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Spectral and Mathematical Music Theory Analyses of the Ikoro Drum Using Visualizations and Sonifications of Beat-Class Theory

Stephen G. ONWUBIKO[1]; Tracianne B. NEILSEN[2]; Andrea CALILHANNA[3]

[1] University of Nigeria

[2] Brigham Young University, United States

[3] University of Sydney, Australia

ABSTRACT

The Ikoro, or Ekwe, is a wooden slit drum of the idiophone family. The Ikoro, which by virtue of its functions and its predominance in the eastern parts of Nigeria with the Igbo tribe, plays an important role in the Igbo musical culture and settings. The Ikoro produces a very deep rich bass sound, which can be heard from a distance, and has a sustained reverberation important in rendering a background beat to music or as a sound of warning. This paper provides a multifaceted look at the features of Ikoro drum sounds. The historical importance and constructional process of the Ikoro are presented. A traditional frequency domain analysis is shown that indicates the sustained reverberation. In addition, the isomorphism between Ikoro music and mathematics are investigated by applying the narrative of mathematical music theory developed by Richard Cohn (Yale). This work explores how the rhythm, meter and pitch of Ikoro music, can be represented through using various techniques such as visualizations and sonifications, by applying Cohn's beat class set theory with Andrew Milne's (WSU) instruments of mathematical music theory, the cyclic graph XronoBeat, and SkiHill apps. These analyses provide a deep understanding of the distinct sound of the Ikoro.

Keywords: African Drums, Ikoro, Musical theory

1. Introduction

For communication between humans and deity, humans and animals, and between people, the Igbo people, in the South-east region of Nigeria, has historically relied on musical instruments. One specific drum, that is central to Igbo music is the Ikoro or Ekwe, pictured in Figure 1. Ikoro drums are used in some Igbo areas of Anambra, Imo, Abia, Enugu and Ebonyi states of Nigeria. The Ikoro drums are a monumental symbol for the Igbo people and are normally positioned or mounted strategically for optimal acoustic at the community's public square (Ama) such as a market. An Ikoro drum is often associated with a major deity or village government and is used to transmit coded and important information to indigenes in the area, both before and after the advent of modern ways of disseminating information.

Although the names Ikoro and Ekwe are used interchangeably—the name used generally varies by tribe—each has distinctive characteristics. The *Ikoro* is made from the bore log of ufie (osisi obala), found in the Igbo region, also known as cam wood tree, while the *Ikoro* is made from mango tree/wood. The different wood causes the Ikoro to have a deeper, bass sound, and the Ikoro to have a lighter sound. The significant difference between the Ikoro and the Ekwe is the size: The Ikoro is typically larger than the Ekwe. In Nkwo market in Umunze, Orumba North Local Government Area of Anambra State, stands the biggest wooden slit drum in Igbo land, or perhaps, in the world (1): the Ikoro Obibiaku, measuring about 9 feet in diameter and 8 feet long.

[1] stephen.onwubiko@gmail.com
[2] tbn@byu.edu
[3] a.calilhanna@gmail.com

Figure 1 - a) An Ikoro being struck and b) and Ikoro.

The Ikoro holds a sacred place in Igbo culture. A community's Ikoro is typically housed in a special location. An example is shown in Figure 2 of where the ulo Ikoro is housed in Akoli-Imenyi of the Bende local government area in Abia state Nigeria. An Oomu (palm front) on the door indicates that the Ikoro is sacred and should be reverenced at all times. Traditionally, only men in general and male children are allowed to play the Ikoro in conjunction with specific ceremonies and festivals.

Although, the Ikoro and its music are generally representative of the culture of the Igbo tribe, the Ikoro is mainly associated with the upper group in their stratified society. In most parts of Igbo land, the Ikoro is typically employed in instrumental music associated with leaders and highly respected people. For example, the Ikoro functions as one of the principal instruments of Ufie music in traditional settings, limited to Ozo title taking, coronation of a king (Iwgwe), the Ofala festival, funeral of a titled person, and the Iguaro or Iwaji festival. Nzewi (2) classified this type of music as Event-Music with the subheading Egwu Ogalanya (Title music).

Figure 2 - The ulo Ikoro is housed in this building in Akoli-Imenyi of the Bende local government area in Abia state Nigeria. An Oomu (palm front) on the door indicates that the Ikoro is sacred and should be reverenced at all times.

2. Physical Characteristics and Construction of the Ikoro Drum

The basic form of an Ikoro drum is a big slit drum from a cylindrical tree trunk. Except for its huge size and the monumental importance attached to it, the Ikoro has little or no difference from other slit drum types in Igbo land. The Ikoro drums with extra projections and body decorations, in their simplest forms represent visual imagery of a male figure lying on his back. The abstract cylindrical mass of the drum forms the main body. It is on this cylindrical mass that a cavity is opened to produce the Ikoro sound. The mouth of this cavity is in the form of two rectangular shapes joined by a narrow slit, as shown in Figure 1. Some areas around Umuahia (like Ohuhu) have examples of such Ikoro drums lacking extra projections or relieved designs on their bodies. This type, however, does not really help us much in understanding the Ikoro because it is in the minority.

3. Results and Analyses

The sounds of the Ikoro drum are examined to quantify the difference between the forward and backward tones using a spectral analysis and to identify the rhythm, meter, and pitch using musical beat-theory. The audio was extracted from a video of the Ikoro drum played for 12 seconds at a tempo of approximately q= 120 beats per minute. The Ikoro was struck in the forward-backward pattern five times followed by the backward-forward pattern five times. The audio, shown in Figure 3a, was saved as a WAV file, which scaled the amplitudes of the recording between +/- 1, thus all amplitudes and levels herein are relative to this scaling. The prominent resonances sound like C3 (Low) and E3 (High).

3.1 Spectral Analysis

The acoustical differences between the sounds from the forward and back striking locations can be seen in both the waveforms and the spectra. The waveforms and spectrograms for the entire recording are shown in Figure 3. The division between striking location is annotated in the waveform in Figure 3a. The corresponding spectrogram is shown in Figure 3b, which shows how the spectrum—frequency content—varies with time. The spectrograms show clearly the difference in higher frequency content between the forward and back sounds, Figure 3c provides a zoomed in version that is more useful for seeing the lower frequency differences. Differences at low frequencies correspond to the perceived change in pitch, while the difference over the rest of the frequencies accounts for the differences in timbre or tone color. To look more closely at the difference between the forward and back striking locations, zoomed in versions are shown for two note pairs. The waveforms and spectra from one of the forward-back sets are displayed in Figure 4.

The waveforms and spectrograms from the Ikoro drum recording show differences in the sounds due to striking location. The waveforms in part a) of Figures 5-6 show that the sound amplitudes for the forward striking location are longer and show a more gradual decrease than the back location. The waveform amplitudes for the back location has an initial decay followed by a slight increase in level before the final decay. The spectrograms in parts b) and c) of Figures 5-6 show these same temporal characteristics and also show differences in the frequency content of the two sounds. There is a definite shift in low frequency content between the two: the forward striking location produces a sound with large levels at lower frequencies than the backward striking location. This changes causes a shift in the perceived pitch between the two notes with striking in the forward location sounding lower than striking in the back. In addition, the high frequency content of the two sounds are different. The forward location produces a tone with more energy in the 1000-2000 Hz band, but the back tone has more energy above 2000 Hz.

The difference can be seen more easily when average spectra are compared, as in Figure 5. The spectra shown are the average of the spectra for each tone's most steady section from the five times the tone is struck first (in Figure 3). The comparison of average spectra in Figure 5 shows the main spectral differences between the forward (blue) and back (red) locations. The lowest peak in the spectrum is typically related to perceived pitch. (Note, all the frequencies presented herein are approximate due to the 3 Hz resolution in the spectrum.) For the forward case, the lowest frequency peak is at 140 Hz and is larger than any other spectral peak by at least 10 dB. For the back case, the lowest peak is at 158 Hz, but the largest peak is at 205 Hz. (For comparison, here are the frequencies associated with notes on a piano, C3 = 131 Hz, D3 = 147 Hz, E3 = 165 Hz, F3 = 175 Hz, and G3 = 196 Hz, and A3 = 220 Hz.). The peak frequency for the forward case of 140 Hz lies between C3 (131 Hz) and D3 (147 Hz), while the lowest peak frequency for the back location of 158 Hz lies between D3 and E3 (165 Hz). The 18 Hz difference between these lowest frequency peaks corresponds approximately in this octave to the interval of a major third. The 205 Hz frequency of the highest peak in the average spectrum indicates that the sound for the back location has a strong frequency component between G3 (196 Hz) and A3 (220 Hz), which likely contributes to the perception that the back sound is a fifth above the forward sound.

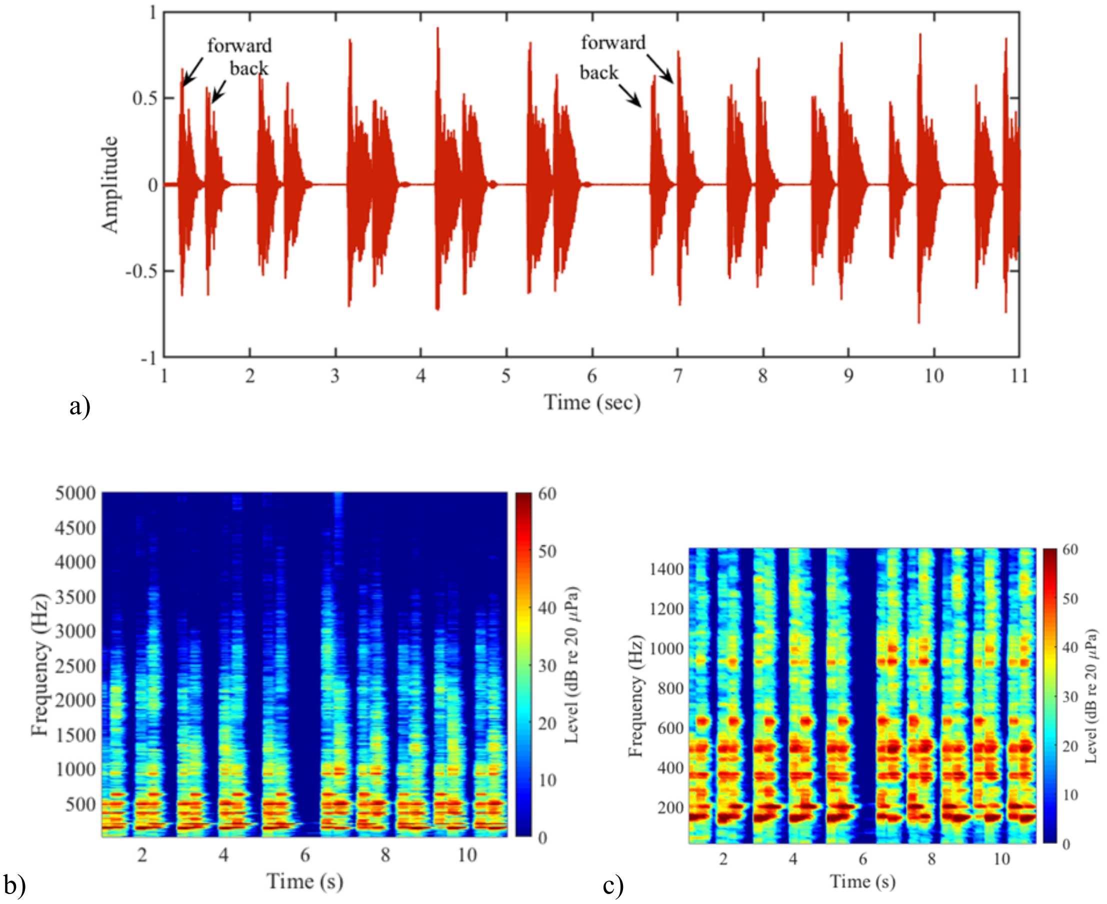


Figure 3 a) Waveform and b) spectrogram of the first recording showing a series of strikes on the Ikoro drum. The first five pairs have the forward tone first followed by the back tone. The second five have back and then forward. Zoomed in version of the spectrogram in c). These amplitudes and levels are relative levels after the sound from videos was converted to a WAV file, which scales waveform amplitudes between +/- 1.

3.2 Rhythm, meter and pitch

The rhythm, meter and pitch of the Ikoro drum sounds are analysed using Cohn's mathematical music theory (3) the first theory of meter to focus on the measurable qualities of both music and mathematics in the psychoacoustic experience of listening to music. To do this, we introduce visualizations and sonifications of mathematical music theory (beat-class theory) to analyse the music of the Ikoro drum to determine the meter and rhythm and, in conjunction with spectral analysis, we determine the mathematical properties of pitch internalized by the listener. Then, the spectral analysis also examines in detail quantifiable elements, such as, volume, frequency, and timbre.

3.2.1 Background

Cohn's beat-class theory represents modern meter theory instead of, for instance, propagating notation-based understandings of meter and rhythm, which propagate inaccurate quantifications of meter. Traditional, notational-based meter theory doesn't recognize all metric levels and only two pulses are recognized by the meter signature. Cohn's modern meter theory, on the other hand, recognizes all of the pulses the listener hears because it is based on the understanding that meter is "an inclusionally related set of distinct, notionally isochronous time-point sets" and it acknowledges research which indicates that musical meter is located in the listener as an embodied psychoacoustic or "mind and body" response to the stimulus of sound (4). In a sense, Cohn's theory provides a universal theory of music because it is based on mathematics, which can be applied to the embodied psychoacoustic experience of music from around the world. Cohn's beat-class theory (5,6) is visualized through the instruments of mathematical music theory: the ski-hill graph (7) and the cyclic graph. Computerized versions of these—the SkiHill app (8) and XronoBeat (9)—enable listeners to record the quantifiable mathematical properties they experience subjectively when listening to music.

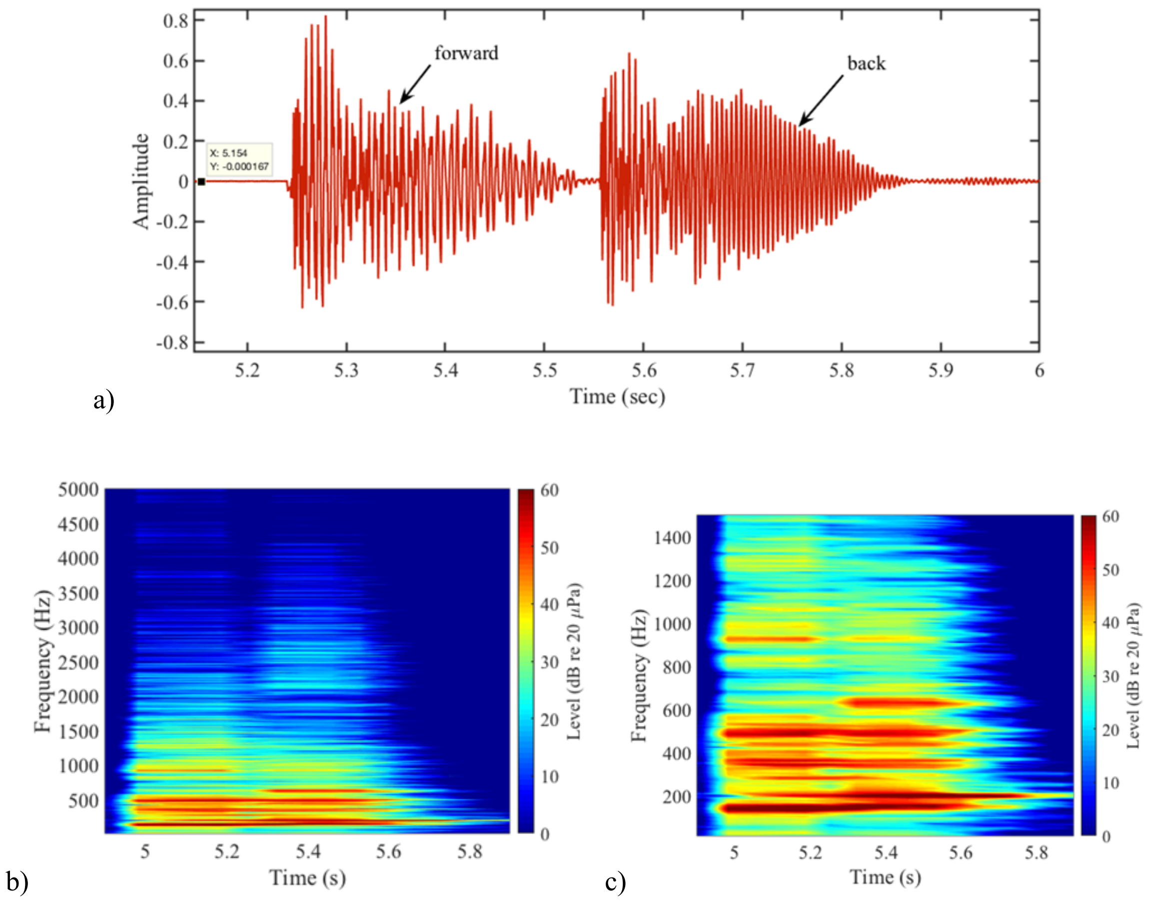


Figure 4 a) Waveform and b) spectrogram from a forward then back strike on the Ikoro drum. Zoomed in version of the spectrogram in b).

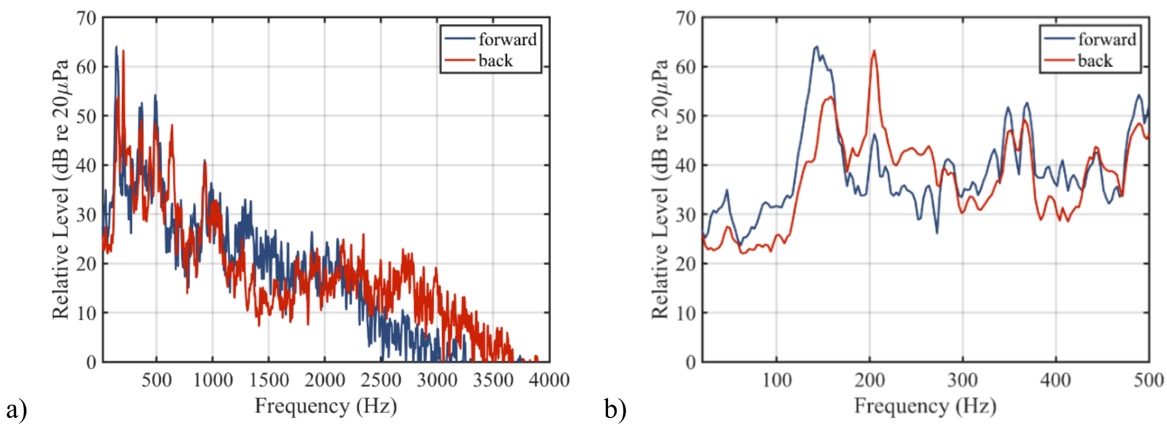


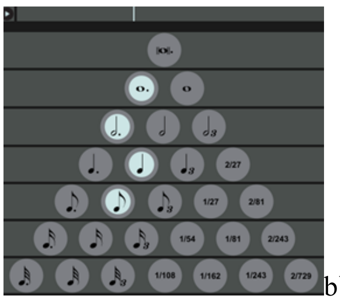
Figure 5 Comparison of the average spectra for forward and back striking.

The ski-hill graph, which is a two-dimensional matrix designed by Cohn to represent hemiolas, is arguably the most compact and efficient instrument of music theory for the listener to quantify meter (10). The nodes of the ski-hill graph are empty to represent that meter is understood as sound experienced rather than as the notation. The listener has the option to choose to map the quantified results of their psychoacoustical embodiment of sound through mapping the pulses they hear that form meter as empty nodes, traditional notation, fractions, polygons, and a choice of sonifications (see Figure 3). Unlike linear-notation, by mapping adjacent pulses in a relation of inclusion in a ratio of 2:1 duple meter to the left direction and adjacent pulses in a relation of inclusion in a ratio of 3:1 triple meter to the right direction, the two different metric pathways or subdivisions provide a useful distinction visually and through sonifications (in the computerized version). Minimal meters are formed in any music where there are duple and triple minimal meters such as those heard in the Ikoro music of the following analysis. Meter is represented as ordered set notation where minimal duple meter is represented as <2>, minimal triple meter as <3> and deep meter as, for example <232>.

The cyclic graph and its computerized version XronoBeat (9) also measures the mathematical properties of meter but in a circular graph which, unlike the ski-hill graph, also has the capacity to represent rhythm and pitch with integers, polygons and sonifications. Rhythm is defined here as timepoints selected from the metric hierarchy and pitch is defined as frequency. Meter, rhythm and pitch are all presented as sets on cyclic graphs in visualisations of beat-class theory as integers, polygons, and sonifications. In this way rhythm, meter and pitch are quantized through the listener's own reporting of these elements as sets using beat-class and pitch-class theory and spectral analysis in visualizations and sonifications.

3.2.2 Application

The results of using the SkiHill app (8) and the XronoBeat (9) on the Ikoro drum sounds are now shown. According to the SkiHill graphs, shown in Figures 1a)-c), the Ikoro drum music exhibits the meter <232> with adjacent pulses in a relation of inclusion in a ratio of 2:1, and minimal triple meter to the right pathways, adjacent pulses in a relation of inclusion in a ratio of 3:1. Figure 1a) represents the meter with traditional staff notation (and sonifications). Figure 1b) represents a hearing of the meter through fractions and polygons which represent a C12 cycle through divisions, periodicity, and sonifications. The results from XronoBeat (9) are shown in Figure 1c) are cyclic graphs, where beat-class theory is represented in sets as integers, polygons, and sonifications representing C12 {0-11}.

a) 

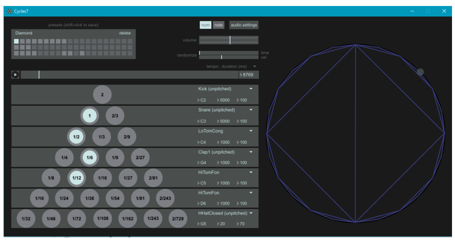
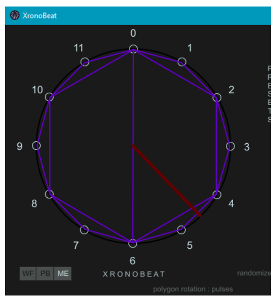
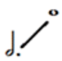
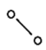
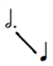
b) 
c) 

Figure 6 - Representations of the deep meter <232> a)-b) ski-hill graphs; c) polygons; d) cyclic graph with integers and polygons.

The selected nodes and their edges in Figure 3 form a metric pathway to represent adjacent pulses in a relation of inclusion in sets (a set refers to pairs of pulses where one of the notes is either two or three times faster or slower than the other) of minimal duple meter in a ratio of 2:1 sloping to the left direction, such as  ,  or  and minimal triple meter in a ratio of 3:1 sloping to the right direction  or  . Unlike pulse stacks in a linear-vertical orientation where the minimal meters can be identified in a straight line, mapping the pulses duple meter to the left and triple meter to the right pathways provides an additional benefit of a representation which differentiates the meters visually as distinct duple and triple meters and pathways. Representation of a deep meter on a ski-hill graph such as <232> means the relationships between the pulses forming duple and triple meters can be observed more closely and studied as isomorphic representations of the embodied experience of mathematics. The integers in Figure 1c) <232> represent the depth of the meter in the metric hierarchy experienced from listening to this piece. In the deep meter <232> the span pulse is worth two of its next fastest (adjacent) pulse in the metric hierarchy, six of the next fastest pulse, and twelve unit or the fastest pulse. Thus, the ski-hill graph enables the listener to articulate the embodied mathematical experience of musical meter without having to default to traditional Western notational understandings of meter (10).

A summary of the temporal evolution of the 12 s Ikoro drum recording in shown in the timeline in Figure 4. The data documented (bottom to top) in Figure 4 represents observations of the following elements: the rhythm in traditional notation; integers for C3 (beat-class theory); a timeline; the onsets as ten sets of two pulses as X's; the listener's subjective accents; an indication of the two pitches as L (Low) and H (High); the numbers for counting meter are based on the number of pulses heard for each timepoint (as indicated by the pulses stacked above in the metric hierarchy section); the top four lines are the pulses a listener can observe from the fastest (bottom) to slowest (top) in the metric hierarchy. Above the lines is an indication of the metric displacement the listener hears and the minimal meters are listed to the left as pairs of pulses in a vertical stack. The metric hierarchy is represented through an indication of the minimal meters through a pulse stack with 2 representing duple meter and 3 representing triple meter and numbers for counting meter. An approximation of the pitch is illustrated (L is approximately C3 and H is approximately E3). The notionally isochronous time point sets (pulses) in the metric hierarchy section of Figure 4 are those which can be observed from hearing the repetition of the rhythm of the Ikoro drumming. Through projection and entrainment the parallelism (MPR 1) experienced through listening to the rhythms, initiates inclusionally-related sets of pulses in ratios of 2:1 or 3:1, to form minimal and deep meters.

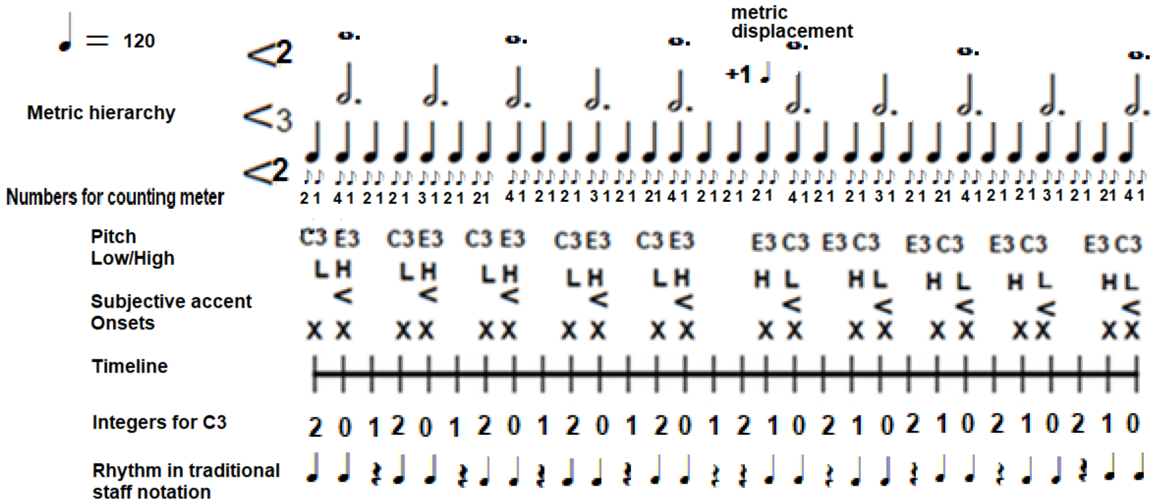


Figure 7 Timeline and initial analysis ('note-taking') for clues to analyse the rhythm, meter and pitch.

From listening closely to the Ikoro drumming solo and quantifying the rhythms, meter and pitch through visualizations and sonifications of Cohn's beat-class theory, many important details of potential cultural significance were discovered that would normally go unnoticed. For instance, through ski-hill graphs it was possible for a listener to map all of the pulses that formed part of their psychoacoustic experience of meter and mathematics. From quantifying the pulses through pairing in 2:1 or 3:1 ratios, minimal meters could be mapped to a metric hierarchy in distinct duple and triple metric pathways to form deep meter. The meter, rhythms and pitch were then mapped to cyclic graphs so as to further quantify the Ikoro drumming solo through examining the cyclical hierarchy, periodicity, sets, ratios, and divisions through polygons to reveal an otherwise hidden metric and tonal structure.

The value and potential of Cohn's mathematical music theory to quantify details about Igbo culture, including music and everyday sounds, is immense. In this way Igbo cultural practices and contributions, which are at risk of disappearing through a rapidly changing world, can be preserved for future generations. Recordings, spectral analysis, written accounts and photographs are all important for the preservation of a culture, however, the importance of the role of the listener in preserving the aural tradition through quantification of music and sound for future generations, should no longer be overlooked.

4. Conclusion

The Ikoro drum plays a central role in Igbo culture. Thus, an important part of preserving their musical heritage is to document the musical and acoustical characteristics of the Ikoro drum. These characteristics have been studied using acoustical signal analysis and Cohn's beat-class theory.

The musical characteristics of the Ikoro drum include the meter, rhythm, and pitch. If this rhythm were to be analysed and notated solely using traditional staff notation, or, as a linear arrangement, a number of important structural elements would go unnoticed. Cohn's beat-class theory, therefore, can provide more accurate accounts of music such as this study of the music of the Igbo's of Nigeria. Thus, although the listener quantifying the Ikoro pitch couldn't hear A3 a machine detected it and the six-note scale was important to study. In a mathematical environment it was possible to study both meter and rhythm with pitch where before none of the music was literally notated only 'felt' or projected and entrained to. Most of the pulses were experienced in the imagination unseen and in a sense unheard but 'felt'.

In approaching musical analysis through visualisation and sonifications of Cohn's beat-class theory the listener articulates their own quantifiable experience of music through the scientific examination of music, such as in our study of the music of the Igbo's Ikoro music of Nigeria. The capacity for the ski-hill graph, to delineate between duple and triple meters provides a powerful reason to include ski-hill graphs in the analysis of any music wherever duple and triple meter are evidenced in the psychoacoustical experience of the listener. We would argue that Cohn's mathematical music theory should be included in classroom music textbooks and online resources so that the cultural significance of music such as the Igbo's can be appreciated and preserved for future generations.

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