Investigating Musical Meter as Shape:
Two Case Studies of Brazilian Samba and Norwegian Telespringar

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ABSTRACT

The perception of musical meter is fundamental for rhythm production and perception in much music. Underlying structures such as pulse, meter, and metrical subdivisions are often described as successive points in time. This paper investigates whether experienced musical meter may not only include such *points in time*, but also *trajectories between the points*–that is, *metrical shapes*.

Previous studies have pointed out that there seems to be a relationship between musical meter and periodic body motion like foot tapping, head nodding and dancing. This paper investigates musical meter in music styles with an intimate relationship with dance, and whether metrical points and trajectories can be understood by investigating performers' periodic body motion.

Two motion capture studies form the empirical basis of this paper; first, a percussionist and a dancer performing Brazilian samba; second, a fiddler and two dancers performing Norwegian telespringar. The analysis showed that it seemed to be a relationship between the periodic fluctuation in audio amplitude and the performers' periodic foot motion on sixteenth note level in samba. Furthermore, motion analysis revealed similar periodic shapes in both percussionist and dancer foot motion. In telespringar there seemed to be a relationship between the metrical beat level and the fiddler's foot stamping. In addition, the beat duration pattern, as indicated by the fiddler's periodic foot stamping, seemed to correspond to the shape of the dancers' vertical body motion.

The results support the view that there is a close relationship between musical meter and performers' periodic body motion. This suggest that the underlying meter may not only include metrical points in time, but that each metrical beat/subdivision duration has a corresponding metrical trajectory with a certain shape. If this is the case, then perceivers' and performers' implicit knowledge of the underlying reference structure in samba and telespringar might incorporate knowledge about the underlying metrical shape.

I. INTRODUCTION

The perception of underlying structures such as pulse, meter, and metrical subdivisions are fundamental for rhythm production and perception in much music. Such structures are not necessarily represented by sonic events, but supply a framework against which we perceive sounding rhythm (e.g., Danielsen, 2010b; London, 2012). In other words, the experience of rhythm includes the interaction between *perceived sonic rhythms* and *underlying reference structures*. This interaction has been approached from various perspectives. Some theories on rhythmic structure are based on music with a written score (e.g., Clarke, 1985; Cooper & Meyer, 1960; Lerdahl & Jackendoff, 1983). Bengtsson (1973) points out that it is important to distinguish between *music as notated* and *music as performed* and *perceived*. The so-called Uppsala school of rhythm sought to analyze musical rhythm based on sound rather than notation (Bengtsson, Gabrielsson, & Thorsén, 1969). Through the use of various apparatuses for

sound recording and analysis, they discovered systematic duration patterns, labelled systematic variations (SYVAR), that seemed to be specific to different styles of music. Their basic hypothesis was that these patterns represent an active force beneath the musical surface.

Keil (1987; 1995) also highlights the importance of analysing music as performed, and argues that music is not primarily about *structure*, but about *process*. For Keil, the power of music is in its *participatory discrepancies* (PD), for example, small differences in timing between performers, "out of synchness", and "out of tuneness". Kvifte (2004), on the other hand, argues that the power of groove derives from the *relation between syntax and process*. He considers syntax to belong to the domain of experience, and points out that our categorization of sonic events as being early, late, or on the beat, for example, depends on an experienced reference structure.

Sethares (2007) points out that musical concepts like beats, rhythms, and meter result from human perception and cognition and are not properties of the sonic signal. London (2012) refers to *subjective rhythmization* (Bolton, 1894) (*subjective metricization* in London's terminology) – that is, that we tend to lock isochronous and equivalent-sounding events into a periodic pattern – to demonstrate that metrical accents are mental constructs which do not necessarily coincide with the pattern of accents in the sound. Instead, one compares the perceived sonic rhythm to a repertoire of familiar *metric templates* (London, 2012).

Underlying structures exist on several metrical levels, for example, a basic pulse level or a grouping of the beats of a basic pulse. The pulse is often described as successive mental beats (see, for example, Honing, 2012; London, 2012; Parncutt, 1994) and *meter* could be described as an organization of those beats. In addition, subdivisions of a given pulse are also usually included in the underlying reference structure (Nketia, 1986). In this text, such underlying subdivision levels will be referred to as *metrical subdivisions*.

Musical meter is often understood as consisting of isochronous time series, and systematic microtiming patterns are often described as deviations from such isochronous structures. However, this preconception has been criticized by several researchers (e.g., Bengtsson, 1987; Kvifte, 2004; Polak, 2010). Non-isochronous meters have for example been found in music styles such as Vienna waltz (Bengtsson & Gabrielsson, 1980), in much traditional dance music in Scandinavia (e.g., Blom, 1981; Groven, 1971; Kvifte, 1999; Ramsten, 2003), Brazilian samba (e.g., Gerischer, 2006; Naveda, Gouyon, Guedes, & Leman, 2009) and in djembe music from Mali (Polak, 2010). Kvifte (2004) suggests that instead of referring to such non-isochronous metrical sequences as "deviations" from an artificial, fixed clock pulse,

such underlying structures can be described in terms of *patterns*, for example, *duration patterns*.

This paper explores whether experienced musical meter may include not only mental *points in time*, or *duration patterns* based on the intervals between such points, but also *trajectories between the points*. Moreover, it investigates whether metrical trajectories can be understood by investigating performers' periodic body motion. The notion of meter as dynamic shape related to body motion has previously been proposed in Western classical music. Becking (1928) emphasized that rather than conducting the music one should let oneself be conducted by the music. He developed a set of composer specific conducting gestures, or "personal curves" (also labelled "Becking curves"), with different shapes that reflected a composer's individual management of gravity. Clynes (1995) also claimed that there is a distinct motor pulse form for particular composers. In order to determine the shape of such pulses, Clynes conducted experiments with artists mentally rehearsing the music while expressing the music's pulse with finger pressure motion. The experience of the composer's pulse in music is dependent on musical training and proficiency, he claims.

Large and Jones (1999) propose a theory of *dynamic attending* which assumes the existence of internal oscillations in a perceiver, and that the external (sonic) rhythm drives these internal oscillations. Influenced by the theory of dynamic attending, Danielsen (2010a) devised a *beat bin* model for groove based music. She demonstrates how conflicting pulse locations might result in two beat locations that merge into one, producing an *extended beat* or *beat shape* (see also Danielsen, Haugen, & Jensenius, 2015). Waadeland (2001) proposes a definition of pulse that relates to a corresponding and continuous *movement curve*, and a model of rhythmic structure where the underlying pulsation can be represented by a mathematical function, creating an up and down *wave motion* where the local minimal points represent the pulse beats.

The concept of metrical shapes might be contextualized further using Godøy's (2003) *motor-mimetic perspective on music perception*. Such a perspective suggests that when we experience music, we simultaneously mentally imitate sound-producing actions that we relate to the sounds that we perceive. Such imitated actions can both be directly related to playing an instrument, and imitative of sonic shapes (as, for example, *sustained*, *impulsive*, or *iterative* sounds) which can be gesturally rendered. The relationship between the simulated sound-producing action and the musical sound may extend across more complex phrases and textures, Godøy claims.

In music cultures where music and dance have evolved together through mutual interaction, music-related imitated actions as described above may also include dance motion. In such music styles, the musician's mental images may derive from both experienced sound-producing actions and images of motion patterns in the corresponding dance. Within a motor-mimetic framework, then, images of the motion patterns in the dance — the actual motion or the shape of the motion — may inform the musician's playing, even when dancers are not present. In this regard, the musician does not have to have direct experience with the actual dance, but he or she must have some sense of the underlying shape of the dance. This is also in line with Blom's (2006) *motor theory of rhythm*, implying that meter obtains specific motion patterns (in, for example a corresponding dance) from a tacit knowledge of style, shared by those familiar with the music genre.

II.   SAMBA AND TELESPRINGAR

This paper focuses on musical meter in two styles of music, namely Norwegian telespringar and Brazilian samba. Both telespringar and samba derive from oral traditions, are often referred to as being in non-isochronous meter, and have an intrinsic relationship with dance. Rhythm studies of these styles often emphasize this intimate relationship and that production and perception of rhythm should be understood in relation with the corresponding dance.

A. Meter in Samba

Brazilian samba is often characterized by its complex rhythm patterns. Samba is normally notated in 2/4 meter and recent studies have revealed that *systematic microtiming*, at the level of sixteenth notes, seems to be a prominent feature of samba groove. In rhythm studies of samba percussion in the region of Bahia in Brazil, based on field recordings (audio) and interviews, Gerischer (2006) revealed a *medium–short–medium–long* duration pattern on sixteenth note level in samba groove. The fourth sixteenth note in a beat in samba groove is not only extended (in duration) but also accentuated, Gerischer claims. She emphasizes that the microtiming pattern in samba groove constitutes an essential aspect of style, and that the musicians add their individual phrasings to these microtiming features. Similar microtiming features are found in a rhythm study of *Samba de Roda* presented by Gouyon (2007). Based on audio analysis of audio excerpts, taken from commercial CDs, Guyon found that the third and the fourth sixteenth note in a beat in samba are played slightly ahead of their corresponding quantized position. A similar study by Naveda et al. (2009) confirms the existence of systematic anticipations of the third and fourth sixteenth note in samba groove. In addition, they found systematic oscillations in amplitude for instruments in certain frequency regions.

Naveda (2011) highlights the intimate relationship between the dance and the music in samba; the necessity to include dance motion in rhythm studies of samba and develop methods for this purpose. In a number of studies, Naveda and his colleagues investigate the relationship between periodic patterns of music and dance from the Afro-Brazilian culture. Inspired by Becking (1928) they explore how repetitive dance patterns are based on *basic gesture*, and how such basic gestures can be related to the time points of the meter. A basic gesture can be defined as a motion pattern of a body part during one period of a repetitive sequence. Naveda and his colleagues' work shows how basic gestures can be linked to musical time points, acoustic loudness and speed (Leman & Naveda, 2010). A novel method labelled *Topological Gesture Analysis* (TGA) was also developed in order to investigate the relationship between musical meter, dance style, and expertise in dance (Naveda & Leman, 2010).

B. Meter in Telespringar

Telespringar is considered one of the older types of Norwegian folk music. Telespringar tunes are normally

notated in 3/4 meter. However, it is commonly understood that the three beats in a telespringar measure are of uneven duration, often referred to as *asymmetrical meter*. Previous studies report that a systematic *long–medium–short* beat duration pattern seems to be a prominent feature of telespringar (Groven, 1971; Kvifte, 1999). It has been pointed out that this beat duration pattern should not be considered deviations from an underlying isochronous pulse, but that the underlying meter in telespringar should be understood as asymmetrical in and of itself (Blom, 1981; Groven, 1971; Haugen, 2015; Kvifte, 2007).

The intimate relationship between the underlying meter and performers' body motion is often emphasized in rhythm studies of telespringar. Foot stamping is considered an integral part of telespringar playing as well as an expression of meter (see, for example, Blom, 2006; Kvifte, 1983). Furthermore, it has been suggested that accents in the foot stamping in telspringar follows a *strong–strong/medium–weak* pattern (Blom, 2006).

It is also emphasized that musical meter in telespringar should be understood in relation to the corresponding dance. Blom (1981) observes that the *vertical motion of dancers' center of gravity* seems to follow a regular pattern of up (*arsis*) and down (*thesis*) motion, which he calls the *dancers' libration pattern or libration curves.* These libration patterns are style specific and related to the musical meter, he claims. In telespringar dancing, Blom goes on to explain, the libration curves consist of two down/up motions in every measure. The first down/up motion corresponds to the duration of the first beat, the second down motion corresponds to the second beat, and the second up motion corresponds to the third beat, he claims. However, recent motion capture studies of telespringar dance have not found support for this claim (Haugen, 2015, 2016; Mårds, 1999).

III. METHOD

Present study investigates musical meter as shape based on sound and motion recordings of samba and telespringar performances. Both musicians' and dancers' body motion are included in the analyses. It is hypothesized that:

a) Musical meter is intrinsically related to body motion, actual or imagined.
b) The underlying meter may not only include experienced *points in time*, or the *duration* between the points, but also *trajectories between the points* – that is, *metrical shapes. Metrical shapes* are style specific.
c) In music styles with an intimate relationship with dance, both metrical points and trajectories can be understood by investigating performers' (musicians' and dancers') periodic body motion.

To this end, professional samba and telespringar performers were recorded. In the samba recording, two experienced samba performers, a percussionist and a dancer, participated. The percussionist played a samba groove on a traditional Brazilian hand frame drum with jingles called *pandeiro,* and the dancer performed the samba dance in *samba no pé* style. In the telespringar recordings, three experienced telespringar performers, a fiddler and a dance couple, participated. The fiddler played telespringar on a *Hardanger fiddle,* a fiddle slightly smaller than a regular

violin, with four or five sympathetic strings that run under the board in addition to the bowed strings. All the performers were instructed to play and dance as they would normally do when performing.
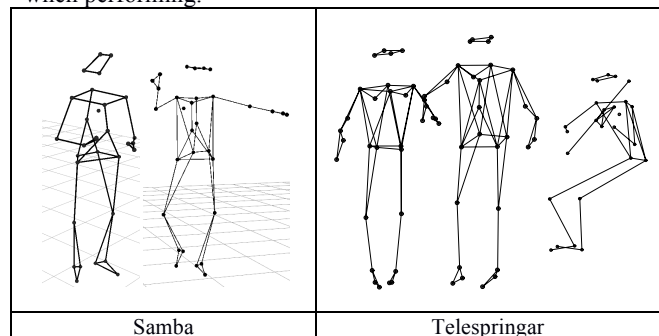

Figure 1. Placement of the markers attached on (left) the samba performers' and (right) the telespringar performers' bodies.

All the recordings were carried out in the fourMs Motion Lab at the Department of Musicology at the University of Oslo. The participants' body motions were recorded using an advanced optical motion capture system from Qualisys tracking at a frame rate of 200 Hz. In the samba recording nine Oqus 300 cameras were used. In the telespringar recording, nine Oqus 300 and four Oqus 400 cameras were used. Reflective markers were attached on the participants' bodies. The marker placement on the samba and the telespringar performers' bodies is presented in Figure 1.

The performances were also video recorded. In the samba recording, the audio analysis is based on the sound from the video. Since the video sound and the motion capture recording were not synchronized, the sound had to be manually adjusted. In the telspringar study, on the other hand, the sound was recorded using Logic Pro X and synchronized with the motion capture recordings using a custom-built Max/MSP patch, running on a Macintosh.

IV. ANALYSES AND RESULTS

The data was analyzed using the MoCap Toolbox (Burger & Toiviainen, 2013), the MIRtoolbox (Lartillot & Toiviainen, 2007), and custom-made Matlab scripts.

A. Samba

In the present study, the samba groove consists of a total of 42 measures. A transcription of four measures of the samba groove pattern (simplified), with an example of a variation in the fourth measure, is shown in Figure 2. The samba groove played in this study indicates several metrical levels: First, the metrical beat level (*pulse*); second, the metrical sixteenth note level; and, third, the measure level (2/4 meter).

Figure 2. A transcription of four measures of the samba groove as played on *pandeiro*. All the sixteenth notes are played, and consequently present in the sound signal.

According to previous rhythm studies on samba, the sixteenth note level is of particular interest. Since all the sixteenth notes are played in this recording, and consequently present in the sound signal, their temporal position could be detected using onset detection. Here I used an onset detection function in the MIRtoolbox that performs a peak-picking procedure on the envelope curve and returns the temporal positions of those peaks (Lartillot & Toiviainen, 2007). It is worth noting that the temporal position obtained from onset detection may not represent the temporal point that is actually *perceived* as the sonic event's onset (e.g., Wright, 2008). However, since I am primarily interested in rhythm *patterns*, my main concern here is that every onset is measured in the same manner.

In accordance with Kvifte's (2004) aforementioned *pattern concept*, the fluctuations in timing on sixteenth note level were represented as a duration pattern. The inter-onset-intervals (IOIs) between the sixteenth notes, estimated from the audio envelope peaks, were calculated and converted into percent values according to their percentage of the beat. Only the beats with four detected onsets were included (N = 63). The mean sixteenth note durations with corresponding standard deviations (SD) are presented in Table 1.

Table 1. The mean sixteenth note durations with corresponding standard deviations (SD) of the first, second, third, and fourth sixteenth note in a beat, based on audio analysis.

Mean beat duration in % (SD)				Mean Tempo in BPM
First	**Second**	**Third**	**Fourth**	
24 (2.7)	23 (3.9)	22 (3.0)	31 (1.8)	96

A one-way analysis of variance (ANOVA) showed significant differences between the durations ($p < 0.001$), and Bonferroni corrected post-hoc pairwise comparisons showed significant differences between the fourth sixteenth note duration and first, second, and third sixteenth note durations (all $p < 0.001$). This is in accordance with previous findings that suggests that the fourth sixteenth note is of longer duration than the others (Gerischer, 2006). No statistically significant differences were found between the duration of the first and second ($p > 0.5$), first and third ($p > 0.05$), or second and third sixteenth note durations ($p > 0.99$), indicating a *short–short–short–long* duration pattern on sixteenth note level in this samba groove.

Previous research also suggests a periodic fluctuation in audio amplitude in samba music (Naveda el al., 2009). In order to get an impression of the fluctuation in amplitude over time in this recording, the audio envelope was divided into measures, as defined by the first detected onset (sixteenth note) in each measure. Next, each envelope chunk was converted into percentages, with each beat duration corresponding to 100 %. Finally, all the measure chunks were plotted in the same plot (see Figure 3b). A qualitative inspection of the amplitude on measure level indicates that during Beat one the fluctuation in amplitude seems to follow the same pattern across measures – that is, the first and the fourth sixteenth notes seem to be played with systematically slightly higher energy that the second and third sixteenth note. During Beat two, on the other hand, the fluctuation in amplitude does not seem to be as periodic as in Beat one. Recalling that the fourth

sixteenth note seems to be of longer duration than the others, indicates that the fourth sixteenth note plays a significant role in samba groove.

Next, I wanted to investigate how the dancer's periodic motion relates to the audio amplitude peaks (sixteenth note
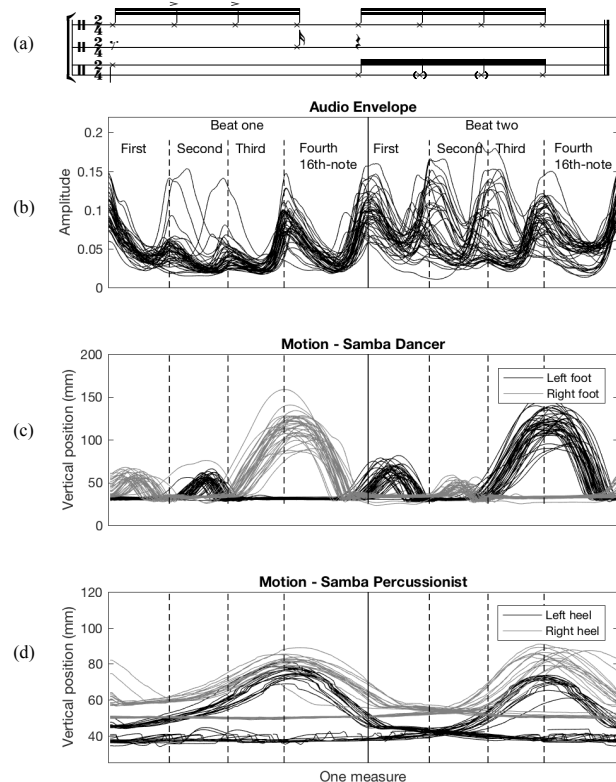

Figure 3. (a) A simplified transcription of one measure of samba groove, (b) fluctuations in audio amplitude, (c) a plot of the vertical position of the dancer's foot motion, and (d) a plot of the vertical position of the percussionist's heel motion, all during one measure.

level). In this study, I focus on the dancer's repetitive and periodic foot motion. In order to get an impression of the dancer's foot motion on measure level, the vertical motion curves of the markers attached to the dancer's heels were divided into measures, as defined by the first detected onset in each measure. In order to make all the measure curves have the same length, all the measure chunks were converted into percentages, where the duration of each beat corresponds to 100 %. Finally, all the measure chunks were plotted in the same plot (Figure 3 c). The dancer alternate between left and right foot and steps down three times during each beat. A comparison of the dancer's steps and the amplitude peaks indicates that the dancer's steps are synchronized with the first three sounding sixteenth notes in each beat. The fact that the dancer's feet motion follows the same non-isochronous pattern as the played sixteenth notes in the sonic samba groove, supports the view that the metrical subdivisions on sixteenth note level in samba are non-isochronous.

It has been pointed out that body motion like foot tapping, upper body swaying, and head nodding often is synchronized with underlying pulse in music (Godøy & Leman, 2010). While playing, the percussionist moves his heels up and down in a periodic pattern, so next I wanted to investigate the

relationship between the percussionist's feet motion, amplitude peaks, and the dancer's dance steps. As with the dancer's steps, the percussionist's vertical heel motion was divided into measures, according to the first detected onset in each measure. All the measure chunks were consequently converted into percentage (each beat corresponded to 100 %), and plotted in the same plot (Figure 3 d). The points in time where the percussionist's heels hit the floor seem to be synchronized with the first sonic sixteenth note in each beat. However, instead of making a continuous up/down motion when moving from beat to beat, the lifting of the heels seems to be synchronized with the fourth sixteenth note in each beat. Furthermore, the motion curve of the percussionist's "heel lifting" seems to be similar to the dancer's lifting of the foot, with a local maximum around the fourth sixteenth note in each beat (see Figure 3 c and d). The percussionist seems to be accentuating the fourth sixteenth note in each beat with his heel motion.

B. Telespringar

In the telespringar study, three performers (a fiddler and a dance couple) participated. Two different tunes, both played on Hardanger fiddle, were recorded and analysed.

The fiddler's foot stamping is considered integral to Hardanger fiddle playing, and it has been suggested that the foot stamping is an expression of meter (see, e.g., Ahlbäck, 2003; Blom, 2006; Kvifte, 1983). The fiddler in this study seems to stamp his toes three times, two times with his left foot and one with his right, in each measure. In order to investigate the duration pattern based on the fiddler's foot stamping, the vertical position and acceleration of the markers attached to the fiddler's toes were plotted (Figure 4). Since the acceleration shows clear peaks that correspond to the point in time when the fiddler toes hit the floor, a beat duration pattern, based on the fiddler's foot stamping, could be calculated based on the intervals between the acceleration peaks. Consequently, a peak picking function was applied to the acceleration data. The intervals between the acceleration peaks were calculated and converted into percentages according to their percentage of the measure. The mean durations of the first, second, and third beats were calculated. The mean durations with corresponding standard deviations (SD) and mean tempo in both tunes are presented in Table 2.

Table 2. The mean beat durations with corresponding standard deviations (SD) of the first, second, and third beats, according to the fiddler's foot stamping, and mean tempo in Tune 1 and Tune 2.

	Mean beat duration in % (SD)			Mean Tempo in BPM
	First	Second	Third	
Tune 1	39 (2.2)	36 (2.9)	25 (1.6)	132
Tune 2	39 (1.5)	38 (1.8)	23 (1.3)	125

A one-way ANOVA showed significant differences between the durations (all $p < 0.001$) for both tunes, and Bonferroni corrected post-hoc pairwise comparisons showed significant differences between all the beat types (all $p < 0.001$ for Tune 1 and all $p < 0.01$ for Tune 2). These results suggest that, even though the average beat duration for the second and third beat in the two tunes are different, they both

follow a *long–medium–short* beat duration pattern, something that is in accordance with previous rhythm studies of telespringar.

The fluctuation in acceleration amplitude in the fiddler's foot stamping also seems to follow a periodic pattern on
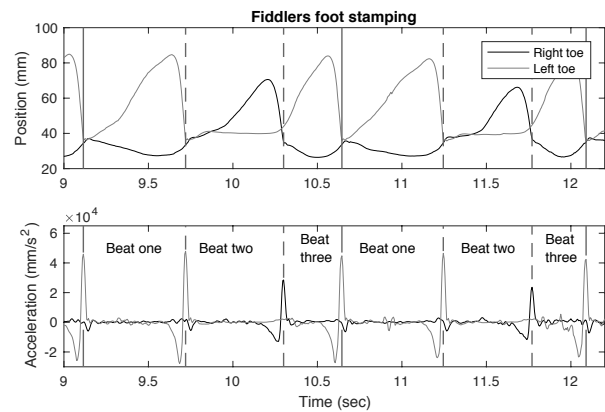

Figure 4. Plots of (top) the vertical position of the markers attached on the fiddler's toes and (bottom) the corresponding vertical acceleration during two measures.

measure level – that is, the first two foot stamps seem to have a higher acceleration peak than the third (see Figure 4). This might support previous observations that suggest that the accents in the foot stamping in telespringar follows a *strong–strong/medium–weak* pattern (Blom, 2006).

According to Blom's (1981, 2006) *libration hypothesis* the meter in telespringar should be understood in relation to the vertical motion of the dancer's centre of gravity. In order to investigate how the dancers libration curves correspond to the fiddler's foot stamping, the vertical position data of the markers attached to the dancers' right hips were divided into chunks of two measures according to the fiddler's first foot stamp in every other measure. The reason for dividing the motion curves into chunks of two measures is that since the dancers have three steps in each measure, it takes two measures to make a full circle. Since the telespringar dance includes a lot of improvisation, the vertical motion of the dancers' hips does not take place within the same range across measures. As I was interested in the shape of the libration curves, and not their exact measured vertical position, the libration curves were normalized by the root mean square (RMS) for each curve. Finally, all the libration curves were converted into percentages, where one measure corresponds to 100 %, and plotted in the same plot. The libration curves for Tune 1 and Tune 2 were plotted separately (see Figure 5 b and 6 b). The plots seem to indicate that the libration curves are very consistent, both across dancers, tunes, and tempi. The stability of the libration curves is also very interesting, considering the extensive use of improvisation in the dance, supporting the view that the dancers' libration curves are related to an underlying structure in telespringar.

Finally, I wanted to investigate whether there might be a relationship between the fluctuation in audio amplitude, the fiddler's foot stamping, and the dancers' libration pattern. An audio envelope curve was calculated, and subsequently divided into chunks of two measures and plotted in the same

plot (Figures 5 a and 6 a). Unlike the visualizations of the audio amplitude of samba, the visualization of the telespringar sound did not show any periodicity. Nor did it seem to be any correspondence between the audio amplitude and the underlying pulse, as indicated by the fiddler's foot stamping.
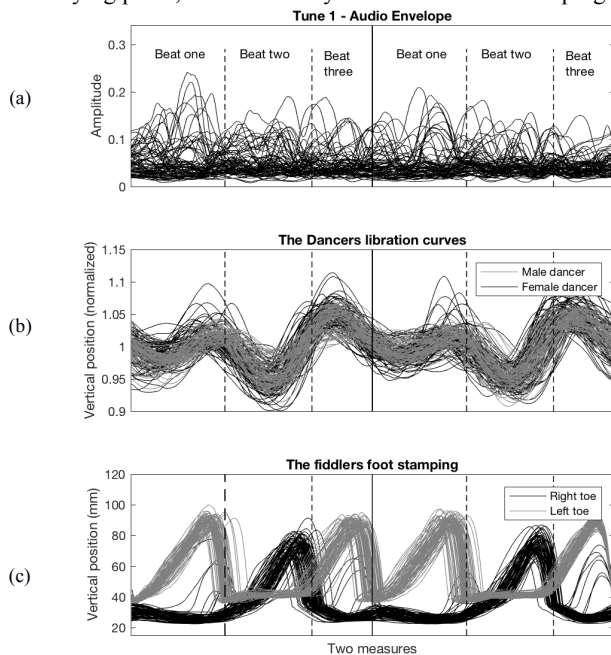

Figure 5. Plots showing (a) the fluctuation in audio amplitude, (b) the dancers libration curves, and (c) the fiddler's foot stamping during two measures in Tune 1.

whereas Beat two might feature more expressivity and improvisation.

The fourth sixteenth note seems to play an important part in samba groove, being both longer in duration and its onset being played systematically louder in the systematic Beat one.
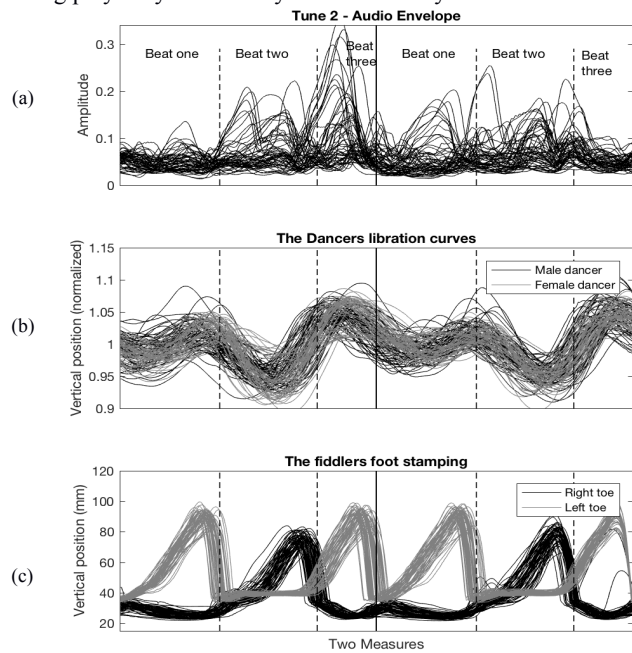

Figure 6. Plots showing (a) the fluctuation in audio amplitude, (b) the dancers libration curves, and (c) the fiddler's foot stamping during two measures in Tune2.

V. DISCUSSION

This paper investigates whether an underlying meter in samba and telespringar may not only consist of temporal *points in time* and *duration between such points*, but also *trajectories between metrical temporal points*. It further suggests that there might be a relationship between such trajectories and performers' periodic body motion, and occasionally fluctuations in audio amplitude.

As mentioned in the introduction section, both performed and perceived rhythm include an interaction between an external sonic rhythm and underlying reference structures, such as pulse and metrical subdivisions. The underlying reference can be, but is not necessarily, represented by sonic events. In addition, sonic rhythms often include events that are played slightly before or after metrical beats or subdivisions; in other words, sonic events that are perceived as belonging to the underlying structure, but not as perfectly matching it. If we think of periodic audio amplitude fluctuations in the same way, there might be an "underlying fluctuation in amplitude" that one may perceive, even though the sonic events do not always follow this pattern. In the present samba recording, a visual inspection of the amplitude fluctuation in the samba groove revealed that fluctuation in amplitude seems to follow a *high–low–low–high* pattern on sixteenth note level in Beat one, whereas in Beat two the amplitude peaks seem to be less systematic. In other words, the amplitude fluctuations in Beat one may constitute an underlying amplitude pattern in samba,

This also seems to be reflected in the participants' foot motion. The percussionist steps his heel down on every pulse beat in the samba groove, but instead of performing a continuous up/down motion from beat to beat, he lifts his heel on every fourth sixteenth note (Figure 3 d). In addition, the percussionist's heel motion has a similar vertical shape to the dancer's foot motion between the third sixteenth note in a beat and the first sixteenth note in the next beat (Figure 3 c and d).

The dancer has three steps in every beat that are synchronized with the first three amplitude peaks in each beat in the played samba groove. This also supports the view that the systematic microtiming in samba is not deviation from an underlying isochronous sixteenth note level, but that the *metrical subdivisions* on sixteenth note level in samba are in non-isochronous.

In telespringar there does not seem to be a clear relationship between the participants' periodic motion patterns and the fluctuation in audio amplitude. Clearly, Hardanger fiddle playing and sound is very different from pandeiro playing and sound. First, the Hardanger fiddle is a bowed instrument resulting in sustained sound shapes without impulsive amplitude peaks. Second, the style of telespringar playing is very ornamented and relies upon the extensive use of slides and grace notes. Evidently, rhythm patterns are not easily detected based on the sound signal from telespringar played on Hardanger fiddle. On the other hand, this makes it even more interesting that the performers' periodic body motion is so regular and consistent. Moreover, it supports the

view that in some music styles, the metrical cues are not necessarily found in a specific sonic rhythm. Instead, our ability to recognize meter can be based on socially learned cues, a *pattern recognition*, related to performers' and perceivers' experience and familiarity with the music culture (Kaminsky, 2014; Kvifte, 2007; London, 2012).

There might be a correspondence between the acceleration amplitude in the fiddler's foot stamping and the underlying meter. The acceleration amplitude seems to follow a *high–high–low* pattern on beat level (see, Figure 4). This is also in line with Blom (2006) who observes that in telespringar, the fiddlers' foot stamping seems to follow a *strong–strong/medium–weak* accent pattern. This acceleration amplitude pattern might also correspond to the dancers' libration curve, since the "valley-shaped" Beat one and Beat two might feel "heavier" than Beat three, which has a light up/down motion, like a small jump (see Figures 5 b and 6 b). However, considering that the style of foot stamping differs considerably between fiddlers, more performers need to be included in the analysis in order to decide whether this is a general pattern.

The results from the telespringar analyses indicate that it is not the *turning points* in the telespringar dancers' vertical motion that relate to the temporal points of an underlying meter, as suggested by Blom (1981). Instead, the *shape* of the libration curve seems to correspond with the underlying *measure* and *beat duration* (see also Haugen 2016). As previously mentioned, thinking of underlying structures as *trajectories between metrical* beats can be contextualized further using the *motor-mimetic* perspective on music perception and cognition (Godøy, 2003). This perspective suggests that a sound can be perceived as a sonic *shape*, which might in turn imply a corresponding imagined action with similar *shape.* The concept of *action/sound shape* correspondences may further be extended to a *metrical motion/duration shape* correspondence, encompassing not only the *duration* between metrical beats*,* but also the trajectories between the metrical beats. Kvifte (2007) suggests that meter perception might be a *pattern recognition* task that is closely related to perceivers' and performers' experience. According to the metrical shape hypothesis suggested in this paper, such pattern recognition may also apply to the trajectories corresponding to the beat durations. Since the music and the dance in telespringar are intrinsically related, such metrical shapes might relate to these periodic motion patterns in the dance. If this is the case, the perceivers' and performers' implicit knowledge of the meter in telespringar might incorporate knowledge about the underlying *metrical shape.* The recognition of these underlying structures might rely upon an *embodied* knowledge that can only be acquired though bodily experience.

Underlying reference structures in music are not always represented by sonic events. Consequently, meter cannot necessarily be analyzed based only on the physical sound signal. In samba, there seems to be a relationship between amplitude peaks in the sonic signal and meter. In telespringar, on the other hand, it is not easy to discover any onsets based on audio analysis alone. The performers' periodic body motions – that is, the fiddler's foot stamping and the dancers' libration pattern – seem to be very stable and related to the underlying meter. This supports the view that there is a close

relationship between musical meter and periodic body motion, and that performers' and perceivers' body motion should be included when investigating musical meter.

VI. CONCLUSION

This paper investigates meter as shape in samba and telespringar based on motion capture recordings of performances. The results support the view that there is a close relationship between musical meter and performers' periodic body motion. The analysis of the performers' periodic body motions also revealed periodic motion shapes on beat level in telespringar and on sixteenth note level in samba. This suggests that the underlying meter may not only include metrical points in time, but that each metrical beat/subdivision duration has a corresponding *metrical trajectory* with a certain *shape*. When investigating musical meter, then, one should not only look at meter as points in time, or the duration between such points, but also possible trajectories between the points.

VII. LIMITATIONS AND FUTURE WORK

The analyses in this paper are based on recordings executed in a motion capture lab, which is not an environment where music is usually performed. It has been pointed out that performers' expertise can compensate for the influence of an artificial environment (Naveda & Leman, 2008), consequently only professional performers participated in the studies. The performers were told to perform as they would normally do, and they all confirmed that they had done so. Because of this, the data presented are thought to represent typical samba and telespringar performances. Nevertheless, future studies should also include recordings in real-world situations. Also, the results in this paper are based on recordings of very few performers. In future work, recordings of more performers should be included.

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