Timing and Groove in the Performance of Cuban Bass and Conga Patterns

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Introduction

For musicians, timing is a serious matter. Having good, consistent time is a key skill and a marker of good musicianship. Equally important is the ability to adjust one's own timing in relation to other instruments to produce a cohesive group sound and develop a good groove.[1] During performance, these adjustments are played out in real-time. They are interactive and typically occur at a micro-timed level.[2] They are of particular importance for core rhythm section instrumentalists (e.g., percussionists, bass players and pianists/guitarists), who work very closely together to provide the underlying rhythmic-harmonic foundation for the rest of the group. This is especially relevant to dance styles such as Cuban *son*[3] and related styles like salsa,[4] because they also provide dancers with a regular groove that has a sense of energy and dynamic forward motion.

[2] This article examines how two professional rhythm section instrumentalists manipulate timing and groove in the live performance of bass and conga patterns widely used in Cuban popular/dance music. The idea behind it is to drill down to a detailed level and uncover the processes and thinking that shape rhythm-section groove production, as seen through the lens of two experienced musicians. The findings can best be placed in

1. The term 'groove' is most commonly used to refer to the repeated rhythmic-harmonic pattern(s) that form part of the structure of a song or a quality of music that evokes engagement and pleasurable participation through physical movement and dance (Hofmann, Wesolowski and Goebl 2017; Senn, Kilchenmann, Bechtold, and Hoesl 2018).
2. Micro-timing refers to the minute, millisecond-level asynchronies between musicians that continuously occur throughout a performance.
3. *Son* was originally a rural dance music that developed in the easternmost region of Cuba in the late nineteenth century and travelled throughout Cuba, the Caribbean, Latin America and others parts of the world during the twentieth century to become one of Cuba's most valued musical expressions (Miller 2014; Moore 2010).
4. Salsa is a dance style that shares many musical features with *son*. It emerged from New York's Latin American musical communities in the 1960s and 1970s and has its roots in Cuban and Puerto Rican popular and folkloric music. Since then, it has become a multifaceted music and dance genre with worldwide appeal (Padura Fuentes 2003; Waxer 2002).

context of ongoing research into what makes music groove and why. I begin, therefore, with a review of the work of other scholars.

EXTANT RESEARCH

[3] Previous research on timing and groove dates back several decades. Starting in the 1960s, ethnomusicologist Charles Keil formulated his well-known theory of "participatory discrepancies" or PDs. He argued that the feeling of tension, drive and participation in groove is largely generated by the slight timing discrepancies between musicians (referred to as offsets in the current article) as they interact during live performances (Keil 1966; 1995; Keil and Feld 1994).

[4] In the 1990s, qualitative accounts taken from in-depth ethnographic studies of jazz documented how timing affects groove. Numerous professional jazz musicians report that successful rhythm section grooves have an easy sense of momentum and flow that comes from both the tight synchrony between players and small adjustments in relative timing positions (Berliner 1994, 349–352; Monson 1996, 56–69).

[5] Conducted in the same decade, a number of more empirical-orientated studies of Jazz (Prögler 1995), Cuban music and salsa suggest that both timing and rhythmic structure are vital to rhythm section groove production. For example, Bilmes (1993) used quantitative measures of repeated phrases used in the performance of Cuban *rumba*, claiming that timing deviations are most important for the expressive feel of percussive music. Alén (1995) measured timing nuances in different toques (basic repeated rhythm patterns) used in Cuban Tumba Francesa performance, finding that slight but consistent deviations from notated metric structure are an important expressive characteristic of the music. Most relevantly, in his article on swing and expression in a commercial recording of salsa, Washburne (1998) examined groove from the perspective of a professional musician, highlighting the continual and complex negotiations needed within the rhythm section in order to maintain excitement and propulsion in the groove. He concluded that these micro-timed negotiations (pushing and pulling against each other) are influenced by the song structure, tempo, key rhythmic patterns, personal preference, and particular points within the beat structure (179).

[6] Research from around 2000 onwards has provided differing perspectives and approaches to the study of groove. Several musicologists have focused on the relationship between groove, rhythmic structure, and metre in electronic dance music (Butler 2006),

funk (Danielsen 2006) and popular music (Zbikowski 2004), and others have looked at factors such as beat salience, syncopation, event density, tempo, and rhythmic variability in various popular music styles (see Kilchenmann, Bechtold and Hoesl 2018 for a recent literature review). Research into the relationship between micro-timing and groove has been, at times, contradictory. Some studies have concluded that offsets are commonplace in the performance of Jazz (Benadon 2006), Brazilian samba (Gerischer 2006), Malian Jembe drumming (Polak 2010) and North Indian Classical music (Cooper 2019), others have reported that these offsets play an important role in groove production in Jazz (Doffman 2009, 2013), while others found no correlation between micro-timed offsets and groove in Jazz and Rock (Madison and Sioros 2014; see also Merker 2014). It has also been reported that offsets can have a negative effect on groove in the performance of rock drum patterns (Frühauf, Kopiez, and Platz 2013) and Samba, Funk and Jazz (Davies, Madison, Silva, and Gouyon 2013).

[7] Concentrating on research into Cuban musical performance, recent studies suggest that the relationship between timing and groove warrants further examination. Empirical research on percussive timing in Afro-Cuban *rumba* performance reveals that timing contours are shaped by the particular rhythmic pattern being played, the role of instruments within the ensemble, and the instrumentalists' choice of rhythmic improvisations in a given performance (Benadon 2017; Benadon, McGraw, and Robinson 2018). In the live performance of *son* and salsa styles, rhythmic-harmonic structure as well as group dynamics and real-time rhythmic interactions also shape timing and groove production within the rhythm section (Poole 2021). Most recently, research on Congolese and *batá* drumming traditions in Santiago de Cuba suggests that while timing and rhythmic interaction are important features of ensemble performance, academic notions of groove and the way in which it is experienced by musicians in Cuba needs reframing from a more phenomenological perspective (McGraw and Benadon 2022).

[8] The approach used in the present article both draws on and contributes to many of the studies cited above, combining quantitative measures of micro-timing taken from live performances (e.g., Benadon 2017) with qualitative accounts taken from the insights of the musicians who played on the recordings (e.g., Berliner 1994; McGraw and Benadon 2022) and the analysis of rhythmic patterns typically found in ethno/musicological studies (e.g. Poole 2021; Washburne 1998). Although not unique (see Goldberg 2019 on Bulgarian drumming and Doffman 2009 on jazz, for example), such an approach is not widely used. However, successfully integrating these multiple and sometimes contrasting

perspectives has the advantage of potentially providing a more detailed and richer account of rhythm section timing and groove production than either would in isolation.

[9] Another unusual aspect of the current study is to deliberatively manipulate relative timing between musicians during live, studio performances. The idea was to capture, in a studio setting, the typical timing adjustment used in live performances but with greater control of some of the variables that can affect rhythm section timing, such as improvised variations of rhythmic-harmonic patterns, and the timing of other ensemble players. Other studies have manipulated timing in this type of setting (Davies, Madison, Silva, and Gouyon 2013; Frühauf, Kopiez, and Platz 2013), but typically make use of synthesized and/or quantized rhythm section parts and click tracks, which may compromise ecological validity.

AIMS

[10] The main aim of this article, then, is to integrate quantitative and qualitative data with the analysis of typical bass and conga patterns to examine the real-time, micro-timed relationships between these two core rhythm section instrumentalists, and to document the effect on groove. Specifically, I am interested in quantifying the precise level of synchrony between musicians as they work together to produce a desirable groove and to look at how small but deliberate and typical adjustments in relative timing positions can impact how the music sounds and feels. I hope that the results will shed more light on the complex relationship between timing and groove in Cuban musical performance and will be of interest to ethno/musicologists and musicians alike.

[11] Music educationalists too could make use of the concepts and findings presented in studies of groove such as this one, a point raised by Joseph Prögler (1995, 50) over twenty-five years ago. Having spent many years teaching music, like Prögler, I see groove as an underutilized pedagogical resource that can be used for developing a detailed understanding of rhythm, timing, and ensemble interaction in groove-based styles like Cuban music. Music students, and in particular rhythm section players, would surely benefit from learning the finely-honed musicianship skills needed to make precise adjustments in timing in order to maintain ensemble synchrony, and to make the music sound like it does when played by more seasoned musicians. The next section provides details of the musicians and performances featured in the forthcoming analyses.

Musicians and Performance Details

[12] Two professional musicians performed in this study: Andy Martin on congas and myself on bass. We both have over twenty-five years' experience of studying Cuban music and performing various styles within this tradition in different ensembles in and around the UK and abroad. Andy studied congas and complementary percussion (clave, guiro, bongos etc.) in London, UK, Havana, Cuba and in Ghana, West Africa, and I studied bass and percussion in *batá* and *son*/salsa styles at SOAS in London and Havana with members of the *son* group Sierra Maestra and the rumba group Clave y Guaguancó. In addition, we have played together in a number of ensembles over the past twenty years. We have spent hundreds of hours performing the patterns used in this study, in many professional contexts, and can therefore be considered very experienced performers who know each other's playing very well.

[13] In these performance contexts, the overall intention is to play together and maintain a synchronous relationship in order to provide a solid foundation for the rest of the ensemble. This timekeeping process inevitably requires the slight adjustment of relative timing in order to maintain the desired level of synchrony. In addition to maintaining a tight synchronous relationship, I have deliberately altered my timing relationship with the congas (by playing ahead or behind) in order to manipulate how the music feels: to increase/decrease the tempo; to inject drive and movement, or to make the groove sound more urgent or laidback, for example.

[14] Taking this idea of the adjustment of relative timing between musicians, my intention in the performances on which the present study is based was to deliberately alter the timing relationships between the congas and bass, in a way that is typical of live performances. To do this, three performances were recorded. The first performance aimed for togetherness, with bass and conga playing in tight synchrony. The aim of the second performance was for the congas to remain constant while the bass played ahead but still "in time." Similarly, in the third performance the congas remained as constant as possible while the bass played intentionally behind. As the adjustment of relative timing was the focus, other elements of the performance remained the same: the three performances were played at the same tempo of around 100 bpm and the bass and congas patterns were repeated throughout without variation.

[15] Due to our experiences working together, performance preparation was minimal. I took a familiar bass part that I had played in many gigs with Andy, one that features in

renditions of Cuban songs like "Pare Cochero" and "Son De La Loma," and asked him to play a typical, complementary conga part. We agreed on a suitable tempo and recorded a few takes to check recording levels and sound quality. Prior to the takes, the purpose of the recordings was made clear to Andy: to play the conga patterns without variation and as consistently as possible, while I varied the bass part in a similar manner to that of conventional live performances.

[16] Despite my efforts to capture performances in an ecologically valid way, the nature of this study means that certain aspects of the recording context differ from a regular performance. Firstly, the bass and congas have been isolated from the full ensemble, which might include other rhythm section instruments (such as additional percussion, piano/guitar) as well as vocals and horns. Secondly, compared to some performance venues, the monitoring in a studio is clearer, making it easier to hear the intricacies of the parts played by fellow musicians. It is possible that both these factors may have distorted timing relationships, affording a more focused, tighter performance. I think, however, that these effects are negligible. I say this because I have recorded and analyzed our playing on many occasions using recordings captured in both venue and studio contexts. By comparison, the recordings used in this study are perhaps a little more considered (mainly due to the lack of improvisation) but nonetheless representative of our playing in terms of relative timing and how we groove together (at least in situations with favorable acoustics/monitoring).

Musical Materials

[17] The conga and bass patterns used for the three performances are shown below in Figure 1. These particular patterns were chosen because they are core rhythmic patterns typically played in Cuban *son* and salsa music. In order to provide some necessary context for the forthcoming discussion, summary details on these patterns and how they are structured and related are now given.

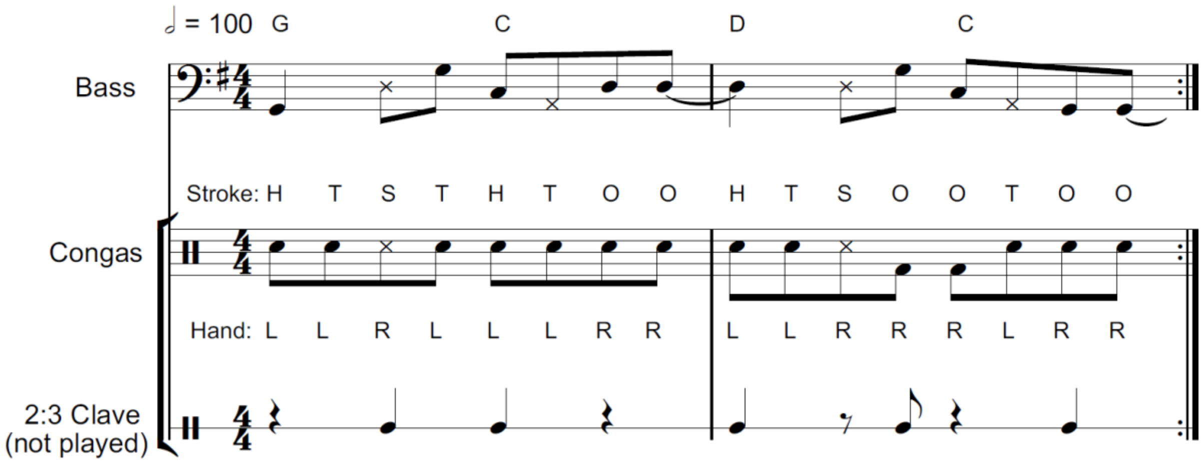

Figure 1. Bass and conga patterns with clave. Conga strokes: H = heel of hand, T=toe/tip of hand, S = slap, O = open tone. Bass notes: x = deadnote.

Clave

[18] The *clave* is an important and central rhythmic feature of Cuban and related musics.[5] Shown in Figure 2 is a "3:2 son clave," so called because there are three strokes in the first bar (3-side) and two in the second (2-side). The term "son" derives from its association with Cuban *son* music (see footnote 3) but it is also used extensively in many related styles such as mambo, songo, salsa and Afro-Cuban jazz. The *clave* underlying the performances here (bottom of Figure 1) is a popular variant called the "2:3 son clave." The stroke placement is identical, but the two-bar pattern is reversed: it starts with the 2-side, followed by the 3-side.

[19] Whether articulated or not (as is the case here), many researchers argue that it functions as an internal guide for musicians influencing composition, arrangement, improvisation and performance (Amira and Cornelius 1992; Peñalosa 2009; Stover 2009). The *clave* is included here for two reasons. Firstly, because it shows how the bass and

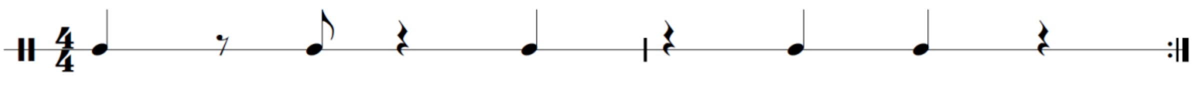

Figure 2. 3:2 Son Clave

5. The term *clave* is of Spanish origin, literally meaning key, clef, code, or keystone. It simultaneously refers to the musical instrument (cylindrical hardwood sticks) on which the rhythm is played and a constantly repeated rhythmic pattern (Orovio 2004, 54).

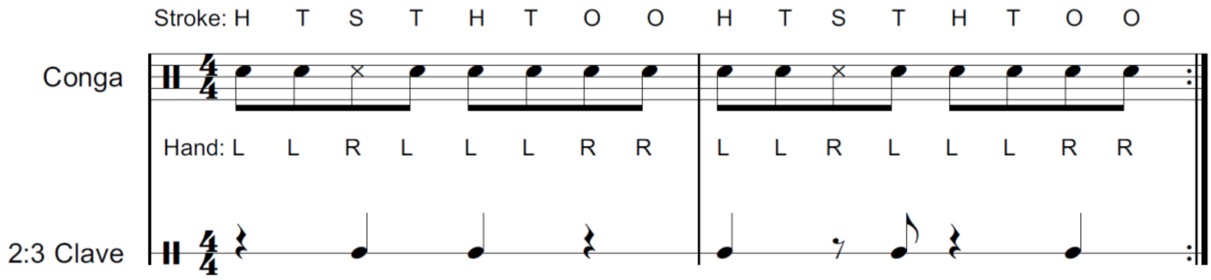

Figure 3. Congas on a Single Drum. Conga strokes: H = heel of hand, T = toe/tip of hand, S = slap, O = open tone.

conga patterns are aligned with the important *clave* strokes within its repeated two-bar structure, and secondly, because it is possible that an internalized central rhythm like the *clave* influences musicians' timing (Chor 2010).

Conga Tumbao

[20] Another central rhythm used in Cuban music is the conga *tumbao* (Figure 3).[6] Rhythmically, it is continuous eighth notes (quavers), but tonally the stroke pattern varies between left and right hands, with different tones and textures being obtained by striking the drum with different parts of the hand (Spiro 2006, 8). Slap tones on beat 2 and open tones on 4 and 4& are stronger and louder, providing natural accents.

[21] The conga *tumbao* played by Andy in this study (Figure 1) is a widely used variation played on two drums, the smaller higher-pitched conga, notated on the third space from the bottom of the stave, and the bigger lower-pitched tumba on the first space. Perhaps then, different stroke patterns, tones and accents have an influence on conga timing profiles and relative timing between the congas and bass.

Bass Tumbao

[22] The archetypal bass *tumbao*, widely used in Cuban music and salsa, is the *bajo anticipado* or "anticipated bass" (Manuel 1985) that has been described as one of the most distinctive features of Cuban popular music (Perna 2005, 112). An example is shown in Figure 4.

6. Derived from the Spanish verb tumbar (to knock down), the term 'tumbao' is used in musical contexts to refer to either groove or the fundamental pattern played repeatedly throughout a song (Orovio 2004, 215).

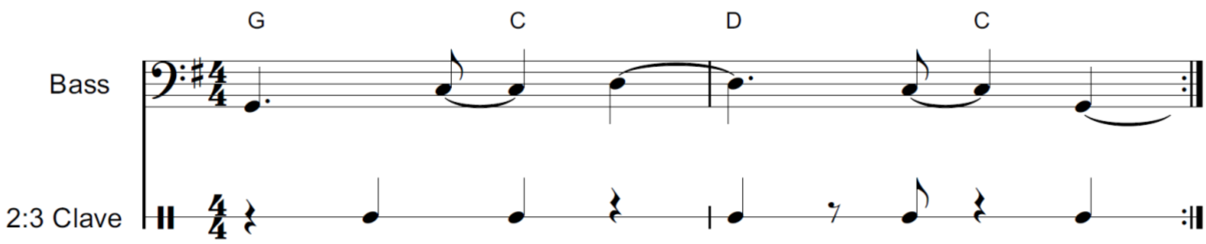

Figure 4. Anticipated Bass Pattern widely used in Cuban Popular Music.

[23] Although this pattern has two anticipated notes per bar, on 2& and 4, the sense of anticipation comes primarily from the bass note on beat 4. This note is tied across the barline to beat 1 of the following bar, thus anticipating the harmonic change played by the chordal instrument. According to Manuel (1985), this has the effect of lending a "unique flow and momentum" (255) to Cuban popular dance styles like *son* and salsa (see also Fitch 2016, Simpson-Litke 2021, and Simpson-Litke and Stover 2019, on the relationship between music and dance in salsa).

[24] Another feature of the anticipated bass is its relationship to the *clave*. Unlike the notes in bar 1 on the 2-side, the notes on the 3-side are *clave*-aligned and are typically lower tones, which provide more emphasis and accentuation at these points in the *clave* cycle. Some researchers refer to these *clave* points as the primary *bombo* (lit. large drum) and *ponche* (punch), arguing that for many instrumentalists and vocalists they are important points of unison, coordination, and emphasis within the *clave* cycle (Mauleón 1993, 67; Peñalosa 2009, 95–113; Simpson-Litke and Stover 2019).

[25] The bass part that I played (Figure 1) is one of the many variants that retains the basic anticipated structure but with additional notes, including chord notes and dead notes (unfretted, muted notes that add a percussive effect). This is typical of the type of basslines played in more contemporary styles like salsa and *timba* (Stagnero and Cher 2001; Del Puerto and Vergara 1994). This particular variant was used here because I know it very well from gigging with Andy, and it has the advantage of providing a greater number of points of comparison with the percussion (six per bar instead of two with the archetypal anticipated bass) when analyzing relative timing. It is possible, then, that anticipated bass notes, *bombo-ponche clave* points, the percussive notes and tonal variations, and how they interact with the *clave* and congas influences timing and groove. The next section details the methods used to analyze the timing of these bass and conga patterns played during the three performances.

METHODS

[26] The quantitative data used for analyses was taken from multitrack audio recordings of three studio performances, recorded in percussionist Andy Martin's studio in North Finchley, London, UK on Thursday 13 August 2020. The performances were recorded live with no overdubs or click tracks and performers were in the same room roughly two metres apart. Before each recording, an electronic metronome was used to establish the tempo (100 bpm) and then switched off.

[27] Three separate tracks were used. Track one captured the conga and track two the tumba. Audix D2 dynamic instrument microphones were used on both drums, placed approximately 2cm from the drumhead. The electric bass was on track three, captured using the direct input (DI). AKG studio headphones were used for monitoring. The microphone and DI lines were plugged into a Tascam US 16 x 08 USB audio interface and recorded with Cubase Pro on a PC.

[28] Tracks were then exported from Cubase and imported into Sonic Visualiser 4.2 (Cannam, Landone, and Sandler 2010), where the onsets (start points) of musical events were identified, marked and labelled. Identifying onsets was done using the Aubio Onset Detector plugin with the Complex Domain Function selected.[7]

[29] After experimentation with the function parameters (mainly the Peak Picker and Silence Thresholds), the most accurate and consistent settings for congas and bass were noted and used to mark onsets for all three performances. Although the audio signal for the two instruments differs slightly (rise times, attack, and decay etc.), the percussive nature of Cuban related musical performance gives a sharp and clear start to each note, making accurate onset identification relatively easy.

[30] The main advantage of using the onset detection function was that it allowed me to mark a high volume of onsets (6183), very quickly and accurately, which is extremely time consuming when done manually. An additional time saver was the function in Sonic Visualiser for automatically and numerically labelling marked onsets in sequence, representing bar numbers and beats per bar (1.1 for bar one, beat one, 1.2 for bar one, beat

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7. The Complex Domain Function combines phase- and energy-based onset detection techniques. It was used in the present study because research has found that it offers robust onset detection with a range of musical instrument including drums and guitar (Bello, Duxbury, Davis and Sandler 2004; Milligan and Bailey 2015).

two, and so on). Finally, for further accuracy, onset markers and labels were checked manually by looking at the position of the marker in relation to the start of the audio signal and adjusting it where necessary. Figure 5 shows a screen shot of marked and labelled conga and bass onsets in Sonic Visualiser.

[31] The onset timing data was saved in Sonic Visualiser and files were imported into an Excel spreadsheet for timing and statistical analyses, and graphing. Two main types of timing analyses were used. Firstly, tempi were calculated using the conga IOIs (inter-onset intervals), or the time between the start of one conga stroke and that of the next. On-beat conga strokes 1 and 5 were used, equivalent to beats 1 and 3 of each bar, giving a half-note (minim) pulse. IOIs were then converted to bpm (beats per minute) by calculating 60 divided by the IOI. This provides a useful picture of tempo fluctuations throughout a performance and of timing profiles within the rhythmic-harmonic structure outlined above. Secondly, relative timings were calculated by measuring the difference (offset) in milliseconds at shared onsets: those points in time within the rhythmic structure where bass and conga onsets are playing together, according to the notated parts. IOIs and player offsets were also used to generate summary statistics (totals, averages, standard deviations).

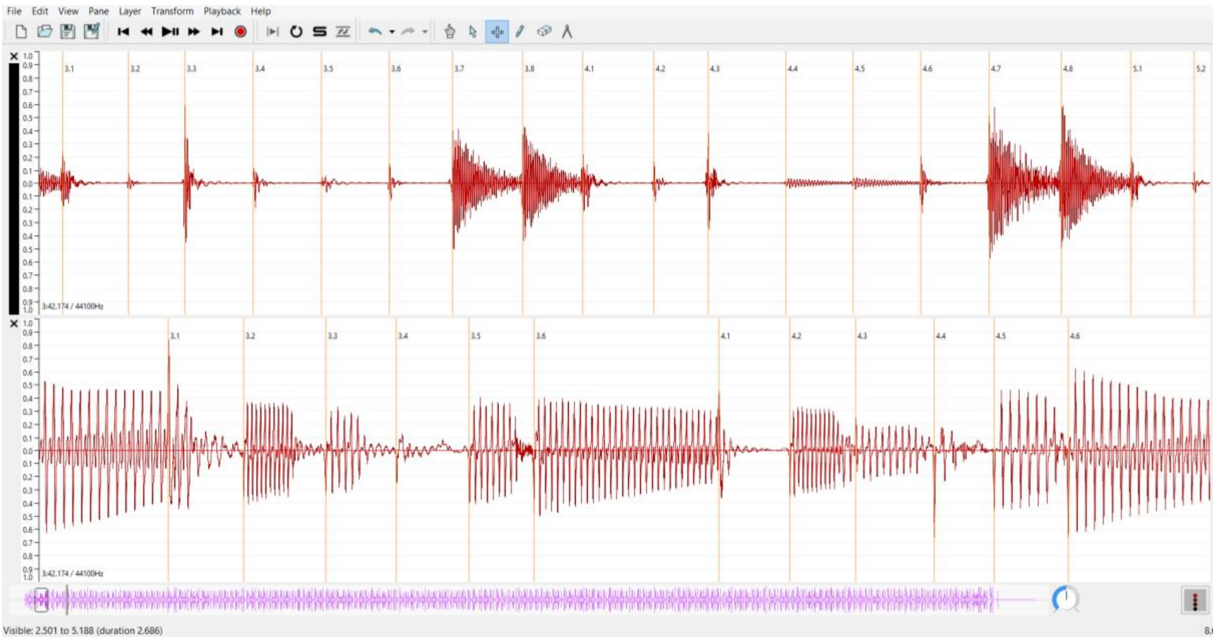

Figure 5. Example audio signal, onset markers (orange lines) and labels for conga and bass in Sonic Visualiser. One clave cycle is shown, labelled, for the conga (upper layer), 3.1 – 3.8 and 4.1 – 4.8, which represents the onsets 1 to 8 for bars 3 to 4. The same labelling is used for the bass (lower layer): onsets 1 to 6 for bars 3 to 4.

Averages provide a useful summary of player's relative timing positions and standard deviations show the level of variance in relative timing between them.

[32] Statistical significance tests, using two-tailed, paired t-tests, were also calculated from player's offsets. If the bass/conga offset p value, generated by the t-tests, was 0.05 or less, this indicates that there is a degree of relationship between instrumentalists with a low-level of chance fluctuations in performance timing. Alternatively, if p is greater than 0.05, it means that there is a higher level of chance fluctuation. These measures are useful because $p \leq 0.05$ shows that the two performers are reliably synchronous with an insignificant level of random performance noise (Rasch 1988), while $p > 0.05$ indicates a degree of timing asynchrony. Table 1 summarizes the timing data generated from analyzing the three performances.

[33] Qualitative data came from detailed listening and re-listening to the recordings by the performing musicians. Listening was independent and took place as soon as possible after the recording session (around one month later) and before any empirical analysis was conducted. Our observations were recorded in the form of typed notes and were semi-structured, based on the themes of tempo, timing, and relative timing, and how they might affect feel and groove. I then analyzed both the qualitative and quantitative data looking for patterns, themes, and correlations. The results obtained from analyzing these data sets are now presented and discussed.

Performance	**One**	**Two**	**Three**
Intention	bass on	bass ahead	bass behind
duration (m:s)	3:34	2:39	2:56
avg. tempo (bpm)	96.88	97.17	98.49
total bars	170	128	144
total conga onsets	1360	1022	1151
total bass onsets	1020	766	864
total onsets	2380	1788	2015

Table 1. Summary timing data for the three performances.

Results and Discussion

Performance 1, Bass with Congas – Audio Example 1

[34] The first aspect of timing to be considered is the overall tempo, taken from the conga performance. This is shown below in Figure 6. As the aim of this first performance was for the congas and bass to remain as consistent and together as possible, the expectation is a high degree of consistency in the timing profile.

[35] The tempo is consistent with some fluctuation. The trend line in Figure 6 shows that the tempo starts at around 99 bpm, gradually slows to around 96 bpm at the halfway point and then increases to around 97 bpm toward the end. After detailed listening, Andy (AM) and I (AP) commented that:

> AM. Generally good time. However, when comparing the first 20 seconds to the final 30 seconds there has been a slight easing of tempo throughout but this is really only noticeable on replay.
>
> AP: The tempo sounds consistent with a slight dip at around 77 seconds.

[36] Table 2 shows the conga tempo at the time points mentioned.

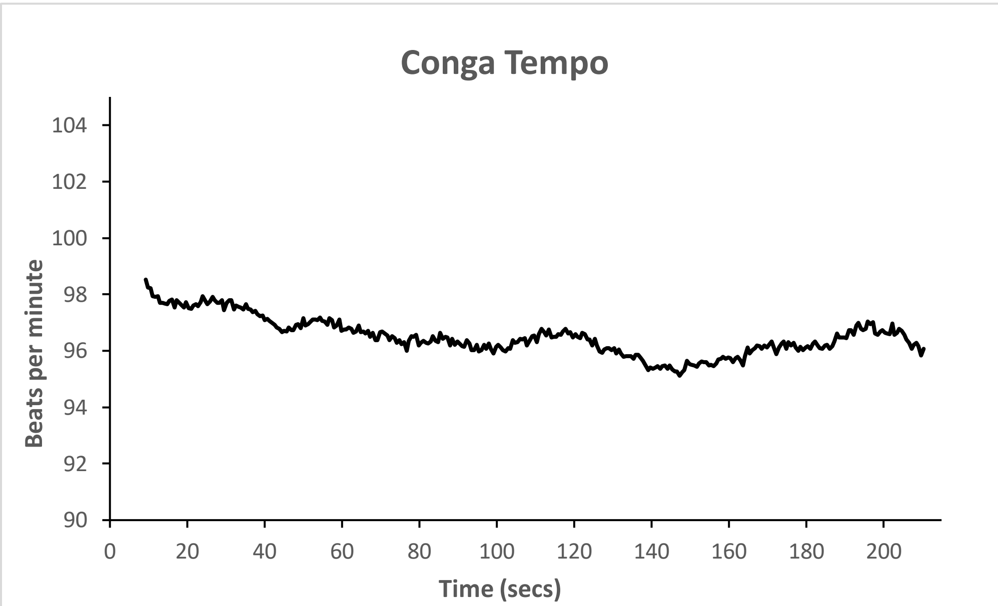

Figure 6. Performance 1, tempo, taken from the conga onsets on beats 1 and 3 of each bar. The trend line is based on a moving average of 15 data points. Average = 96.88bpm. Std. = 6.44.

Time (**secs**)	**Average Tempo** (**bpm**)
AM	
0 to 10	99.09
30 secs to end	96.76
Difference	2.33
AP	
0 to 77	97.61
77 to end	96.44
Difference	1.17

Table 2. Average conga tempo at specific time points mentioned by the musicians.

[37] There are some interesting correlations between the timing data and our comments. Firstly, temporal fluctuations are very small, a difference of 2.33 bpm (2.35%) and 1.17 bpm (1.2%) on average (Table 2). This falls at the lower end of the boundaries for "just-noticeable difference" (JND) proposed by music psychologists, which ranges from around 1–6% (London, Thompson, Burger, Hildreth, and Toiviainen 2019, 2462), and correlates with the "slight easing of tempo" heard by us. Secondly, although detectable, temporal fluctuations are not large enough to be considered atypical, falling within the boundaries of "good" and "consistent" timing (see the appendix for a more detailed profile of conga tempo at each metric location).

[38] Against this temporal backdrop, the box plots in Figure 7 show bass/conga offsets in milliseconds at each corresponding metric position across the two-bar rhythmic-harmonic structure transcribed in Figure 1. A transcription of the bass pattern, taken from Figure 1, is shown above the graph for reference purposes with metric position labels for each bass onset corresponding to conga onsets on the x-axis. Table 3 provides more detail in the form of summary statistics.

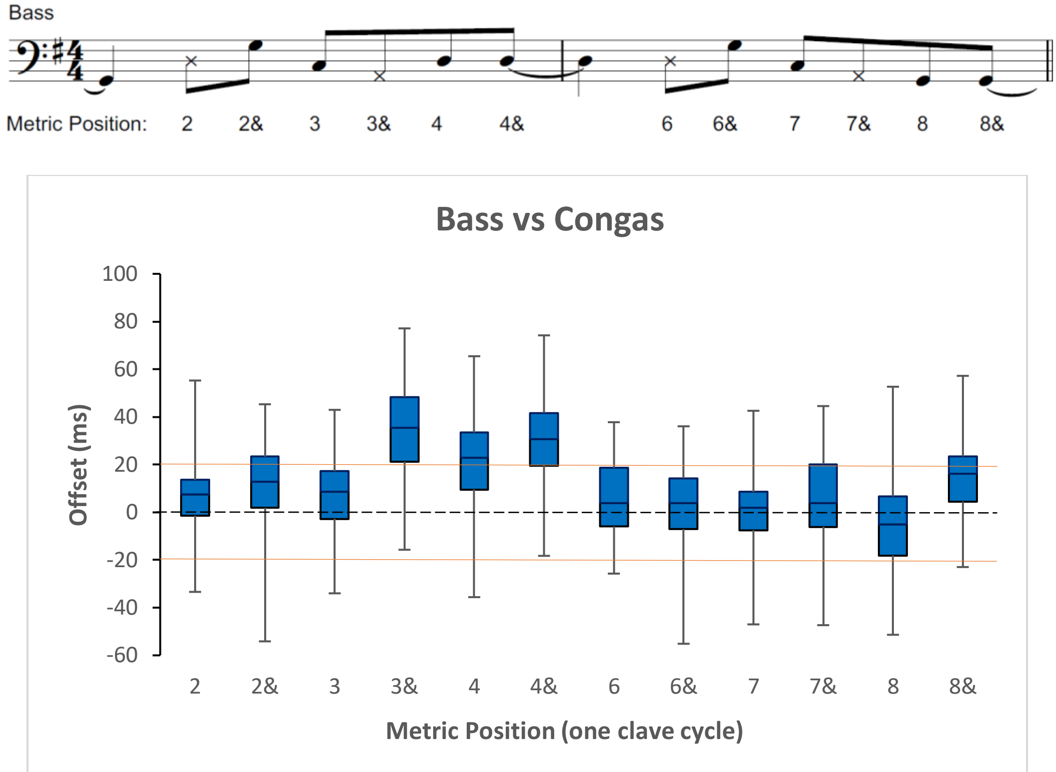

Figure 7. Performance 1, bass/conga offsets in milliseconds at each metric position shared by the bass and congas over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line at 0, represents exact synchrony and the orange lines are the upper boundaries of Hirsh's (1959) perceptual thresholds. Average bass offset = 11.20 ms, Std. = 20.89, $p < 0.00$.

	two side						three side					
clave	**x**		**x**					**x**			**x**	
pos.	**2**	**2&**	**3**	**3&**	**4**	**4&**	**6**	**6&**	**7**	**7&**	**8**	**8&**
avg. (ms)	6.18	11.97	7.49	34.56	20.14	30.65	6.72	2.60	0.68	4.19	−5.37	14.63
std.	15.41	16.31	17.43	17.83	20.17	17.54	16.13	17.90	15.49	19.38	19.27	16.82
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.183*	*0.688*	0.049	0.01	0.00

Table 3. Performance 1, bass/conga offset summary statistics at each metric position. *P* values of 0.05 or less are statistically significant, suggesting bass/conga synchrony. Those greater than 0.05 are not statistically significant and are shown in italics. Relevant clave strokes are also shown with an "x."

[39] The intention was for the bass to play in tight synchrony with the congas. The box plots in Figure 7 show that the bass is fluctuating from an ahead to behind position at all metric locations in relation to the congas, but on average the bass is slightly behind by 11.20 ms (Figure 7 caption). This is below the proposed ±15 to 20 ms perceptual threshold identified by Hirsh (1959, 759), and bass/conga offsets across the whole performance are statistically significant ($p < 0$, Figure 7 caption), providing quantitative evidence that we are playing synchronously as intended.

[40] However, on the latter half of the 2-side of the *clave* at metric positions 3&, 4 and 4& the bass is greater than 20ms behind the congas: an average of 34.56ms, 20.14ms and 30.65ms respectively (Table 3). By contrast, position 8 stands out as being the only position played ahead, albeit by a very small amount: an average of –5.37ms. Positions 6& and 7 on the 3-side are the only ones that are not statistically significant, indicating a degree of asynchrony at these metric locations, but the average offset is very small at 2.6ms and 0.68ms (Table 3). Our observations on the performance provide further insights.

> AM: Sounds together as intended.
>
> Prefer this! Good feel throughout. In a live gig situation, variables in sound and musician spacing can make this relaxed feel difficult to achieve.
>
> AP: Good solid, steady feel throughout.
>
> Of the three, I think that this performance is most like what we are trying to achieve at gigs, that is, together but with a sense of energy and drive.

[41] We both noted that this performance was "together" and "solid," and that it represents our preferred level synchrony, closest to that experienced at gigs. Moreover, this qualitative evidence suggests that the larger, contrasting offsets seen in the quantitative data does not adversely affect the intended musical feel and is typical of our timing relationships. Lastly, Andy makes a very good point that this relaxed and together feel is sometimes difficult to achieve at gigs when musicians are spaced too far apart and/or the acoustics are poor. The result is that musicians cannot hear each other properly, compromising the ability to play tightly together. Taking this performance as the 'norm', the next one focuses on the bass playing deliberately ahead of the congas.

Performance 2, Bass Ahead of the Congas – Audio Example 2

[42] As with performance one, the results of the analysis of performance two first

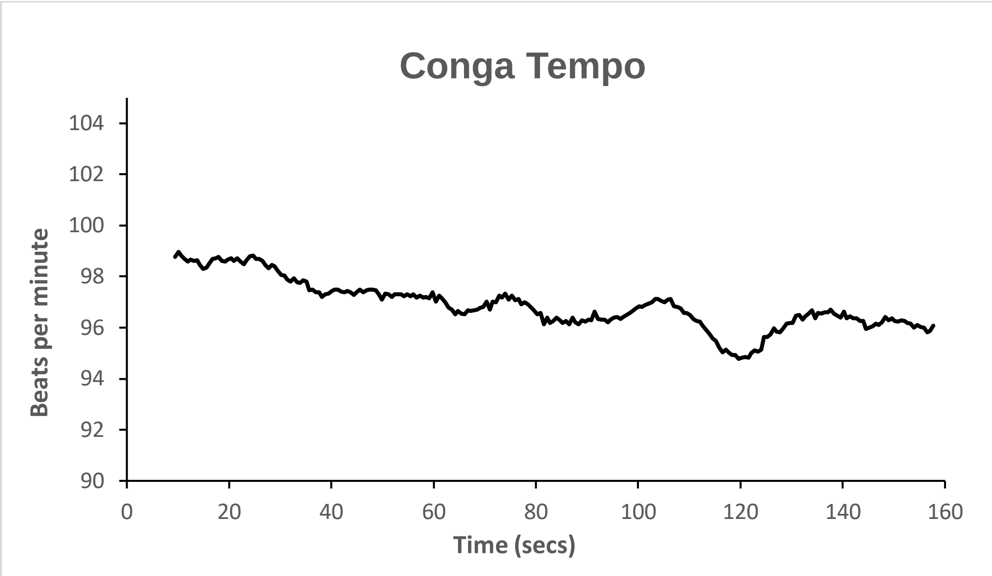

Figure 8. Performance 2, tempo, taken from the conga onsets on beats 1 and 3 of each bar. The trend line is based on a moving average of 15 data points. Average = 97.17bpm. Std. = 6.29.

considers tempo as articulated by the congas, as shown in Figure 8.

[43] The trend line in Figure 8 shows that the tempo starts at around 99 bpm, gradually slows to 95bpm at around 120 seconds and then increases to around 97bpm toward the end. This is a slightly higher percentage of tempo variation than the first performance (around 1–2%) with a difference of 2–4% but is still at the lower end of JND thresholds. These small differences are detectable on listening. We commented that:

> AM: A feeling of the congas slowing gradually throughout the take. Perhaps a deliberate attempt to avoid being pulled along by the bass?
>
> AP: Sounds like it starts to slow at 53 seconds.

[44] There is a clear correlation between the empirical data and what we hear: a gradual slowing of tempo throughout the performance. Andy makes an interesting point about the possible relationship between this easing of tempo in the congas and relative bass/conga timing, commenting that this slight decrease in his performance tempo is an "attempt to avoid being pulled along by the bass," which is playing deliberately ahead. I know from previous conversations with Andy that this is something we have both experienced at gigs. When another instrumentalist is playing exaggeratedly behind or ahead (as in the case here) you have one of two options: go with them and accept a change in tempo (sometimes desirable, sometimes not) or try to keep your own timing as steady

as possible, and, if your co-performer does not react, accept a degree of asynchrony. Here, of course, Andy is trying do to the latter and play as consistently as possible regardless of bass timing. His comments indicate that, in attempting to do this, he may have intuitively overcompensated by pulling the tempo back slightly, which underscores the interactive and reactive nature of timing relationships and groove production (Poole 2021).

[45] Figure 9 and Table 4 shows how far the bass moves from the congas during this performance.

[46] The intention was for the bass to play ahead. I approached this by pushing the tempo forward slightly and consistently in relation to each conga stroke without moving too far ahead. For me, there is a fine-grained balance to be struck when doing this: if you do not shift far enough, there is little sonic change; but if you move too far ahead, synchrony is

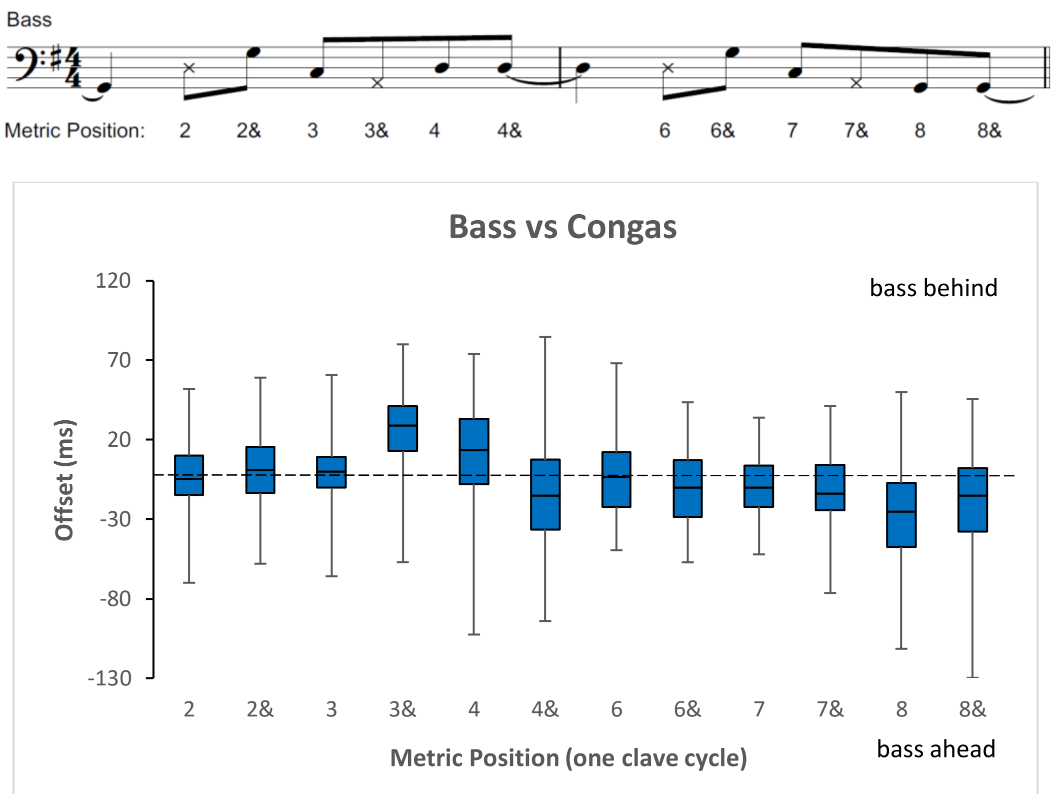

Figure 9. Performance 2, bass/conga offsets in milliseconds at each metric position shared by the bass and congas over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line at 0 represents exact synchrony. Average offset = –4.97ms, Std. = 30.19, $p < 0.00$.

two side							three side					
clave	x		x					x			x	
pos.	**2**	**2&**	**3**	**3&**	**4**	**4&**	**6**	**6&**	**7**	**7&**	**8**	**8&**
avg (ms).	–3.30	–0.47	–0.92	26.07	10.29	–12.42	–3.91	–10.13	–9.16	–11.98	–26.24	–18.02
std.	24.50	25.27	21.59	26.35	31.64	32.51	24.89	24.05	18.77	25.39	33.88	35.78
p	*0.29*	*0.88*	*0.73*	0.00	0.01	0.00	*0.21*	0.00	0.00	0.00	0.00	0.00

Table 4. Performance 2, bass/conga offset summary statistics at each metric position. *P* values of 0.05 or less are statistically significant, suggesting bass/conga synchrony. Those greater than 0.05 are not statistically significant and are shown in italics. Relevant clave strokes are also shown with an "x."

disrupted is an unpleasing way. Take this process to its extreme and the bass notes sound like they are falling on the next metric position, the effect being it sounds like a different bass pattern.

[47] The results of this process are reflected in an average bass/conga offset of –4.97ms (Figure 9 caption). Compared to the average in performance one (11.20ms), the bass has shifted from behind the congas to ahead by 16.17ms. Further comparison of the two performances shows that there is more variation in bass timing data: Std. = 20.89ms for performance one and Std. = 30.19ms for performance two, a difference of 9.30ms. This difference is to be expected given the performance remit. However, offsets are statistically significant ($p < 0$, Figure 9 caption), suggesting that they are not large enough to overtly disrupt synchrony. Our observations provide more detailed insights into relative timing and the resultant musical feel.

> AM: The first 30 seconds feel good with a slight pushing by the bass. At c 50 seconds and beyond there is a sense of the bass pushing more on beats 8 and 8&, creating a feeling of trying to "hold it together." A slight unsteady feeling, perhaps due to the stronger tone of these beats?
>
> AP: The bass sounds nicely ahead and pushing until around 35 seconds, then it starts to sound too ahead and a bit messy. It sounds more ahead on 8 and 8& on the 3-side when playing the low Gs.

[48] We both thought that from 0 to around 30 seconds the bass sounded slightly ahead but pleasingly so, while in the remainder of the performance the bass sounded too ahead,

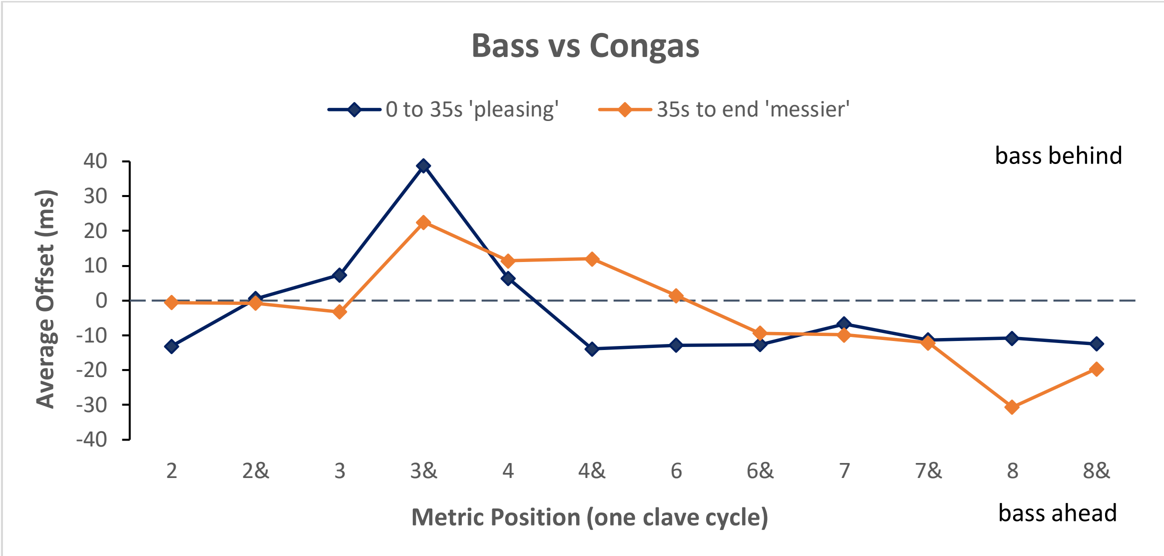

Figure 10. Performance 2, average bass/conga offsets in milliseconds at each metric position at different time segments. 0 to 35 secs, average offset = −3.39 ms, Std. = 25.09. 35 secs to end, average offset = -–5.42 ms, Std. = 31.49.

giving an unsteady and slightly messy feel. Figure 10 shows the time segments mentioned, and Table 5 gives further details in the form of summary statistics.

	two side						**three side**					
0 to 35s 'pleasing'												
clave	x		x					x			x	
pos.	**2**	**2&**	**3**	**3&**	**4**	**4&**	**6**	**6&**	**7**	**7&**	**8**	**8&**
avg. (ms)	−13.15	0.57	7.37	38.74	6.43	−13.86	−12.83	−12.66	−6.70	−11.32	−10.83	−12.40
std.	13.77	21.18	20.10	15.47	17.15	34.82	17.59	22.38	17.64	18.67	23.37	22.20
p	0.00	*0.92*	*0.19*	0.00	*0.18*	*0.16*	0.02	0.05	*0.18*	0.04	*0.11*	*0.06*
35s to end 'messier'												
avg. (ms)	−0.54	0.77	−3.25	22.52	11.37	−12.02	−1.41	−9.42	−9.84	−12.17	−30.64	−19.62
std.	26.20	26.48	21.61	27.76	34.69	32.20	26.18	26.67	19.19	27.19	35.29	38.84
p	*0.89*	*0.84*	*0.29*	0.00	0.02	0.01	*0.71*	0.01	0.00	0.00	0.00	0.00

Table 5. Performance 2, bass/conga offset summary statistics at each metric position. *P* values of 0.05 or less are statistically significant, suggesting bass/conga synchrony. Those greater than 0.05 are not statistically significant and are shown in italics. Relevant clave strokes are also shown with an 'x.'

[49] Overall, in the second, 'messier' segment the bass has moved more ahead but by a very small amount: from –3.39 to –5.42ms, a difference of just 2.03ms on average (Figure 10 caption). The Std. value has also increased from 25.09 to 31.49, a difference of 6.40ms. Again, a small increase but indicative of slightly more variation in the data and a 'looser' performance during the second half of the performance.

[50] Looking at specific metric positions, we both thought that the bass was more ahead at 8 and 8& on the 3-side during the 'messier' segment and that this was primarily responsible for creating the unsteady feel. The timing data shows that the bass has moved more ahead at position 8, from –10.83 to –30.64ms, a difference of 19.81ms (the largest increase of all ahead positions). And at position 8& the bass has also moved more ahead from –12.40 to –19.62ms, a smaller average difference compared to position 8 of 7.22ms (Table 5). The Std. values have also increased at both positions, by 11.92 at position 8 and by 16.63 at position 8& (the largest Std. increase for all positions), indicating greater variation in the timing (Table 5). Interestingly, the p values for both positions change from being not statistically significant to significant (Table 5), suggesting greater synchrony in the 'messier' segment and not greater asynchrony as our comments demonstrate. Given that there is agreement between the musicians' observations, the Std. and average offsets but not the p values, I speculate that measures of statistical significance are perhaps a less reliable indicator of synchrony. Of course, further investigation is needed to verify this point, perhaps using a range of statistical significance tests with a larger data set. However, this appears to be case for the timing data analyzed here and has possible ramifications for empirical studies of rhythm section synchrony.

[51] Another possibility is that musicians are more sensitive to timing deviations at these points in the metric structure. Position 8 is *clave*-aligned and at the end of the repeated 2-3 clave cycle. Moreover, positions 8 and 8& are key points in the bass anticipation of beat one, a central feature of this type of bass pattern (see the above section on 'musical materials'). At the time of performance, I remember trying to play ahead at all positions throughout the metric cycle, but it felt more natural to push when playing low Gs at the end of each clave cycle. For me, playing more ahead at locations 8 and 8& exaggerates the sense of forward motion already present in the bass pattern, thereby enhancing the anticipatory effect. This highlights how relative timing can be shaped by personal preference, rhythmic-harmonic structure and the particular rhythmic pattern chosen for a given performance (Benadon 2017; Washburne 1998). How do these highly localized and small shifts in relative timing affect the overall feel?

> AM: [Of the three performances, which do you prefer?]. Not this!
>
> AP: Overall the feel is very urgent and forward in the bass but not nicely so. It just sounds slightly separated from the congas. It's urgent but somehow has less energy and is uncomfortable. I would not want to dance to this.

[52] The general impression is that the performance did not feel right due to a lack of togetherness, despite having more of a sense of urgency and forwardness, which are often a feature of this music. Interestingly, it shows, from a timing perspective, how shifting one rhythm section instrument at specific metric locations and by small amounts can affect how danceable the music feels. This is just my opinion, and I am a musician, not a dancer. Therefore, an interesting area for future research would be to gather responses to these micro-timed adjustments from a greater number of listeners, including non-rhythm section musicians and dancers.

Performance 3, Bass Behind the Congas – Audio Example 3

[53] In contrast to the previous performance, in this final one, the bass plays deliberately behind. Before looking at relative timing, the tempo profile taken from the congas is considered below in Figure 11.

[54] A similar tempo profile to the previous two performances is evident in Figure 11,

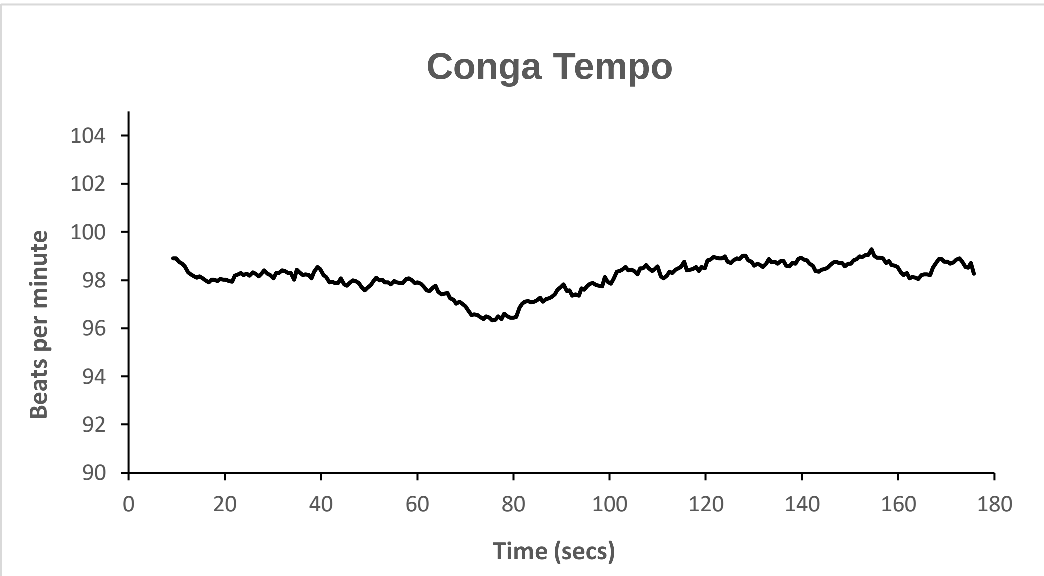

Figure 11. Performance 3, tempo, taken from the conga onsets on beats 1 and 3 of each bar. The trend line is based on a moving average of 15 data points. Average = 98.49 bpm. Std. = 6.14.

with some fluctuations throughout and a slight dip in tempo in the middle portion of the performance. Specifically, the trend line shows that the tempo starts at around 99 bpm, gradually slows to 96 bpm at around 70 seconds and then returns to around 99 bpm toward the end. Again, these tempo changes are small but detectable on listening.

> AM: [tempo is] fluctuating!
>
> AP: Not the most settled conga and bass parts due to fluctuation. The congas speed up slightly from around 100 seconds.

[55] Quantitatively, the tempo fluctuates by around 3%, which is very similar to the previous performances, suggesting that this type of temporal profile is a feature of our playing during these sessions. Bass/conga relative timing profiles provide more detail on where these temporal fluctuations occur within the metric cycle.

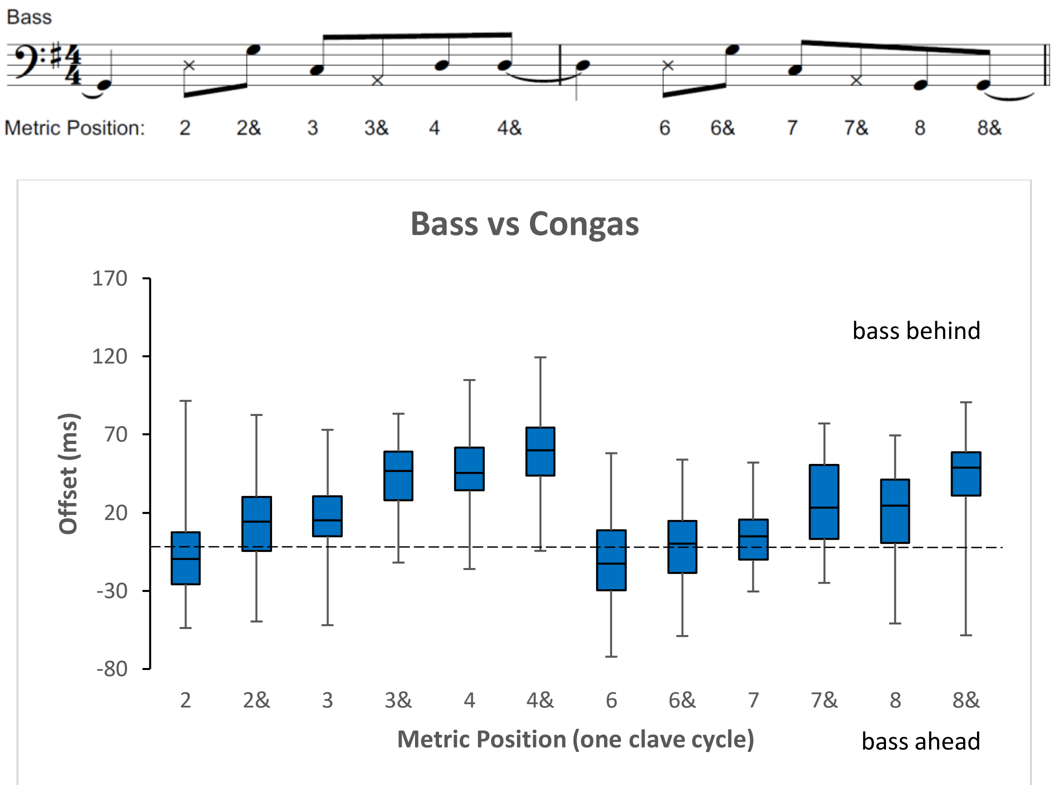

Figure 12. Performance 3, bass/conga offsets in milliseconds at each metric position shared by the bass and congas over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line at 0, represents exact synchrony. Average offset = 20.87ms, Std. = 33.18, $p < 0.00$.

two side							**three side**					
clave	**x**		**x**					**x**			**x**	
pos.	**2**	**2&**	**3**	**3&**	**4**	**4&**	**6**	**6&**	**7**	**7&**	**8**	**8&**
avg (ms).	−5.87	13.09	15.98	43.53	47.28	57.33	−9.48	−1.64	4.12	25.02	19.19	42.26
std.	26.47	27.51	23.59	22.54	24.19	26.62	26.50	23.49	18.09	27.00	28.28	29.24
P	*0.06*	0.00	0.00	0.00	0.00	0.00	0.003	*0.56*	*0.06*	0.00	0.00	0.00

Table 6. Performance 3, bass/conga offset summary statistics at each metric position. *P* values of 0.05 or less are statistically significant, suggesting bass/conga synchrony. Those greater than 0.05 are not statistically significant and are shown in italics. Relevant clave strokes are also shown with an "x."

[56] The intention was for the bass to play behind the congas. My approach to doing this was very similar to performance two but in the opposite direction: I pulled the tempo back slightly and as evenly as possible in relation to the conga strokes without shifting too far so that synchrony was overtly disrupted. This is reflected in an average bass offset of 20.87ms (Figure 12 caption). Compared to the 'norm' of the first performance (11.20ms), the bass has shifted to a more behind position by an average of 9.67 ms. This performance also has the largest Std. of the three, 33.18ms (Figure 12 caption), compared to 20.89ms for performance one and 30.19ms for performance two, indicating greater bass/conga separation. Like the previous performances, the overall p value is statistically significant ($p < 0$, Figure 12 caption), showing that a degree of synchrony is maintained in the performance, despite the exaggerated behindness of the bass. Another notable pattern seen in all three performances is a tendency for the bass to enjoy a tighter relationship with the congas in the first part of both sides of the clave, and to adjust timing more markedly in the latter positions. Our comments paint a more detail picture of this trend.

> AM: At the end of each two-bar phrase of the tumbao, the bass has a more noticeable slowing feeling. Halfway through the take, the general groove feels untidy. A slight messy feeling felt during the first half of each tumbao pattern when the bass is playing behind.

This feels ok throughout the second half of the tumbao when the bass is playing its lowest note.

AP: Messy performance in the second half of the take. The 4 and 4& of each clave cycle seem noticeably behind in the bass.

[57] We both noted that at times the bass and congas felt slightly separated, describing the performance as 'untidy' and 'messy' but that this feeling was not evident throughout the whole performance. The second half was messier than the first, and metric locations 4 and 4& on the 2-side of the clave were noticeably behind. Figure 13 below compares the sections mentioned and Table 7 provided the accompanying of summary statistics.

[58] The trend lines in Figure 13 shows that the bass has a tendency to play slightly more behind throughout the second half at all metric locations (apart from position 3, which is ahead slightly). The average shifts from 15.50 ms behind in the first half to 25.69 ms in the second (Figure 13 caption), a difference of 10.19 ms. The Std. value also increases slightly from 31.05 to 34.32 ms (Figure 13 caption), signifying less consistency in the bass timing during the second half. This correlates with our observations that this half sounds messier.

[59] Focusing on the specific metric positions mentioned (4 and 4&), in the first half, the bass is behind by an average of 36.34ms at position 4 and by 45.52ms at position 4&. In the second half it increases to 57.06ms and 67.89ms at the same positions (Table 7), a

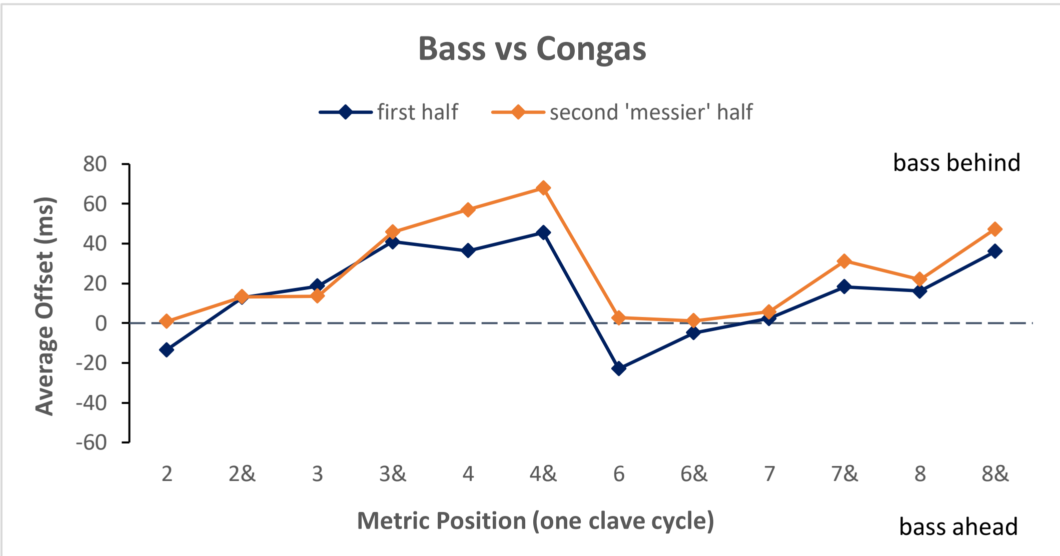

Figure 13. Performance 3, average bass/conga offsets in milliseconds at each metric position for the two halves. First half average offset = 15.50ms, Std. = 31.05. Second half average offset = 25.69ms, Std. = 34.32.

two side							three side					
first half												
Clave	x		x					x			x	
pos.	**2**	**2&**	**3**	**3&**	**4**	**4&**	**6**	**6&**	**7**	**7&**	**8**	**8&**
avg. (ms)	−13.41	12.94	18.59	40.92	36.34	45.52	−22.99	−4.85	2.38	18.32	16.15	36.12
std.	21.48	24.12	19.29	24.05	20.38	23.03	19.95	19.63	15.80	25.45	29.36	30.23
p	0.00	0.00	0.00	0.00	0.00	0.00	0.00	*0.16*	*0.39*	0.00	0.00	0.00
second 'messier' half												
avg. (ms)	0.87	13.21	13.65	45.86	57.06	67.89	2.61	1.23	5.68	31.27	21.90	47.35
std.	28.88	30.55	26.91	21.15	23.33	25.37	25.97	26.41	20.00	26.89	27.38	27.34
p	*0.85*	0.01	0.00	0.00	0.00	0.00	*0.54*	*0.78*	*0.09*	0.00	0.00	0.00

Table 7. Performance 3, bass/conga offset summary statistics at each metric position. *P* values of 0.05 or less are statistically significant, suggesting bass/conga synchrony. Those greater than 0.05 are not statistically significant and are shown in italics. Relevant clave strokes are also shown with an "x."

relatively large average difference of 20.72ms and 22.37ms respectively. Moreover, these positions are the most behind of all metric locations and also the largest offsets seen across all three performances.

[60] Results from research in music psychology suggest that differences of around 60 ms (10% of the beat duration) seen here lie close to JND perceptual thresholds for note length deviations below 240ms, which is around 68ms (14%) with real-world stimuli (Levitin, Grahn, and London 2018, 54). This quantitative data connects with our observations that the bass seems noticeably behind at these metric locations. However, in the previous performance the largest deviant bass notes at positions 8 and 8& are much smaller at 30.64ms (5%) and 19.62ms (3%) (Table 5) but have a similar disruptive effect on the

music, which is evidence that these thresholds are lower for experienced practitioners. Comparing the findings from perceptual, lab-based JND studies with the findings from more real-world observations found here is an interesting avenue for further research, and would provide a better understanding of the potential differences in JND thresholds for listeners with a broad range of experiences and different levels of musicality.

[61] Similar to the previous performance, I suspect that the reason for larger offsets at positions 4 and 4& on the 2-side of the *clave* is that the bass part is influencing my timing here. Like positions 8 and 8& on the 3-side of the *clave*, positions 4 and 4& are key points of anticipation of the first beat in the next bar (see Figure 1), and a natural place to manipulate the timing for the desired effect, in this case by playing behind. This adds more weight to the idea that relative timing is shaped by metric structure and/or the pattern being played (Benadon 2017; Washburne 1998).

[62] A potential difference in the quantitative and qualitative data is that positions 4 and 4& are statistically significant in both the first and second 'messier' half (Table 7) demonstrating that, from a quantitative perspective, these offsets are not large enough to be considered asynchronous. Although not overtly asynchronous they are sufficient to create an 'untidy' sensation, at least to our ears. And the overall feel?

> AM: Quite like this relaxed feel for certain songs . . . not the messy elements!
>
> AP: It sounds relaxed but untogether. Interestingly the parts sound less messy when heard together than apart.
>
> This is not what I aim for in performances due to the lack of togetherness and lack of energy. However, I have heard live recordings of myself that sound a bit like this when the acoustics or monitoring are not great and playing becomes more guesswork than intentional.

[63] Relaxed but untogether is the general impression but, as Andy points out, this can be desirable for certain songs. I noted that when listening to bass and conga parts together they sounded less messy than in isolation. This speaks to the importance of relative timing within the rhythm section and how instrumentalists work collectively to produce a feel that is more than the sum of its parts. My last point echoes one made earlier by Andy: making precise and small adjustment to relative timing in order to manipulate the musical feel can be challenging during live performances when the acoustics and monitoring are less than ideal.

SUMMARY AND CONCLUSION

[64] The aim of this article was to adjust relative timing in the bass on three separate live/studio performances by deliberately playing with, ahead and behind the congas. I was interested in using mixed methods to quantify and examine the precise timing relationships between the bass and congas, and how timing adjustments can affect how the music grooves.

[65] The results show that only very small and subtle adjustments in timing are needed to alter how the music feels. For tempo, an average of 1–2bpm (1–2%) is detectable to experienced ears but is still considered to be 'good' time. A small increase to around 2–4bpm (2–4%) is enough for the tempo to sound less settled and stable.

[66] Similarly, adjustments in relative timing were also small. An average bass/conga offset of 11.20ms in performance one resulted in a together, solid and tight sound, most typical of the type of energetic groove we aim for at gigs. When playing markedly ahead, an average bass offset of –3.39ms (a difference of 14.59ms compared to the first performance) resulted in a groove that sounded pleasingly more urgent with an increased sense of forward motion. When this increased to –5.42ms (a difference of just 2.03ms) the groove started to sound messier, more uncomfortable and had less energy. When playing markedly behind, an average bass offset of 15.50ms, just 4.30ms behind performance one, resulted in a groove that was considered nicely relaxed for certain songs. When this increased to 25.69ms (a difference of 10.19ms) the groove sounded untogether and lacked energy. This shows that the rhythm section musicians in this study adjust timing within a desirable synchronous window of around 10ms to manipulate the feel of the groove. Moreover, an average timing adjustment of a little as 2ms beyond that window is sufficient to make the groove start to sound unpleasingly untogether.

[67] Overall averages, however, do not tell the whole story. It was found that bass offsets were more exaggerated at certain metric positions within the *clave* cycle, especially those that occur on the latter half of the 2-side and the 3-side. Of these, positions 4 and 4& on the 2 side, and 8 and 8& on the 3-side had a particular impact on groove. An average bass timing adjustment of around 7–20ms at these positions was sufficient to evoke a noticeable and undesirable change in the groove. The reason for this is that these positions are of considerable importance within the rhythmic-harmonic framework, coinciding with anticipated bass notes on both sides of the clave and the final stroke of the clave sequence on the 3-side. These results highlight how relative timing can be shaped by

metric structure and the rhythmic-harmonic pattern being performed. Other factors that influence timing include the musicians' proximity to each other, favorable acoustics/monitoring resulting in the ability to hear each other properly, and real-time interactions and reactions.

[68] I have found the results of this study to be very illuminating and at times they have provided surprising insights into the often-intuitive processes that shape timing and rhythm-section groove production. I think that uncovering this detailed level of timing and player awareness is an advantage of the approach used, one that makes use of insights from two experienced musicians, and integrates quantitative and qualitative data. Both data sets have potential value beyond the scope of this project. The quantitative data might be used in a comparative study of groove that looks at the differences between live performances and digitally altered or generated ones. And the qualitative data could be used to compare subjective responses with those of a number of other musicians and non-musician listeners in music perception studies looking at JND thresholds.

[69] Music education is another potential avenue of use for this type of study. In the introduction I proposed that the concepts and findings from studies of groove like this one are a valuable resource for music teaching and learning. As an educationalist, I am interested how music students might best develop the skills needed to play synchronously and interactively within an ensemble and how to most effectively teach the fine-grained relative timing adjustments needed for groove production. I know from personal experience that this is not always easy because there are many factors that influence the groove production process such as personal preference, acoustics and the pattern being played. Add to this other influential factors like the players' mood, a variety of skill levels in the group, the chemistry (or lack of) within the ensemble, and cultural and stylistic differences, and a multifaceted and complex but very intriguing picture begins to emerge—a challenge for anyone teaching groove. This study demonstrates that sometimes slightly vague concepts like aheadness, behindness, and togetherness, and how they relate to rhythm-harmonic frameworks can be measured and made more solid and tangible. Not the whole story but an important first step when instructing others.

[70] While it has its merits, this study has two obvious drawbacks. First, the qualitative data taken from two musicians' observations are well informed but subjective and therefore limited in generality. Second, while every effort was made to record in conditions closest to live performances, ecological validity has been partially

compromised: no pattern improvisations, no sectional (verse-chorus) transitions, a reduced number of rhythm section instrumentalists and no audience, for example. All these factors could influence timing and groove.

[71] This invites several avenues for future research. It would be informative to use a similar approach to record a live performance and conduct analyses of a full rhythm section – often bell, cáscara, clave, congas, bongos, güiro, maracas, bass, and piano/guitar – and to examine the complexities of the timing relationships between greater numbers of musicians. In particular, a full examination of the *clave* and how it might influence rhythm section timing, an issue only touched upon here, would also be highly informative. More broadly, tackling the important issue of the influence of participating non-musicians such as audience members and dancers would provide insights into the broader nature of groove and its use and production in live performance situations.

[72] Lastly, a cross-cultural study of rhythm section timing in related *clave*-based music such as Afro-Brazilian and West African traditions would contribute to a wider understanding of the intriguing relationship between timing, rhythm, groove, and musicianship in distinct but related musical cultures. As a musician and ethnomusicologist, I would be very interested in engaging with this type of performance-led, real-world research.

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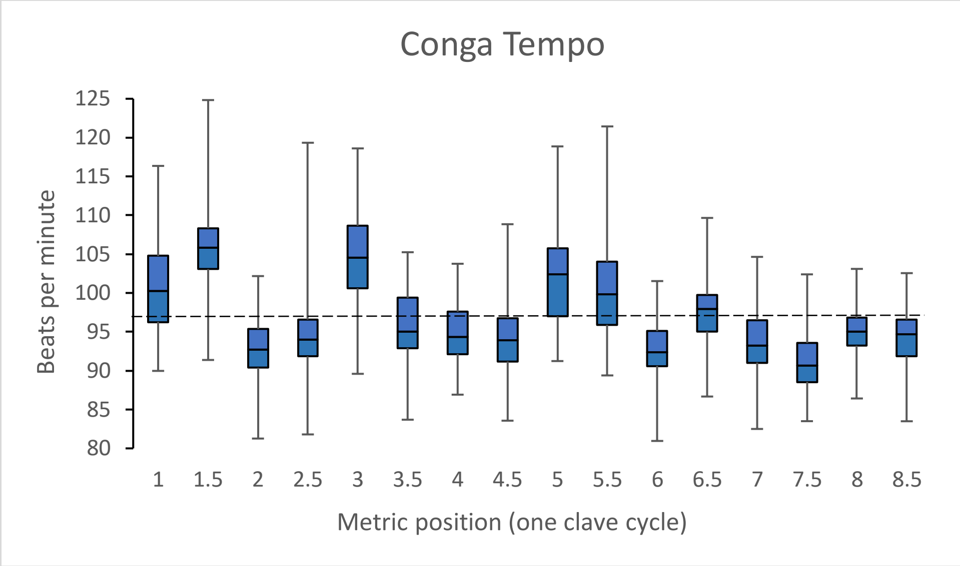
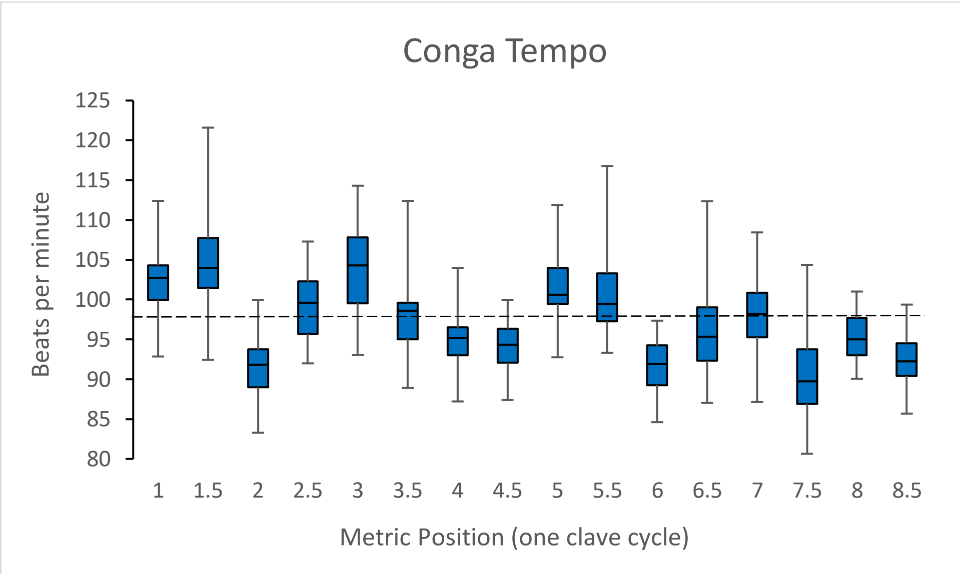
APPENDIX

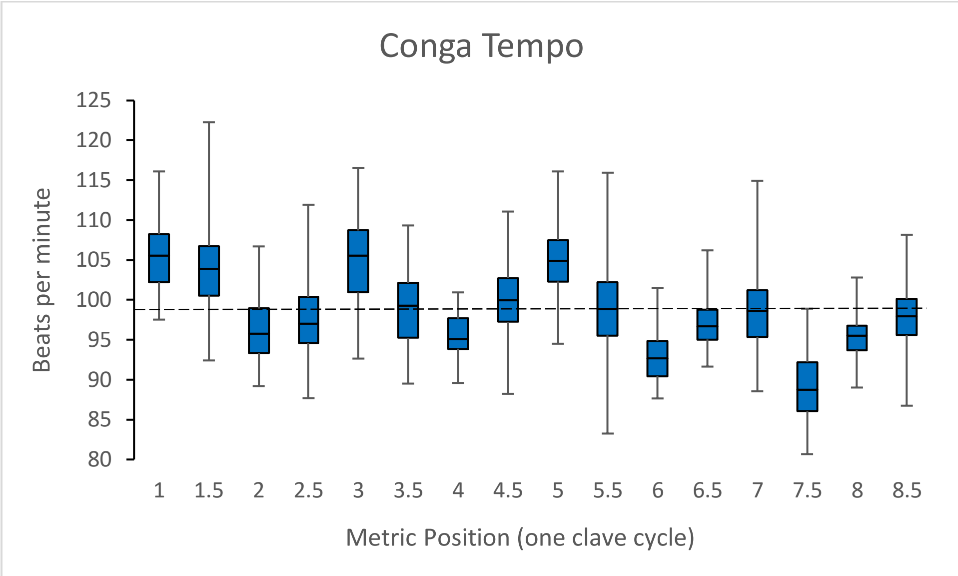
Tempos for the three performances based on the conga IOI (inter-onset interval):



Performance 1. Conga tempo at each metric position over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line is the average bpm (96.88).



Performance 2. Conga tempo at each metric position over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line is the average bpm (97.17).



Performance 3. Conga tempo at each metric position over one clave cycle. Box plots show the median value (black line in the middle of each box) and the range of values (capped lines extending from the boxes). The dotted line is the average bpm (98.49).