu percussive music is highly repetitive, and played as loud and as fast as possible. These features give rise to a very strong euphoria in the dancers and the public. Just a few rhythmical patterns exist in Maracatu and depend on the metrical form that the poet is following: the main genres are "marcha" and "samba," although the samba of Maracatu has nothing to do with the well-known samba music of Brazil. In Maracatu, marcha and samba indicate both the metrical subdivision of the poet's couplets, the rhythm played by the terno, and the melodies played by the musicos. Various melodies may be associated to the marcha pattern and/or samba pattern, depending on the melodic line that the poet chooses to sing his verses.

In Maracatu, the five percussion instruments of the terno, shown in Fig. 2, are: *Bombo* – a bass drum-like instrument played with two sticks, one for each side. We refer to Bombo High as the upper skin, and Bombo Low as the lower. *Gonguê* – an iron instrument comprised of two bells of different pitches. We refer to Gonguê High as the higher, and Gonguê Low as the lower pitched bell. *Porca* – a friction drum, played with a damp cloth holding the stick. *Tarol* – similar to a small snare drum, but thinner. *Mineiro* – a metal tube filled with beads or other small objects, which is shaken to create a rattle-type sound.

Following transcriptions in [17] for both the marcha and samba, the Porca plays a regular quarter note pattern. Likewise for the marcha, the lower bell of the Gonguê has

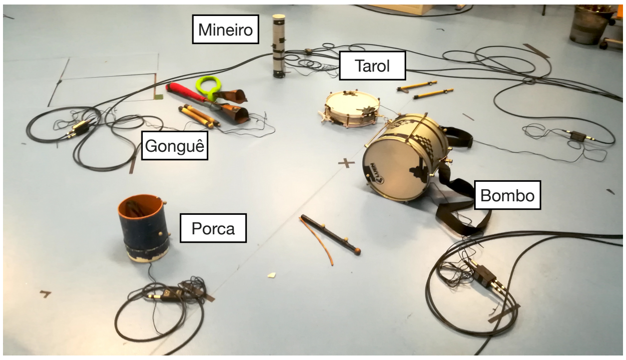

Figure 2: The instruments of the terno (with identifying labels overlaid) including the connection of the contact microphones.

the same pattern. Thus, for marcha we assume that either could provide a time-keeping role.

3. DATA ACQUISITION

In this work, we wished to analyse each percussionist's performance in isolation. While multiple microphone setups have been successfully used to acquire separated audio data for rhythmic and microtiming analysis [18], the physical arrangement of the Maracatu percussionists in a tight circle, together with the very loud playing style, makes this impractical and highly prone to "spillage." In turn, this would make any subsequent annotation and microtiming analysis extremely challenging. A promising alternative is to consider the use of contact microphones.

For this study, we used the Schertler Basik Set universal contact microphone. Each microphone includes a phantom-power adaptor box which delivers a line-level signal, with a 60 Hz–15 kHz frequency response. The sensitivity on the instrument is -34 dB (time-averaged sound level). We found these microphones provided high-quality audio recordings with minimal spillage and distortion.

For the microphone placement, we sought to balance the optimum location for sound capture while minimizing any impact to each musician's playing style. Given the small size of the Schertler pickup (less than 1 cm in diameter), this aspect was relatively straightforward.

We placed two pickups on the Gonguê – one per bell, and two on the Bombo – one per skin. For the remainder, the Tarol, Porca, and Mineiro we used a single pickup. The contact microphones were individually connected to a Motu UltraLite-mk3 Hybrid (USB/Firewire) with nominal gain at the input and no further processing. The recording session consisted of discrete, synchronised tracks, one per microphone, recorded in a Pro Tools 2019 mixing session configured to record at 44.1 kHz, with 16-bit depth.

We used this setup in the fixed location performance, rather than the parade. Over the total performance duration of 48 minutes, we partitioned the performance into 34 individual pieces (i.e., editing out the poetry), with a mean duration of 39.4 s. Of these 34 pieces, 28 were marcha, 5 were samba, and in one piece the percussionists played samba, while the musicos played marcha.

4. MICROTIMING MODEL

In order to undertake any assessment of the microtiming present in recordings, we must obtain precise temporal markers which indicate the note onset positions. Following existing work in microtiming analysis [12, 14] it is necessary to create a reference beat grid against which to compare the locations of performed onsets with quantised beat and/or sub-beat positions. In this way, each beat interval can be assigned a normalised duration of 1, and thus a rhythmic pattern containing four equal sub-divisions would occur at normalised positions 0, 0.25, 0.50, and 0.75. When summarising this information over multiple beats, it is possible to observe systematic microtiming patterns–called microtiming profiles [12]–, where, in the case of Brazilian samba, the third and fourth sub-divisions of the beats have been shown to occur ahead of their quantised position [12, 14]. Note that because the relative position of onsets is normalized with respect to the beat interval, the modelling of microtiming profiles is independent of tempo changes, which allows us to visualise their change over time in a consistent manner. In this section, we first describe the means by which onsets and beat annotations were obtained, followed by the technique used to estimate microtiming profiles through time.

4.1 Onset Annotation

The 34 pieces in the Maracatu performance totalled approximately 22 minutes. Across all 7 channels, this led to a total of 238 contact microphone signals to be analysed. As shown in Fig. 3, even though the separation between channels is mostly very good, some spillage still occurred. This is especially prominent between the bells of the Gonguê which are physically connected. We also observed spillage where one instrument had yet to begin playing and the vibrations carried through the air were picked up thanks to the extremely high sensitivity of the contact microphones.

Given our proposed signal acquisition process using contact microphones, we assumed that largely isolated percussion tracks would be relatively straightforward for a well-known onset detection method using deep neural networks [19]. On this basis, we hoped to be able obtain reliable onset information in a semi-automatic way, where minor corrections (shifts, insertions, and deletions) could be performed. In practice, we found that the rather unusual waveform shapes of the Gonguê, Porca, and Mineiro events created numerous problems for the onset detection system and thus provided little benefit over manual annotation from scratch. Indeed, the recordings of the Mineiro were so challenging to annotate in a precise and consistent way, that we chose not to include them at this stage of our analysis. Ultimately, we selected four instruments: two instruments with time-keeping roles (Porca and Gonguê Low) and two rhythmically expressive instruments in which to observe microtiming (Tarol and Bombo High).

To provide the final onset annotations we followed the

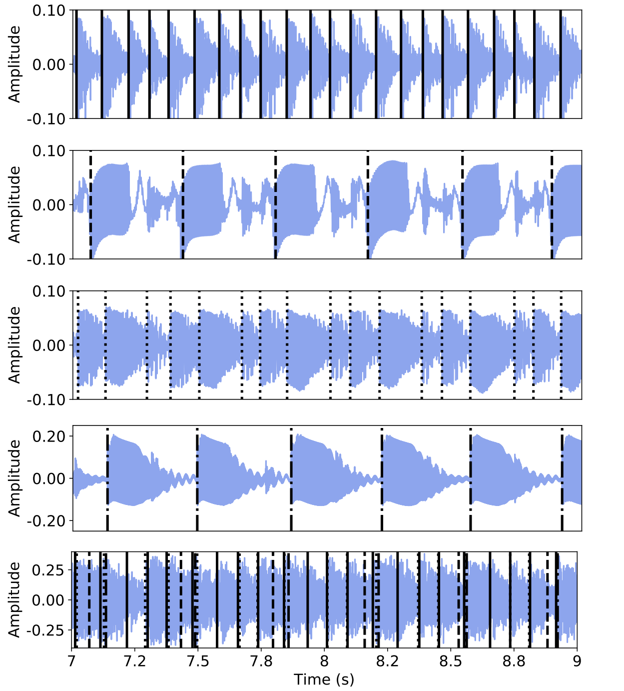

Figure 3: Illustration of signals with annotated onsets in approximately one bar. Top to bottom: Tarol with annotations (solid line); Porca with annotations (dashed line); Bombo High with annotations (dotted line); Gonguê Low with annotations (dash-dotted line); Audio mixture with overlaid onset times of the four instruments.

methodology applied to Brazilian samba [12] and adapted an existing deep neural network [20] and retrained it specific to each instrument using a subset of manually annotations. Even using *instrument-adapted* networks, some manual correction was required, both to contend with issues of temporal localization as well as extra and missed detections. As a coarse indication of the annotation effort, we highlight 51 onsets in just 2 s in the lowest plot of Fig. 3, with $\sim 45,000$ over the four instruments.

4.2 Microtiming Estimation

Our microtiming modelling is based on the approach in [12], which models microtiming profiles per beat as a multi-dimensional variable **m**, where each component m_i with $i = 1, ..., N$, with N the total number of onsets per beat, describes the evolution over time of the relative position of onset i with respect to the beat. The model in [12] estimates the beat and onset likelihoods, and infers the beat positions and associated microtiming profiles jointly using conditional random fields (CRFs). In this work we follow these ideas, but instead of inferring beat and microtiming profiles jointly with a CRF as in [12], we perform the beat and onset inference offline, and then group the onsets and beats using Algorithm 1. The reason for this is two fold: our proposed approach is simpler and computationally cheaper than the CRF approach, with the limitation that it would not be robust in presence of noisy signals or mixtures, which is not the case here. Also, since we are in-

Algorithm 1: Microtiming modelling

Input: b, o, τ, r
Output: **m**, t
for $i \leftarrow$ *1 to len(b)-1* **do**
  $\Delta b \leftarrow b^{(i+1)}$ - $b^{(i)}$;
  $t_{ini} \leftarrow b^{(i)}$ - $\tau \times \Delta b$;
  $t_{end} \leftarrow b^{(i+1)}$ - $\tau \times \Delta b$;
  $o_{beat} \leftarrow o[t_{ini} < o < t_{end}]$;
  if *len*(o_{beat}) $< r$ ***and*** o_{beat} *is not empty* **then**
    $o_{temp} \leftarrow range(0, 1, 1/r) + t_{ini}$;
    for $j \leftarrow$ *1 to len*(o_{beat}) **do**
      $k_{min} \leftarrow \arg\min_k(|o_{beat}^{(j)} - o_{temp}^{(k)}|)$;
      $o_{fix}[k_{min}] \leftarrow o_{beat}^{(j)}$;
    end
    $o_{beat} \leftarrow \mathrm{interp}(o_{fix}[nan], o_{fix}[\sim nan])$
  else
    continue;
  end
  for $j \leftarrow$ *2 to len*(o_{beat}) **do**
    $v_{IOI}^{(j-1)} \leftarrow o_{beat}^{(j)} - o_{beat}^{(j-1)}$
  end
  $\mathbf{m}^{(i)} \leftarrow v_{IOI}$ / Δb ;
  $t^{(i)} \leftarrow b^{(i)}$
end

terested in both within-instrument and between-instrument microtiming, we need a flexible model that allows changing the beat reference, which we can do since we compute beats and onsets offline and integrate them afterwards.

Algorithm 1 is structured as follows: for each beat b we obtain the onsets o_{beat} that fall within the beat interval $[t_{ini}, t_{end}]$ by a tolerance given by τ, and check if we have the expected number of onsets (denoted by r in Algorithm 1). If not, we deduce which onsets are missing by comparing the given onsets with a template containing evenly-distributed positions (0.25, 0.5 and 0.75 in the case of three expected onsets). Next, we interpolate the missing onsets for better visualisation of the microtiming pattern. Finally, we obtain the microtiming profile **m** by dividing all inter-onset-intervals by the beat interval length. We exclude beats with more than the expected number of onsets.

Microtiming deviations and their variation across time have been studied in the context of time-keeper instruments (e.g., in Brazilian samba [12], Uruguayan candombe [18], and jazz [21]). While previous approaches focus on within-instrument rhythmic patterns, we also explore the microtiming generated between time-keepers and non-time-keeper instruments. We apply a similar strategy to that in [12] to analyse the profiles visually.

Both existing work and Algorithm 1 assume that there is *one* main rhythmic pattern played during most of the recording. This hypothesis holds in most of the recordings we obtained, however, unlike other examples such as the BRID dataset [22] where it holds to a great extent, in Maracatu, it is not true for samba.

For the analysis of between-instrument microtiming de-

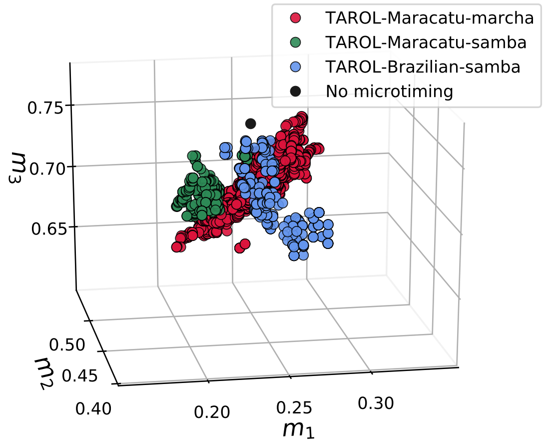

Figure 4: Comparison of Maracatu sub-genres and Tarol (Caixa) in Brazilian samba.

viations, we follow the existing literature about Maracatu [17] and use the Porca and Gonguê Low onsets as beat references for the other instruments since they play the role of time-keepers and are meant to play the beat. For the within-instrument analysis for Tarol and Bombo, we estimated the beats using the *madmom* library [23] [1] , which performed well in the solo tracks, and we adjusted the final beat positions to the closest onset.

5. MICROTIMING ANALYSIS

Marcha vs. samba: Both by listening to the recordings and inspection of the microtiming profiles, we discovered that samba has far greater variation in rhythmic patterns than marcha. In addition, the beat estimation revealed a noticeable difference in tempo, with marcha approximately 165 bpm where as samba was faster at around 180 bpm. Transcriptions from [17] also state that there is greater variation in the notated rhythmic patterns for samba compared to marcha. From the perspective of drawing robust conclusions about microtiming profiles, which, using our approach, rely quite strongly on a consistent rhythmic pattern, we were only able to conduct reliable analysis for Tarol within-instrument microtiming. To enable a high-level comparison, which also includes the use of Tarol (referred to as Caixa in [12]) in Brazilian samba we present a scatter plot of m_1 vs. m_2 vs. m_3 in Fig. 4. Perhaps the most striking observation is that for marcha, the Tarol shows a much wider variation in the m_1 and m_3 dimensions, where as the limited data we obtain for Maracatu samba occupies a tighter cluster, and Brazilian samba varies more prominently over m_2. This indicates a different use of microtiming for Tarol in our recordings both within Maracatu sub-genres and compared to Brazilian samba.

Microtiming profiles in marcha: In Fig. 5 we observe both the within- and between-instrument microtiming analysis for Tarol (left column) and Bombo High (right column) for recording #28. For the between-instrument analysis we use the Gonguê Low and Porca as time-keepers (middle and bottom rows respectively). When comparing between-instrument and within-instrument profiles, we observe one additional trace for both instruments: the deviation at the beat level (which is normalised out for within-instrument analysis). Referring back to Fig. 3 we can see microtiming profiles consistent with a sub-division of the beat into four $1/16$th notes for Tarol, with the second $1/16$th note (m_1) not played for Bombo High.

Looking at the microtiming profiles through time, we see more fluctuation in Tarol compared to Bombo High. In particular for Tarol, the smoothed microtiming profiles move above and below the quantised positions indicating a dynamic use of microtiming. Furthermore, a direct comparison of Tarol with Bombo High illustrates different profiles. Across the entire set of recordings, we found the following median profiles: Tarol [0.25, 0.47, 0.715], and Bombo High [0.46, 0.69].

When contrasting the time-keepers, we observe much greater variation when the Porca beats are used as reference compared to Gonguê Low, including an unexpected downward trend for both Tarol and Bombo High. While not present in all marcha, we observed several similar instances, which can be attributed to the beats of the Porca being played *ahead* of the beat and slowly aligning in phase by the end. Looking again at Fig 3, we see the Porca annotations are earlier than the other instruments consistently by upto 20 ms. A possible explanation may be that the Gonguê is louder and thus takes a more prominent time-keeping role, allowing the Porca to take a more expressive role. Regardless, we assert the importance of analysing the behaviour of the time-keeper instruments.

6. REFLECTIONS

One objective of current ethnomusicological research is to reveal how musicians of different cultures develop strategies for playing together that differ in subtle ways to those in Western culture. These strategies are often implicit, associated to verbal categories that express local views on how music “should sound” in a particular cultural context [25]. These verbal categories often rely on non-musical concepts and metaphors, often related to other sensorial domains (vision, taste, etc.) [26].

Ethnographic field research is a first, necessary step for unveiling subtle strategies of playing together that are at stake in a particular musical culture. Formal analysis of live performances is then needed to understand to what acoustic reality these local concepts refer. To this end, MIR techniques, such as microtiming analysis, can provide innovative solutions for exploring qualities of the music that would otherwise be hard to describe.

In the Zona da Mata region, Carnival is not a simple distraction but rather a ritual involving a complex set of mystical beliefs and social concerns. At this time of the year invisible negative “entidades” (entities) are believed to be more active and even dangerous, and interpersonal relations are marked by feelings of envy and jealousy. Carnival is therefore considered as a threat both for individuals and

[1] We used the model that implements Böck et al. [24] in version 0.16.1.

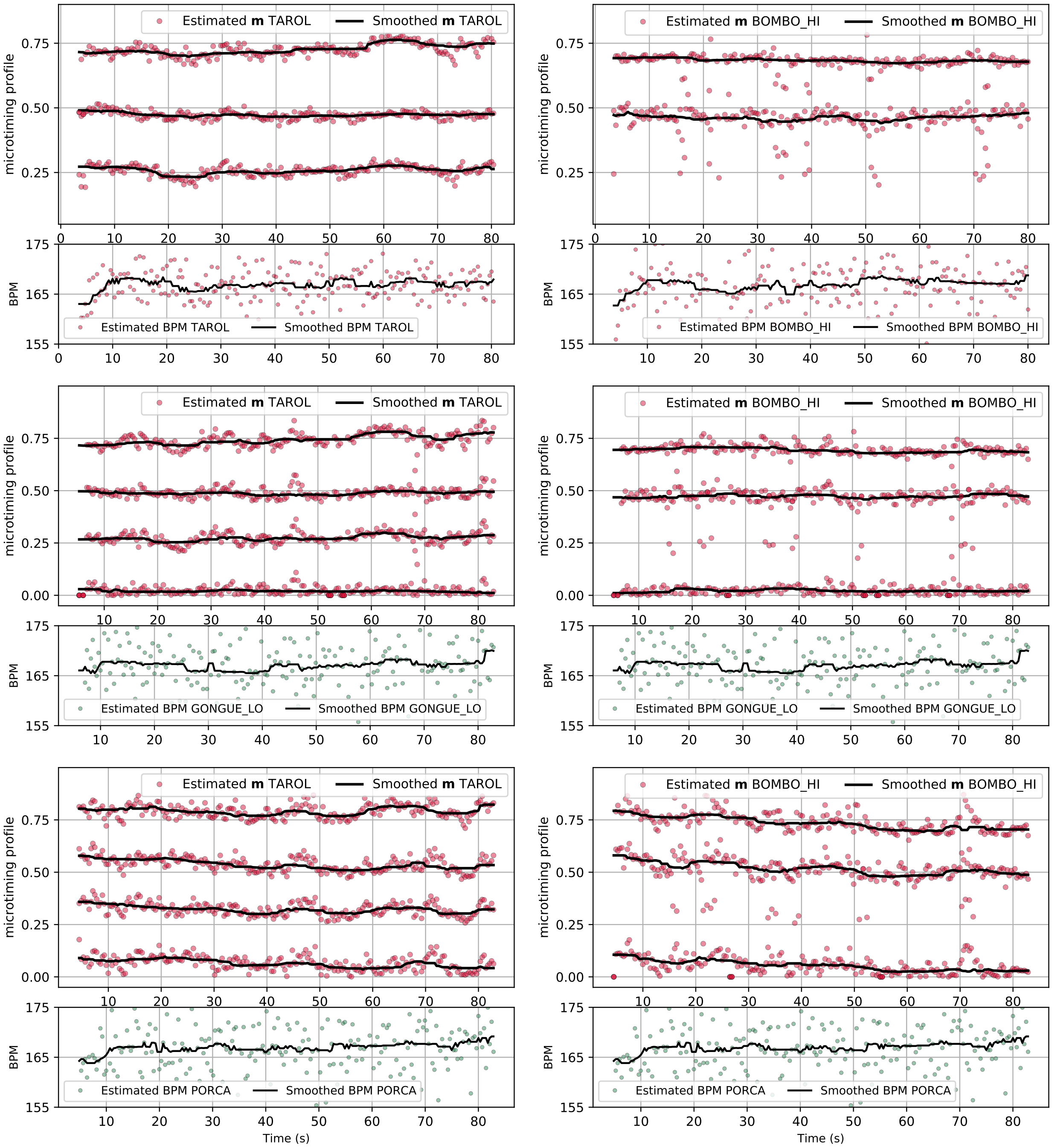

Figure 5: Microtiming profiles in recording #28 for Tarol and Bombo High, left and right respectively. The microtiming estimations use within-instrument, Gonguê Low and Porca beats as reference in top, middle and bottom plots respectively.

the community. Maracatu de baque solto is a performance-ritual that allows people to overcome these risks.

It is important to stress that the Maracatu musicians had never travelled outside of Brazil, and bringing them to Europe was logistically complicated. In addition, the signal acquisition and onset annotation were also non-trivial, meaning several challenges needed to be overcome before even beginning to analyse the microtiming in Maracatu in a computational way. Nevertheless, within the confines of a small dataset, limited to one set of musicians, our preliminary analysis revealed new findings on the use of microtiming, in particular its dynamic nature in Maracatu.

In the long term, our aim is to understand what it means to play in "consonance" and to "close the Maracatu." Both concepts point to subtle manners of producing sounds collectively, that differ form the ones observed in other musical contexts. Since no formal analyses of Maracatu music have been previously realised, this paper is a first attempt to understand how musicians rhythmically interact during a live performance. In future research, we intend to play back the recordings to the musicians to understand if "consonancia" and "closure" can be associated to the specific microtiming profiles highlighted in this paper.

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