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Effect of tempo on relative note durations in a performed samba groove

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ABSTRACT

Previous studies have revealed uneven duration patterns at the sixteenth note level of samba. In the present study, we investigated the influence of tempo on such sixteenth-note patterns in a performed samba groove.The results revealed an uneven duration pattern in all tempi. Interestingly, the shortest note becomes relatively shorter and the longest relatively longer as the tempo increases. We suggest that the differences in relative durations between tempi reflect the need to maintain the samba sixteenth note 'template' in all tempi: producing the samba 'feel' requires that relative durations have to be adjusted to tempo.

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Rhythm; tempo; groove; non-isochronous subdivision; samba; lower limit of duration; timing

1. Introduction

Pulse[1] is often described as successive mental beats that provide a fundamental reference level against which we perceive and interpret rhythm (Honing, 2012; London, 2012; Parncutt, 1994) and *metre* as an organisation of these beats. However, metric structures consisting of units of uneven durations, hereafter referred to as non-isochronous duration patterns, have been found in many musical styles, both at the level of the tactus (e.g. Bengtsson & Gabrielsson, 1980; Blom, 1981; Groven, 1971; Haugen, 2016a; Johansson, 2017; Kvifte, 1999; Ramsten, 2003) and at the level of subdivision (e.g. Benadon, 2006; Collier & Collier, 2002; Friberg and Sundström 1997, 2002; Gerischer, 2006; Gouyon, 2007; Haugen & Godøy, 2014; Moelants, 2011; Naveda et al., 2009; Polak, 2010). How tempo affects the relationships between the different beats or notes within such non-isochronous rhythmic patterns is, however, an under-explored field of investigation. A key question is to what extent the non-isochronous distribution of events is evened out in faster tempi, for example, as a result of bodily or perceptual constraints producing a lower limit or 'floor effect' for the duration or as a consequence of a reduction of rhythmic categories when two initially uneven short notes merge into one single category. If such effects do exist, the non-isochronous duration pattern should become more even with increasing tempo.

2. Tempo and rhythm production

Tempo, understood as the rate at which a piece of music is performed and/or perceived, is an important component of the experienced rhythm. In music, the tempo is often associated with the rate of the perceived underlying pulse. Consequently, changes in the sonic rhythm do not necessarily generate a change in tempo (London, 2001). Pulse perception, or beat induction, can, therefore, be considered equivalent to judging tempo (Repp & Su, 2013).

The effect of tempo on timing in musical performances has been investigated in several studies. In an early study of recordings of Satie's *Vexations*, a piece consisting of a short theme that is repeated, Michon (1974) observed that the relative durations of certain notes seemed to be affected by tempo variations. He concludes that the subjective temporal structure of the piece varies with tempo. Clarke (1982) later replicated Michon's finding. Two pianists were instructed to vary

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[1] Also referred to as the *beat* (e.g. Honing, 2013), *regulative beat* (Nketia, 1986), *subjective beat* (Chernoff, 1979), *tactus* (London, 2012), *inner pulsation* (Kubik, 1990), and *internal beat* (Danielsen, 2006).

the tempo for each repetition of the theme, but keep the tempo stable within each part. Clarke found the same timing profiles (deviations from the exact) for all tempi, but that that timing patterns seemed to become *more* regular as the tempo increased. Furthermore, he found that the rhythmic structure of the piece was modified by tempo fluctuations: the music was segmented into more units (groups) at slower tempi. He suggests that this is because an upper duration limit of perception constrains the overall group size, leading the performer to subdivide larger groups when played in a slow tempo.

Ina study of Schumann's *Träumerei*, Repp (1994) investigated whether the expressive timing of the melody would scale proportionally with tempo. Two pianists played the piece at three different tempi; a preferred tempo that they chose, a faster tempo, and a slower tempo, the latter two decided by the conductor of the study. Prior to each recording, the performers were presented with a metronome at the tempo at which they were to play the piece. Repp found that the timing of the performances was largely invariant under tempo transposition. The ratio between the notes did not change when the tempo changed, and the timing of grace notes, or ornaments, also scaled proportionally with changes in tempo. He concludes that for certain types of music it is possible to change the tempo without changing the quality and expression of a performance significantly. However, a similar study by Desain and Honing (1994) came to the opposite result: in the performance of a piece by Beethoven, the durations of the grace notes did *not* scale proportionally with global tempo. They suggest that one of the reasons for why they got a different result from Repp, could be that *Träumerei* is a slow expressive piece, whereas the Beethoven piece has a very clear rhythmic structure.

An effect of tempo has also been found in French baroque music performed with so-called *notes inégales* – that is, when the first of two equally notated notes are played with longer duration than the second (similar to eighth notes in jazz swing). Moelants (2011) conducted a study with eight harpsichordists and eight baroque violinists who performed fragments from French gavottes in a *slow*, *moderate*, and *fast* tempo. He found that although the performers largely agreed on ratios between 1.25 and 2.0, individual interpretation varied greatly. The main tendency was that performers played more even when the tempo increased, but some performers did the opposite. Moelants concludes that the performers use inégalité as an expressive means according to their personal taste.

Particularly interesting in relation to the present context is a study of Clementi's *Sonatina, op.36, no. 3, second movement*, where Clarke (1985) discovered an effect of tempo of performed long–short note duration patterns. Clarke found that in *long–short* patterns consisting of a dotted eighth note (*long*) and a sixteenth note (*short*), the ratio between the long and the short note decreased at faster tempi, whereas the opposite was the case for patterns consisting of a dotted quarter note (*long*) and an eighth note (*short*). He suggests that this effect is a consequence of a reduction of *rhythmic categories*. In slower tempi he observed four distinct rhythm categories: (1) dotted quarter note, (2) dotted eighth note, (3) eighth note, and (4) sixteenth note. However, as the tempo increases, he explains, the absolute durations of the eighth note and the sixteenth note become so similar that it becomes impossible for the performer to maintain these two note values as two different categories. Consequently, the eighth note and the sixteenth note are merged into one single *short* category, with a duration that is shorter than an eighth note, but longer than a sixteenth note. In faster tempi, then, there are only three rhythmic categories: (1) dotted quarter note, (2) dotted eighth note, and (3) eighth/sixteenth note. He concludes from this that 'rhythm structures are internally represented in a categorical, rather than a continuous, fashion' (Clarke, 1985, p. 220).

3. Previous research into the relationship between tempo and non-isochronous duration patterns in groove-based music

Effects of tempo on performed rhythm have also been found in studies of so-called *groove-based* music. The term *groove* is often used to describe style-specific repetitive rhythm patterns performed in a particular manner regarding both timing, sound, and the shaping of the rhythmical events (e.g. Câmara & Danielsen, 2018; Iyer, 2002; Keil & Feld, 2005) music denotes music genres which rely on such specific grooves. Fundamental for understanding a groove, is the perception of a particular reference structure, such as pulse, metre, and metrical subdivisions (Danielsen et al., 2015; Pressing, 2002). If one does not perceive the intended metre, the groove can change character or break down completely. A groove is thus more than a rhythm pattern; it is also an *experience*. The *groove experience* describes the 'feel' of a specific music style and is often associated with the desire of wanting to move (e.g. Keil & Feld, 2005; Madison, 2006; Pressing, 2002) and a sense of pleasure (e.g. Janata et al., 2012; Witek et al., 2014). The state of 'being in the groove' has been described as a euphoric feeling, often related to a sense of flow and timelessness (Danielsen, 2006; Janata et al., 2012).

In groove-based music, studies of the effect of tempo on non-isochronous duration patterns – that is, patterns consisting of units of uneven durations, have largely been conducted in jazz swing. Jazz swing is characterised by a *long–short* duration pattern on the eighth note level, often referred to as *swing ratio*. The swing ratio in performed jazz swing often falls between straight eighths (1:1) and triplet eighths (2:1), but a swing ratio as high as 3:1 or even slightly higher has also been observed (Friberg and Sundström, 1997). In an early study, Ellis (1991) recorded three professional jazz saxophonists who performed jazz swing patterns in five different tempi ranging from 90 to 120 bpm (bpm). Two of the performers showed a trend toward playing the *long–short* eighth note duration pattern more evenly as the tempo increased, whereas the third performer followed nearly the same swing ratio at all tempi. Friberg and Sundström (1997) also studied the effect of tempo on swing ratio by measuring the ride cymbal onsets in six commercial jazz recordings with four different drummers. The tempi of the excerpts varied between about 100 and 320 bpm. They found an approximately linear decrease of swing ratio with increasing tempo – that is, the eighth notes became more even as the tempo increased. At the slower tempi, around 120 bpm, they observed swing ratios as high as 3.5:1. Almost 30 years later, Dittmar et al. (2015) replicated the study conducted by Friberg and Sundström (1997). They developed an automatic swing ratio estimation procedure enabling investigation of several hundreds of ride cymbal patterns played by a wide range of drummers. The general trend corresponded with Friberg and Sundström's finding. However, some drummers kept almost the same swing ratio across different tempi. Honing and Haas (2008) also investigated the effect of tempo on jazz swing in a study with three professional jazz drummers playing a jazz swing pattern along with a metronome at nine different tempi ranging from 103 to 240 bpm (580–250 ms). In their study, the swing ratios mostly varied between 2.0 and 2.5 and each drummer had a significantly different swing ratio for each tempo. However, the swing ratio did not scale proportionally with tempo. Accordingly, Honing and Haas refer to the *tempo-specific timing hypothesis* (Honing, 2006), which indicates that there is an intimate coupling between timing and tempo in music, and they suggested that jazz experts adapt the swing ratio to the overall tempo in order to obtain the effect of swing at different tempi.

Some studies have suggested that a *lower limit of duration* might constrain ratios between non-isochronous subdivisions. Friberg and Sundström (1997) observed a floor effect – that is, in tempi from 150 bpm and faster the short second eighth note in the swing pattern seemed to stabilise around 100 ms. They suggest that this might work as a lower range of duration which, in turn, can explain the decrease in swing ratio at fast tempi. Dittmar et al. (2015) found a similar tendency: the second eighth note durations varied between 80 and 110 ms at tempi faster than 150 bpm. This also accords with a lower limit for subdivision duration suggested to constrain West African drumming, namely 80–100 ms (Polak, 2017). Honing and Haas (2008), on the other hand, did not find support for a lower limit around 100 ms for duration nor a linear decrease of swing ratio in their study of jazz swing drumming. However, Honing and Haas did not test the drummers at faster tempi than 240 bpm (250 ms quarter note duration). This might have influenced the results since both Friberg and Sundström and Dittmar et al included performances in 240–300 bpm and some even faster than 300 bpm.

3.1. Non-isochronous subdivisions in samba

The aim of the present study is to investigate whether there is an effect of tempo on non-isochronous subdivisions in samba groove. Samba is normally notated as 2/4 m – that is, there are two beats in a measure. Each beat has four subdivisions, or what is known as sixteenth notes. Recent studies have revealed that systematic microtiming at the level of sixteenth notes seems to be a prominent feature of samba groove. In an experiment studying systematic microtiming in samba, Gouyon (2007) collected 49 short excerpts of traditional samba music from Rio de Janeiro, taken from commercial CDs. Using computer techniques in audio analysis, he found that the third and the fourth sixteenth note in a beat in samba are played slightly ahead of their corresponding quantised position. This result was confirmed in a similar study by Naveda et al. (2009) where 106 excerpts of samba music influenced by Rio de Janeiro's styles of samba, taken from commercial CDs, were analysed.

A couple of studies have investigated the systematic non-isochronous pattern on the sixteenth note level in samba as *duration patterns*. Gerischer (2006) carried out rhythm studies of samba percussion in the region of Bahia in Brazil, based on field recordings (audio) and interviews. In order to illustrate the systematic uneven sixteenth note durations in samba, she presents the sixteenth notes durations in Nominal Units of Time (NUT) (Marzac-Holland et al., 1983), where 100 represents one even sixteenth note duration, 400 NUTs an 'idealised' beat, and 1600 NUTs a four-beat cycle (Gerischer, 2006).

Table 1. Averaged sixteenth note durations in NUTs during four-beat cycles in *reco reco*, *triangle*, and *pandeiro* playing from Gerischer (2006, p. 105).

		Sixteenth note durations				
Instrument	Beats	First	Second	Third	Fourth	Tempo (bpm)
Reco reco	First	97	85	96	121	83–131[a]
	Second	100	88	101	114	
	Third	96	87	94	124	
	Fourth	102	82	94	120	
	Grand Mean (NUTs)[b]	99	85	96	120	
	Grand Mean (%)[b]	25	21	24	30	
Triangle	First	108	76	99	119	
	Second	105	76	100	113	
	Third	104	79	100	118	
	Fourth	105	78	100	118	
	Grand Mean (NUTs)[b]	106	77	100	117	
	Grand Mean (%)[b]	26	20	25	29	
Pandeiro	First	107	74	93	128	
	Second	104	80	89	123	
	Third	114	73	85	126	
	Fourth	112	78	91	121	
	Grand Mean (NUTs)[b]	109	76	90	125	
	Grand Mean (%)[b]	27	19	22	31	
Duration pattern:		Medium	Short	Medium	Long	

[a]Gerischer (2006) presents the tempi in her study in average inter-onset-intervals between sixteenth notes. The range is 115–180 ms, which is equivalent to 460–720 ms between beats. This has been converted into beats per minute (bpm).
[b]Calculated from the numbers presented by Gerischer.

Sixteenth note durations in both *reco-reco*,[2] *triangle*, and *pandeiro*[3] playing were included. Gerischer found that the first and third sixteenth notes in a beat are insignificantly different from the 'ideal' of 100, whereas the second sixteenth note is shorter and the fourth longer than 100 in all three instruments, resulting in a *medium (M)–short (S)–medium (M)–long (L)* duration pattern on sixteenth note level (see Table 1). Furthermore, she found that not only is the fourth sixteenth note in a beat in samba extended (in duration), it is also accentuated, indicating that the fourth sixteenth note plays a significant role. She emphasises that the microtiming pattern in samba groove constitutes an essential aspect of the style and that the musicians add their individual phrasings to these the microtiming features.

Duration patterns on the sixteenth note level in samba groove were also investigated in two motion capture studies carried out by Haugen and Godøy (2014) and Haugen (2017). The same two professional samba performers, a percussionist and a dancer, from outside Rio de Janeiro participated in both studies. The percussionist played *pandeiro* and the dancer performed a dance in *samba no pé* style. In Haugen and Godøy's (2014) study, the percussionist played alone whereas in Haugen's study (2017) the percussionist and dancer were recorded simultaneously. In both studies, statistical analyses showed that the fourth sixteenth note was significantly longer in duration than the others (see Table 2). However, no significant differences were found between the first, second, and third sixteenth notes, resulting in a *medium (M)–medium (M)–medium (M)–long (L)* duration pattern. The same duration pattern was also found in the participants' periodic body motion, which supports the view that the fourth sixteenth note is crucial and, moreover, that the non-isochronous duration pattern on the sixteenth note level constitutes an essential feature of samba. The duration patterns were, however, slightly different from the *medium (M)–short (S)–medium (M)–long (L)* patterns that Gerischer (2006) found. Haugen and Godøy (2014) suggest that this might be due to regional differences, since Gerischer studied percussion from the region of Bahia, whereas the performers in Haugen and Godøy's study were from Rio de Janeiro.

Table 2. Duration patterns on sixteenth note level in samba from Haugen and Godøy (2014) and Haugen (2017) based on audio recordings of percussion (*pandeiro*) playing.

	Sixteenth note durations in % (SD)				Tempo
	First	Second	Third	Fourth	(bpm)
Haugen and Godøy (2014)[a]	23 (3.9)	24 (6.3)	23 (4.4)	31 (2.1)	–
Haugen (2017)[b]	24 (2.7)	23 (3.9)	22 (3.9)	31 (1.8)	96
Duration pattern:	*medium*	*medium*	*medium*	long	

[a]Based on an audio recording of a solo percussion performance.
[b]Based on an audio recording of a percussion and dance performance.

None of the studies above have had a particular focus on tempo. However, Gerischer reports average tempi

[2] The Brazilian (metal) *reco-reco* instrument has two or three stretched metal springs on top that is scraped on with a metal stick.
[3] *Pandeiro* is a traditional Brazilian hand frame drum with jingles (*platinelas*) similar to a tambourine.

between 83 and 131 bpm, which lies within the tempo range in the present study, see below. In Haugen and Godøy (2014) the tempo was not calculated, but in the percussion and dance recording investigated in Haugen (2017) the mean tempo is 96 bpm. This is also in the middle of the tempo range of the present study.

Summing up, previous research point to an accentuated prolonged fourth sixteenth note being crucial to the samba rhythm. However, none of the studies have investigated whether this pattern might be influenced by tempo. In this study the aim was to investigate, first, whether there is an effect of tempo on the non-isochronous duration pattern of sixteenth notes in a performed samba groove. Because previous results are mixed, we were open as to whether we would find such an effect or not. Secondly, we wanted to investigate whether there is a lower limit for sixteenth note duration that constrains the duration pattern in the fast tempi. Based on previous research (Dittmar et al., 2015; Friberg and Sundström, 1997; Polak, 2017) we expected to find a floor effect in the range of 80–100 ms. Finally, we were interested in whether notes of similar duration would merge into one single rhythmic category in fast tempo, as suggested by Clarke (1985).

4. Method

4.1. Participants, task, apparatus, and procedure

Two experienced samba performers from São Paulo in Brazil, a percussionist and a dancer, were recorded. The performers were standing and facing each other. The dancer performed the samba dance in *samba no pé* style. The percussionist played a samba groove on *pandeiro*, a traditional Brazilian hand frame drum similar to a tambourine. In addition to the sound-producing actions, the percussionist was walking on the spot in accordance with the basic beat (tactus) – that is, two steps in a measure, additionally causing the body to sway from side to side in accordance with the beat. A visual inspection of the percussionist's vertical feet motion indicates that the lifting of the feet, between the beat, corresponds to the fourth sixteenth note in a beat, something that has also been observed in previous studies of pandeiro playing (Haugen, 2017; Haugen & Godøy, 2014).

The performers were asked to perform the same samba groove in three different tempi: *fast*, *preferred*, and *slow* tempo. The tempi were chosen by the performers: 133, 100, and 69 bpm (bpm) respectively. Each recording lasted about one minute. All the recordings were carried out in the fourMs motion capture lab at the Department of Musicology at the University of Oslo.[4] Both sound and the performers' body motion were recorded. The participants' body motions were recorded using a state-of-the-art optical motion capture system from Qualisys.[5] The sound was recorded using Reaper[6] and recorded simultaneously with the motion capture recordings using a custom-built Max/MSP patch, running on a Macintosh. The performances were also video recorded for reference purpose.

4.2. Sound production

The results in the present paper are based on an analysis of the recorded sound from the pandeiro. The pandeiro is held in the left hand and played by the right. A pandeiro rhythm emerges by alternating between the strokes of the right thumb, fingertips and palm. Different stroke techniques produce different sounds that can be classified as followed: high and low frequency bass sounds, slap sound and jingle sound (Roy et al., 2007; Sabanovich, 1988). Figure 1 shows a simplified transcription for two bars of the samba grooves played in this study, including the start break consisting of one-eighth note, and a plot of the corresponding audio waveform, envelope, and detected onsets. All the sixteenth notes are played (audible), the second beat in the bar is featured by a low frequency bass sound, and the fourth sixteenth note in a beat is accentuated, something that is in accordance with previous descriptions of samba groove (Gerischer, 2006; Haugen, 2017; Naveda, 2011).

4.3. Audio analysis

Because all the sixteenth notes are played and present in the sound signal as acute amplitude peaks, their temporal positions could be measured using an onset detection function in the MIRToolbox (Lartillot & Toiviainen, 2007). The onset detection function used in this study performs a peak picking procedure on the envelope curve and returns the temporal positions of those peaks (see Figure 1). It should be noted that the temporal position of these peaks might not correspond exactly to the *perceptual onsets*, understood as the points in time when the beginning of sonic events are perceived (e.g. Vos, 1981), nor to the so-called *perceptual attack time* (Gordon, 1987; Wright, 2008), or the *perceptual* center (Danielsen et al., 2019; Morton & Frankish, 1976). However, since we are primarily investigating duration patterns here, and not whether the estimated temporal position equal the perceptual onset or perceptual attacks, the main concern is that every onset is measured in the same manner.

[4] https://www.hf.uio.no/ritmo/english/groups/fourms/about/labs/

[5] https://www.qualisys.com

[6] https://www.reaper.fm

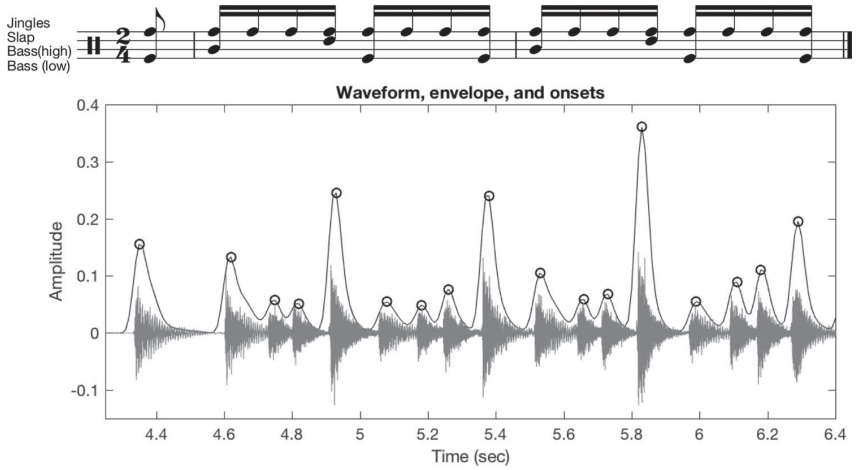

Figure 1. A simplified transcription of the two first measures of the samba groove, including the one eighth note 'start break', a plot showing the corresponding amplitude waveform, envelope and detected onsets (circles).

4.4. Data analysis

First, the inter-onset-intervals (IOIs) between all the estimated sixteenth notes measured in milliseconds (ms) were calculated (hereafter referred to as sixteenth note durations). Next, the mean tempo and the mean first, second, third, and fourth sixteenth note durations and mean beat durations for each recording were calculated. In addition, the sixteenth note durations were converted into percent values, according to their percentage of the beat, and their mean duration in percent calculated.

4.5. Statistical analysis

In order to test differences between mean sixteenth note durations, a two-way repeated measures ANOVA was conducted with sixteenth-note type (first, second, third, and fourth) and tempo (fast, preferred, and slow) as the independent variables and sixteenth note duration as the dependent variable ($N = 65$). The main effect of sixteenth-note type was further tested using one-way repeated measures ANOVAs with Bonferroni corrected post-hoc tests for each tempo. The difference in relative duration for each sixteenth note type between tempi were tested using one-way repeated measures ANOVAs with Bonferroni corrected post-hoc tests for each sixteenth note type measured in percent. For some of the tests, Mauchly's Test of Sphericity indicated that the assumption of sphericity had been violated, and in these cases, Greenhouse-Geisser corrections were used. All statistical analyses were performed using SPSS version 25 (IBM Inc.).

5. Results

The mean tempo and the mean beat durations and sixteenth note durations, measured both in milliseconds and percent, with corresponding standard deviations (SD) for the fast, preferred, and slow tempo are presented in Table 3.

A 4×3 repeated measures ANOVA of sixteenth note durations measured in milliseconds was conducted, with sixteenth note type (first, second, third and fourth sixteenth note) and tempo (fast, preferred, slow) as independent variables. As expected, the analysis showed a significant main effect of tempo [$F(1.834) = 25744, p < 0.001$, $\eta_p^2 = 0.998$], since the sixteenth note durations necessarily must become shorter as the tempo increases. It also showed a significant main effect of sixteenth note types [$F(2.631) = 1864$, $p < 0.001$, $\eta_p^2 = 0.967$], and a significant interaction between sixteenth note type and tempo [$F(3.729) = 97, p < 0.001, \eta_p^2 = 0.601$]. A plot of mean durations of the sixteenth notes in the three different tempi (Figure 2) shows that the non-isochronous duration pattern becomes more non-isochronous, that is, the mean duration of the short second sixteenth note becomes proportionally shorter and the fourth sixteenth note becomes proportionally longer, when the tempo increases.

In order to test the difference in relative duration for each sixteenth note type between tempi, one-way repeated measures ANOVAs with tempo as the independent variable were carried out for each sixteenth note type measured in percent. The analysis showed significant differences between tempi for both the first [$F(2, 128) = 89$, $p < 0.001$, $\eta_p^2 = 0.581$],

Table 3. Mean beat durations and mean first, second, third, and fourth sixteenth note durations, measured in milliseconds (top) and percent (bottom), with corresponding standard deviation at three different tempi: fast, preferred, and slow.

			Mean sixteenth note duration (SD)			
Tempo (bpm)	*N*	Mean beat duration (SD)	First	Second	Third	Fourth
			Measured in milliseconds (ms):			
Fast (133)	65	452 (9.1)	121 (7.1)	69 (6.0)	112 (5.1)	153 (8.6)
Preferred (100)	65	602.5 (12.1)	157 (8.7)	110 (8.4)	142 (5.8)	196 (9.0)
Slow (69)	65	871.9 (17.3)	212 (9.7)	198 (12.4)	206 (6.6)	256 (9.5)
			Measured in percent (%):			
Fast (133)	133	–	27 (1.3)	15 (1.3)	25 (1.3)	34 (1.7)
Preferred (100)	97	–	26 (1.2)	18 (1.5)	24 (0.9)	33 (1.2)
Slow (69)	65	–	24 (0.9)[a]	23 (1.3)	24 (0.9)[b]	29 (0.9)

[a]Mean duration rounded down from 24.3 and standard deviation rounded down from 0.93.
[b]Mean duration rounded up from 23.6 and standard deviation rounded up from 0.86.

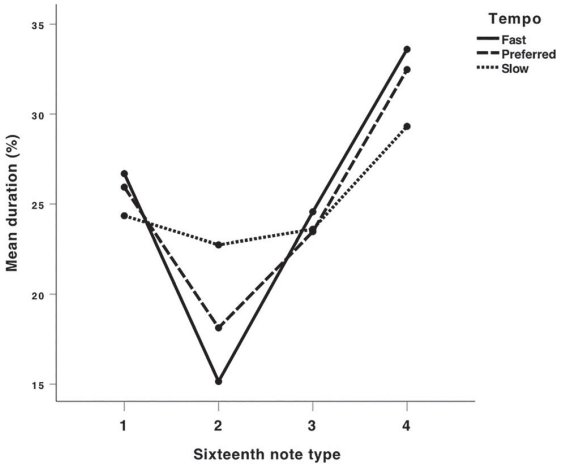

Figure 2. Plot showing the mean duration for the sixteenth notes (first, second, third, and fourth) in percent in three different tempi, fast (solid line), preferred (dashed line), and slow (dotted lin).

second [$F(2, 128) = 596$, $p < 0.001$, $\eta_p^2 = 0.903$], third [$F(1.806, 115.6) = 32$, $p < 0.001$, $\eta_p^2 = 0.33$], and fourth [$F(1.781, 114) = 253$, $p < 0.001$, $\eta_p^2 = 0.799$] sixteenth note. Bonferroni corrected post-hoc tests showed significant differences between all tempi for the first (all $p < 0.01$), second (all $p < 0.001$), and fourth (all $p < 0.001$) sixteenth note. For the third sixteenth note, significant differences were found between the fast and the preferred tempi and between the fast and the slow tempi (both $p < 0.001$), but no significant difference between the preferred and the slow tempi ($p > 0.5$).

5.1. Influence of a lower limit of duration

The results presented above reveal that the second sixteenth note is significantly shorter than the other sixteenth notes in all tempi. Next, we wanted to test whether there is an influence of a lower limit of duration by examining the second sixteenth note durations in the fast tempo. A box plot with all the second sixteenth note durations in milliseconds in all tempi (see Figure 3) shows that, in the fast tempo, almost all the second sixteenth note durations are below 80 ms.

A histogram displaying the distribution of the second sixteenth note durations in the fast tempo (see Figure 4) shows that the mean duration is only 68 ms and the range is 55–85 ms.[7]

5.2. The influence of tempo on rhythmic categories

Finally, we wanted to test whether sixteenth notes of similar duration merge into one single note duration at faster tempi. One-way repeated measures ANOVAs with sixteenth note type as the independent variable were carried out for each tempo, showing significant differences between sixteenth note durations in both the fast [$F(2.441,\ 156.2) = 1420$, $p < 0.001$, $\eta_p^2 = 0.957$], preferred [$F(2.067,\ 132.3) = 1140$, $p < 0.001$, $\eta_p^2 = 0.947$], and slow tempo [$F(2.559, 163.8) = 423, p < 0.001, \eta_p^2 = 0.869$]. Bonferroni corrected post-hoc tests showed significant differences between *all* sixteenth note types in all three tempi (all $p < 0.001$ except from the difference between the second and third in the slow tempo $p < 0.005$). The results show that there are four rhythmic categories on sixteenth note level, indicating a *medium long (ML)–short (S)–medium short (MS)–long (L)* duration pattern, in all tempi.

6. Discussion

The aim of the present study was to investigate the non-isochronous subdivision pattern in samba and in particular how tempo affects the relationships between the

[7] The mean duration 68 ms presented here differs slightly from the mean duration 69 ms presented in Table 3. The reason is that in order to compare the different tempi, only the first 65 sixteenth note durations were included in the two-way ANOVA, and consequently in Table 3. Here, on the other hand, all the 133 sixteenth-note durations in the fast tempo are included.

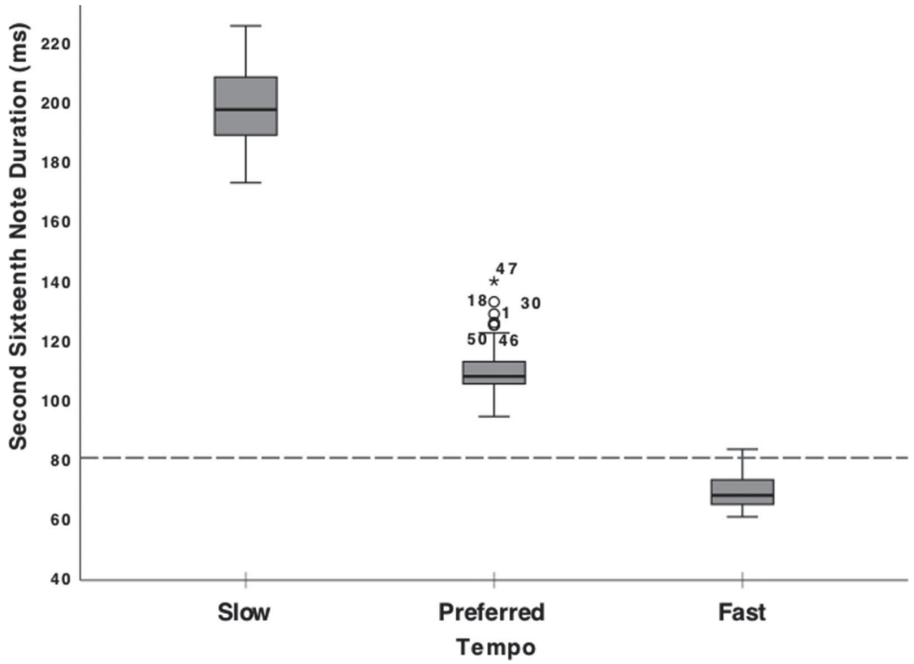

Figure 3. Box plot showing the distribution of the second sixteenth note durations in the slow, preferred, and fast tempo. 80 ms indicated by horizontal dashed line.

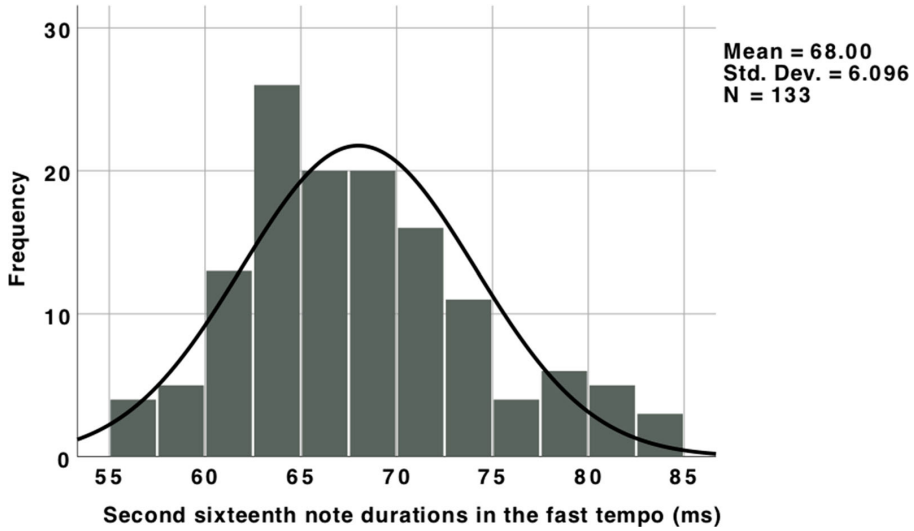

Figure 4. The distribution of the second sixteenth note durations in the fast tempo.

different beats or notes within such non-isochronous musical patterns.

The results confirm findings from previous research into samba groove, which have revealed that the fourth sixteenth note in a beat is longer in duration than the others (Gerischer, 2006; Gouyon, 2007; Haugen, 2016b; Haugen & Godøy, 2014; Naveda et al., 2009). In this study we additionally found that all the sixteenth notes where significantly different in all tempi, indicating a *medium long (ML)–short (S)–medium short (MS)–long (L)* duration pattern on sixteenth note level that is consistent across tempi (see Table 3). Even though this *ML–S–MS–L* duration pattern is unchanged across tempi, there is, however, an effect of tempo on the relative sixteenth note

durations measured in percent. Interestingly, the result in the present paper seems to be the opposite of some previous studies. As previously mentioned, Friberg and Sundström (1997) and Dittmar et al. (2015) found that the *long–short* pattern in jazz swing tended to become more even as the tempo increased. Similar results were found for *long–short* patterns in a performed piano piece by Clarke (1985). In the present study we found, on the contrary, that the sixteenth notes in the samba performance become *more* non-isochronous as the tempo increases.

If we compare the *ML–S–MS–L* duration pattern found in this study with the duration patterns found in previous studies of samba, we see that they are slightly different from each other. Gerischer, 2006, for example, found a *medium (M)– short (S)–medium (M)–long (L)* duration pattern (see Table 1). However, the sixteenth note durations presented in Gerischer's paper point to the second sixteenth note also being systematically shorter in duration than the first and third sixteenth note–that is, the duration pattern resembles the one found in the present paper. Unfortunately, we do not have access to Gerischer's data, so we do not know whether these differences are statistically significant. The duration patterns found in Haugen and Godøy (2014) and Haugen (2017), on the other hand, followed a *medium (M)–medium(M)–medium(M)–long(L)* duration pattern of sixteenth notes (see Table 2). In Haugen and Godøy's (2014) study the tempo was not calculated, but the tempo in Haugen's (2017) study overlaps with the present study, and it is thus likely that these differences are not related to tempo but rather to individual and/or regional differences.

As previously mentioned, some previous studies on music with non-isochronous duration patterns, such as the *long–short* duration pattern on eighth note level in jazz swing, have suggested that a *lower limit of duration* might constrain such duration patterns – that is, the duration pattern becomes more even as the tempo increases (Dittmar et al., 2015; Friberg and Sundström, 1997). The assumption that there exists such a lower limit of duration was not confirmed in this study. Our findings show that the duration of the second sixteenth note in the fast tempo is on average shorter than 80–100 ms, which has been suggested as a lower limit for duration in other genres (Dittmar et al., 2015; Polak, 2017). If the duration patterns found in the present study were 'restricted' by a lower limit of duration, there should either have been an upper limit for the overall tempo, not allowing second sixteenth note durations under a lower limit, or the second sixteenth note should have stabilised around a lower limit of duration at the fast tempo, producing a floor effect that consequently made it more similar to the first and third sixteenth note durations. Neither seem to be the case here. The shortest sixteenth note duration is shorter than what has previously been suggested as a lower limit of duration which implies that the duration pattern in this samba groove was not constrained by a lower limit of duration.

We neither found any evidence of the rhythmic categories overlapping as a result of increase of tempo. This explanation was suggested by Clarke (1985) to account for the change in ratios in two *long–short* patterns, namely, a dotted quarter note (*long*) – eighth note (*short*) pattern and a dotted eighth note (*long*) – sixteenth note (*short*) pattern, in fast tempi. According to his explanation the fast tempo makes it impossible for the performer to maintain the short eighth note and the short sixteenth note as two separate rhythmic categories, and instead they are merged into one intermediate short category. In the present study there are also four rhythmic categories: (1) *medium long*, (2) *short*, (3) *medium short*, and (4) *long*. However, unlike in Clarke's study, all four rhythmic categories exist in all tempi, and moreover, the short becomes relatively shorter as the tempo increases. If we employ Clarke's argument regarding how short notes of similar duration will merge into one category when the tempo increases, because it is impossible to maintain them in separate categories, one could suggest that the performer in the present study strives for keeping the different durational categories in the fast tempo; the short note has to be made relatively shorter in order to be maintained as a separate category. However, this does not explain how it is possible to maintain the *medium long (ML)* and the *medium short (MS)* sixteenth note durations in separate rhythmic categories. The difference between them is only 6, 15, and 9 milliseconds in the *slow*, *preferred,* and *fast* tempi, respectively.

How can we explain that the rhythmic categories merge in Clarke's study and not in the present samba study? One explanation for the diverging results might be that the *long–short* patterns investigated by Clarke (1985), occur occasionally during the musical piece, whereas the sixteenth notes pattern in the present samba study is a periodic pattern that is repeated throughout the performance. It might be easier to distinguish between similar rhythmic categories in such a repeating pattern. Another explanation could be that the two music genres possess different *beat bins*, a concept coined by Danielsen (2010). A beat bin can be understood as the temporal interval surrounding every metrical beat (and metrical subdivision) where a sonic event would be perceived as being played 'on' the corresponding metrical event. Building on the *theory of dynamic attending* (Jones, 2019; Large & Jones, 1999), a beat implies a distribution of attentional energy – that is, also the (internal) beat

has a certain extension in time and a shape (Danielsen, 2019). Accordingly, it has been suggested that the beat bin width is dependent on music style (see also Johansson's (2010) concept of *rhythmic tolerance*). In the case of Clarke's (1985) study, then, the metrical eighth and sixteenth notes in the piano piece might be thought to have quite wide beat bins. When the tempo increases, the eighth and the sixteenth notes' beat bins start to overlap, allowing the sonic eighth and sixteenth notes to have the same duration and still be performed (and maybe perceived) as belonging to the metrical eighth and sixteenth note respectively. The samba groove in the present study, on the other hand, seems to have extreme narrow beat bins on sixteenth note level, which prevent overlapping beat bins and merging of rhythmic categories, even when the sixteenth notes become very similar. Interestingly, the deviations between successive sixteenth note durations in the present samba groove range between 8–54 milliseconds, which are just above the *just noticeable difference* (JND) of 6 milliseconds previously found for inter-onset-intervals shorter than 240 milliseconds (Friberg & Sundberg, 1995). Our results imply that humans are capable to differentiate between very similar durations and that even very fine-meshed rhythmical patterns can be perceived and reproduced with high accuracy, depending on the musical context.

However, if the performer is neither constrained by a lower limit of duration nor by overlapping rhythmic categories or beat bins when the tempo increases, why do relative duration patterns change as the tempo changes? We suggest that this interaction is related to how this particular, style-specific rhythm pattern has to be articulated to convey the specific *ML–S–MS–L feeling* of the samba groove in different tempi. This is in line with what Honing and Haas (2008) found in their study of jazz swing, where all the performers performed *long–short* eighth notes in all tempi, but the ratios were adapted to the overall tempo. They suggest that the performers do so in order to maintain or obtain the effect of swing at different tempi. Accordingly, we suggest that the differences in relative duration between the sixteenth notes in samba are changed in order to maintain the 'samba groove experience' in all tempi. As has been shown in several studies (e.g. Gerischer, 2006; Gouyon, 2007; Haugen & Godøy, 2014; Naveda et al., 2009) non-isochronous subdivision is a salient part of the 'groove template' of samba. To maintain this template in various tempi, the relationship between the durations of subdivisions has to be changed.

This might point to a general aspect of groove-based music, namely that in order to maintain a specific groove style in different tempi, the relative durations must be adjusted accordingly. Duration *patterns* have to be consistent at a categorical level across tempi, but their ratios need not to be so. This implies that groove patterns are in fact patterns of duration *categories* (*long-short*, and so on) rather than being reliant on fixed percentages or ratios.

7. Conclusion

The present study investigates the non-isochronous duration pattern on sixteenth note level in a performed samba groove and the effect of tempo on this pattern. The results show that all the sixteenth notes were significantly different in all tempi, suggesting a *medium long (ML)–short (S)–medium short (MS)–long (L)* duration pattern across tempi. This is in accordance with previous studies on samba grooves finding that the fourth sixteenth note in a beat tends to be longer than the other sixteenth notes.

The results also show an effect of tempo on the duration pattern. Tempo interacts with sixteenth note type, such that when the tempo increases, the short second sixteenth note becomes even shorter and the long fourth sixteenth note even longer compared to the other sixteenth notes. This means that the non-isochronous duration pattern on sixteenth note level becomes even more pronounced when the tempo increases.

A possible influence of a lower limit for sixteenth note duration was investigated. In the fast tempo (133 bpm), the mean duration for the short second sixteenth note was only 68 ms, which is below the 80–100 ms range suggested as a lower limit for duration in other genres (Dittmar et al., 2015; Polak, 2017). We neither found that rhythmic categories of similar duration merge as a result of increase of tempo, as suggested by Clarke (1985). In our study, all four rhythmical categories of subdivision are maintained in all tempi, despite being very similar. We suggest that larger rhythmic tolerance (wider beat bins) in the piano performance studied by Clarke resulted in overlapping categories in fast tempi in his study, whereas the narrow beat bins of the subdivisional layer in the samba groove can explain the findings in the present study.

In sum, the results imply that the effect of tempo on the duration patterns in this study does not seem to be due to perceptual constraints like a lower limit of duration, neither a reduction of rhythmical categories as the tempo increases. Instead we suggest that the relative change in duration pattern is related to the 'samba groove experience'. In order to maintain a specific samba 'feel' in different tempi, the relative durations of the groove pattern have to be adjusted accordingly. This implies that, in groove-based music, duration patterns have to be consistent at a *categorical* level across tempi, but their ratios need not to be so: groove patterns are patterns of duration *categories* and do not rely on fixed percentages or ratios.

8. Limitations and future work

In future studies we also want to include the performers' periodic body motion, in order to determine whether there might be an effect of tempo on duration patterns in performers' periodic body motion as well, or whether this is only a feature of the sound.

The percussionist in this study was interacting with a dancer, something that might have restricted the overall tempo. Future studies could also include solo percussion recordings to investigate even faster tempi than the ones included here. Because it might be possible to play even faster on another instrument, it would also be of interest to include more instruments. This might represent a way to investigate further the lower limit of duration and when this might start to have effect at the level of subdivisions in samba.

Furthermore, the effect of tempo on duration patterns might not only be dependent on music style or practice, but also performers' individual style, taste and way of playing. In the present study we have only recorded one performer. Consequently, we cannot say whether the effect of tempo on duration patterns in samba found in this study – that is, that the pattern becomes more non-isochronous as the tempo increase, is a general tendency. We need more recordings in order to be able to draw more general conclusions. A conclusion that might be drawn from the present study, however, is that in order to get a better understanding of human production and perception of musical rhythm in general, it is important to include studies of different music genres and music cultures.

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